ANALYSIS OF EFFECTIVENESS AND COSTS of RETROFIT EMISSION CONTROL SYSTEMS for USED MOTOR VEHICLES

volume II

system descriptions

Environmental Protection Agency

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In Association With Northrop Corporation

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FOREWORD

The Environmental Protection Agency, as Administrator of the Clean Air Amendments Act of 1970, is required to assist States and air pollution control agencies in meeting national ambient air quality standards and mobile or stationary source emission standards, by issuing information on control techniques. Contract 68-04-0038 was performed with the Office of Air Programs, Division of Emission Control Technology, to determine what emission control techniques are feasible for retrofit to used cars, considering emission reduction effectiveness, costs, effect on vehicle performance, and the facilities and labor skills required for retrofit device installation and eventual maintenance and inspection. This report documents the results obtained, the pertinent data upon which the results are based, the techniques of test and analysis, and the recommendations for future programs to implement the results. The report consists of the following six volumes:

I. Program Summary: Highlights the principal program results and conclusions as to the overall feasibility of retrofit methods for vehicle emission control. Provides guidelines for the evaluation of retrofit approaches and the implementation of control programs.

II. System Descriptions: Documents the physical, functional, and performance characteristics of the candidate retrofit methods and their installation requirements and costs.

III. Performance Analysis: Documents the relative effectiveness and costs of retrofit methods, the techniques of analysis and testing, and the assumptions and rationale upon which the analysis was based.

IV. Test and Analytical Procedures: Documents the approach to the overall program objectives and the tasks and procedures implemented to meet the objectives.

V. Appendices: Documents the raw data obtained from retrofit development sources and data of overall applicability to the report.

VI. Addendum for Durability Tests: Documents the results of 25,000-mile durability tests on four representative retrofit devices.

PREFACE

The system descriptions presented in this document were prepared using data either obtained from the retrofit device development sources or developed through test and analysis as part of the study effort. In many cases the only data used were those provided by the retrofit sources, since the study schedule and the large number of devices found to exist did not permit data development to be performed for each device. The presentation of developer data does not mean that the study contractor agrees with or supports the concepts or rationale expressed or implied in such data.

ACKNOWLEDGMENTS

This program was conducted under the direction and with the assistance of Dr. Jose L. Bascunana, Project Officer of the Environmental Protection Agency. Emission Control Technology, Inc., provided the methodology for performance analysis under a subcontract agreement with Olson Laboratories, Inc.

The accomplishment of this program was made possible by the cooperation and assistance of the many developers and manufacturers of retrofit devices. Their contribution of coordination time, data, and retrofit device hardware is very much appreciated.

GLOSSARY

AMA	Automobile Manufacturers Association
CEI	Cost Effectiveness Index
CI	Cost Index
CID	Cubic Inch Displacement
CNG	Compressed natural gas
CO	Carbon monoxide
CVS	Constant volume sampling
DI	Driveability Index
EGR	Exhaust gas recirculation
EI	Emission Index
EPA	Environmental Protection Agency
GM/MI	Grams per mile
HC	Hydrocarbons
LNG	Liquified natural gas
LPG	Liquified petroleum gas
MMBM	Mean-miles-before-maintenance
MMBPF	Mean-miles-before-partial-failure
MMBTF	Mean-miles-before-total-failure
MPH	Miles per hour
MPG	Miles per gallon
MTTM	Mean-time-to-maintain
MTTR	Mean-time-to-repair
NDIR	Nondispersive infrared
NOx	Oxides of nitrogen
OEM	Original equipment
PCV	Positive crankcase ventilation
PI	Performance Index
PPM	Parts per million
WOT	Wide open throttle

VOLUME II

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1 — INTRODUCTION

SECTION 1
INTRODUCTION

A major objective of the retrofit study program was to gather and develop as much information as possible about emission control devices that are available for retrofit to used cars. This volume describes 65 such devices to the level of detail possible based on the data that could be obtained and developed within the study schedule. The purpose of these descriptions is to show what retrofit devices exist, their configurations and principles of operation, their performance characteristics, the cost to the vehicle owner, and the skills and facilities required to install and maintain the devices. This information will inform States and other agencies responsible for implementing vehicle emission controls as to what devices are available for application to their respective air quality control requirements. Within the retrofit study itself, this information provided a basic source of quantitative input to the performance analysis of retrofit devices presented in Volume III.

1.1 DEFINITION OF RETROFIT METHOD AND LIGHT DUTY VEHICLE

In the context of this study, "retrofit" means to equip those vehicles that were produced prior to the introduction of factory installed emission controls with emission control systems which may or may not be similar to those installed on new model vehicles. In this way, cars that are presently uncontrolled with respect to all or some emissions could be brought under control.

A retrofit "method," "system," or "device," is defined as any mechanism, process, or technique, except for regular vehicle maintenance, that may be added or applied to a vehicle by modification or adjustment, to reduce vehicle emissions. To be a qualified retrofit method, it must be within a reasonable range of size, complexity, and cost; and must be founded on sound engineering principles for use on an uncontrolled light-duty vehicle. In this report, the expressions "retrofit system" and "retrofit device" are used synonomously. "Retrofit method" is used when referring to retrofit systems or devices as a means of controlling used car emissions, as compared to alternative methods such as periodic vehicle inspection.

The definition of "light-duty vehicle" as set forth by the Environmental Protection Agency in the Code of Federal Regulations, Title 45, Chapter XII, Part 1201 (Reference 3), is as follows:

> ". . .any motor vehicle either designed primarily for transportation of property and rated at 6,000 pounds gross vehicle weight (GVW), or less, or designed primarily for transportation of persons and having a capacity of 12 persons or less."

A further requirement of the study was that the vehicle have a reciprocating engine which burns gasoline or a gaseous fuel; it was not within the scope of the study to evaluate retrofit systems for diesel engines or engines of nonconventional configuration such as the rotary or gas turbine engines.

The model years to which retrofit devices for emission control would be applicable are pre-1973 vehicles which, for varying degrees and pollutants, are uncontrolled for emissions. These vehicles are referred to in this report as a group by the expression "used cars."

1.2 RETROFIT METHOD CLASSIFICATION SYSTEM

The sources of vehicle emissions provide the general structure of a system for classifying retrofit devices. This general classification structure groups the retrofit devices by emission source, as follows:

a. Exhaust emission control methods
b. Crankcase emission blowby control methods
c. Fuel evaporative emission control methods
d. Emission control combinations of the above.

These groups represent the encompassing generic categories of devices and are the groups by which the devices were classified for study. Within each group, further subordination of the classification system was made by allocating to each group, according to related characteristics, retrofit types and subtypes. The detailed classification structure is described in the next section (refer to Table 2-1) Whereas the generic group level of classification is by emission source, the type level is by physical location and functional interface of the control within the vehicle. Where subtype classes are used, they represent specific control techniques, such as catalytic converters, thermal reactors, or ignition timing modifications.

The study of the effectiveness and costs of retrofit methods for light-duty vehicle emissions control excluded:

a. Regular vehicle maintenance

b. Engine tuneup

c. Inspection test programs, such as visual inspection, crankcase emissions inspection test, idle emissions inspection test, and short-cycle emissions inspection test.

d. The used car retrofit systems under development by General Motors Corporation, the Ford Motor Company, and the Chrysler Corporation.

By definition, the above, items a. through c., approaches to vehicle emission control cannot be incorporated on a vehicle by retrofitting and therefore do not belong in the retrofit classification. As required by the study contract, item d. was excluded so as not to duplicate other investigations.

Within the types of retrofit devices studied, the corresponding type of emission control incorporated or to be incorporated on pre-1973 cars at the time of their manufacture is shown in Table 1-1. These points of emission control incorporation on a production line basis demarcate the vehicle populations to which the respective

Table 1-1. TYPE OF VEHICLE EMISSION CONTROLS INCORPORATED ON EXISTING "USED CARS" AT TIME OF MANUFACTURE

SOURCE OF CONTROL REQUIREMENT	MODEL YEAR OF CONTROL INITIATION			
	BLOWBY (HC)	EXHAUST		EVAPORATIVE (HC)
		HC/CO	NOx	
Federal	1963	1968	1973	1971
California	1961	1966	1971	1970

retrofit types of control would be applicable. As indicated, long term effectiveness of blowby controls, on a retrofit basis, is limited. Use of the vehicles to which such controls would be applicable should be practically ended by 1973. This does not preclude applying such controls as a means of hastening phaseout of these early vehicle models. The vehicles most beneficial for retrofit applications are those between 1963 and 1968 for exhaust control of hydrocarbon (HC) and carbon monoxide (CO), between 1963 and 1973 for exhaust control of nitrogen oxides (NOx), and between 1963 and 1971 for evaporative control of HC.

1.3 DATA SEARCH AND DEVELOPMENT REQUIREMENTS

To evaluate the effectiveness and costs of retrofit methods for light-duty vehicle emission control, it was necessary to obtain or develop a set of data on each device sufficient to evaluate each device on a total systems basis. This was necessary in that any emission reduction benefit that a device might provide had to be evaluated against the constraints that the use of the device might entail. For example, vehicle driveability, safety, reliability, maintainability, initial cost, or recurring (operating) costs could detract from the emission reduction benefits to such an extent that the overall benefits would be less than those with the vehicle in its uncontrolled state.

The range of information required for each device included:

a. A comprehensive description of the system or device and its operation, including all significant facts relative to the purpose of the system and its different components, with drawings and pictures as appropriate.

b. A description of the work required to install each retrofit system on typical vehicles, including the facilities, amount of time, and labor skill level required.

c. Identification of the maintenance and/or inspection required, with the frequency of such activity and details of inspection rejection criteria.

d. Emissions reduction for CO, HC, and NOx, with estimated errors, confidence intervals and the test procedure, the vehicle model years of applicability, and emission variation with mileage accumulation.

e. Effect of the retrofit device on fuel type, fuel consumption, pollutant emissions (other than CO, HC, and NOx such as particulates), driveability, and safety.

f. Installation and operating costs incurred by the vehicle owner.

g. A discussion of the reliability and practicality of each retrofit device, considering its usefulness for the future and the continuity of control it would provide for modified or new emission standards.

h. A discussion of the relative effectiveness and costs of these retrofit devices.

The data search was performed by first identifying all possible sources of information from companies, individuals, and agencies engaged in research, development, or production of retrofit devices. These sources included the Environmental Protection Agency, the California Air Resources Board, Olson Laboratories, Incorporated, and other Federal, State, and local air quality control agencies. The Society of Automotive Engineers and the Air Pollution Control Association roster issues were also used to identify prospective developers.

The identification of retrofit device sources was approached in three ways: a letter of inquiry was sent to prospective sources of such information; a patent search was conducted; and a news release announcing the program was sent to major news media.

If an information source responded positively as a developer or producer of a retrofit device, a data questionnaire was sent, requesting details as to the emission reduction, driveability, reliability, maintainability, safety, installation, and cost characteristics of the device.

1.4 SYSTEM DESCRIPTION APPROACH

Detailed system descriptions were prepared based on analysis of the data obtained from the retrofit development sources and from the test program. The quantified performance parameters derived through this evaluation were used as input to the performance analysis of devices presented in Volume III.

The total characteristics of each retrofit system or device were brought under consideration. The characteristics evaluated included the physical size, weight, shape, and construction of the system; the functional or operational principles; and the performance characteristics, including emission reduction, fuel consumption, reliability, maintainability, driveability, safety, installation and maintenance requirements, and costs. These characteristics were then summarized, with consideration of the system's development status, to highlight the overall feasibility of each system for retrofit use. Some of the basic ground rules used in evaluating these characteristics were as follows:

a. Emission Reduction: Practically all devices were analyzed for emission reduction performance in terms of exhaust emissions. Only two devices had data other than for exhaust emissions and these were for particulate matter. No fuel evaporative or blowby emissions data were reported by the development sources.

In using the exhaust emissions data reported by the development sources, preference was given to data measured by means of the 1972 Federal Test Procedure constant-volume-sampling (CVS) mass measurement, grams-per-mile method. Exhaust emissions data obtained by the concentration measurement, parts-per-million method of the 1970 Federal Test Procedure were given secondary preference. In all cases the number of tests, as well as the test procedure, were considered important.

Emission reduction performance was quantified as percentage reduction. To calculate this, it was necessary for a device to have data for the exhaust emissions of the test vehicle without the device installed (referred to as the baseline) and then a second set of data for the same vehicle with the device installed.

b. Fuel Consumption: Fuel consumption data were obtained in the representative device tests performed under the 1972 Federal Test Procedure as part of the retrofit study. Preference was given to these data; however, in the absence of such data, developer fuel consumption test results were reported - though not used in the performance analysis of Volume III. In all cases, fuel consumption data were reviewed with due consideration for the number of tests represented, because of the adverse impact fuel consumption can have on the cost feasibility of a device.

c. Reliability: Reliability was considered in terms of the overall service life of a device in mean-miles-before-total-failure (MMBTF) and in mean-miles-before-partial-failure (MMBPF). Total failure was defined as a failure which would make a device completely ineffective in accomplishing its emission control purpose, and would require replacement of all or a large number of the principal components of a device. Partial failure was defined as the failure of a device component that could affect performance adversely, but not constitute total device failure. Because of the general lack of data on the reliability of automotive components and the short study schedule, no attempt was made in most cases to quantify partial failures. Components which could fail were identified, but the mean miles before partial failure were generally considered to be the same as the mean miles before total failure. The mean-time-to-repair (MTTR) a failed device was calculated as the average of all repair times.

d. Maintainability: Maintainability was analyzed in terms of mean-miles-before maintenance (MMBM) and mean-time-to-maintain (MTTM). MMBM was calculated as the average mileage of all maintenance actions. MTTM was calculated as the average of the maintenance hours for all maintenance periods.

e. Driveability: Driveability analysis was based on data obtained from the retrofit program and development sources, though the latter were for the most part not based on formal procedures and therefore were not considered conclusive. Each device for which valid data were obtained was studied for both critical and general driveability characteristics. Critical characteristics included stall and backfire. General driveability included starting and idle and the hesitation, surge, and stretchiness characteristics associated with cruise or acceleration.

f. Safety: Safety characteristics of a device were analyzed in terms of those which could be hazardous to humans, either in or outside the vehicle, and to the vehicle.

g. Installation: The installation requirements of a device were analyzed in terms of the procedural steps required to accomplish installation and the associated tools and skill levels. The amount of time required for each step was estimated.

h. Costs: The costs associated with a device were analyzed both in terms of the initial installation cost, including labor and material, and the recurring cost. Recurring cost was estimated on the basis of maintenance and such operating costs as fuel consumption or savings. Recurring cost was tabulated along with initial cost so as to provide an indication of the overall cost which a device might entail.

In some cases, the system information provided by the retrofit source was too vague to apply the detailed system description approach and reach a feasibility conclusion. In each such case, the available information was summarized even though no conclusions as to the system's suitability for emission reduction use on a retrofit basis could be made. When the developer's explanation of operating principles for a device could not be substantiated on the basis of current vehicle emission control technology, these claims were not subjected to test or analysis. Sometimes, the developer's explanation was quoted. These quotations should not be construed as an expression of either agreement or disagreement with the developer's claims. It should be noted that some material provided by the developers was sales literature containing highly promotional claims for device performance and theory of operation. It was not within the scope of this study to dispute such claims.

1.5 DATA SURVEY RESULTS

The data survey by which the study was initiated indicated 469 potential sources of information about retrofit methods that are either under development or in production for application to used cars. The information obtained through these contacts, including the data development effort, provided an overview of the current state of retrofit technology, in addition to providing the specific details of the feasibility of individual retrofit devices. From this overview, it was possible to evaluate the general character of development efforts in the retrofit field, in terms of the soundness of the design concepts being used and the quality of the design engineering represented by the hardware mechanization of these concepts.

In general, retrofit devices were found to vary considerably in basic concepts, in the analytical substantiation of the concepts and their conversion to hardware, in the extent of product engineering, in the rationale as to what constitutes emission reduction, in test methods, in the quality of prototypes, and in general business or financial backing and marketability. The devices found to exist ranged from devices based on sound engineering principles and highly sophisticated mechanisms to devices offering little or no potential emission reduction. In some cases, these latter devices actually increased emissions over the level obtained with the uncontrolled vehicle. In other cases the devices showed beneficial reduction of emissions, but were still in a relatively undeveloped prototype stage.

The developers and producers of the devices were found to range from individuals who are investing their own time and money, to established engineering firms that are engaged in the retrofit field on a full-time business basis. In general, the information obtained from individual developers was characterized by the lack of a comprehensive developmental effort. Accordingly, the data obtained were frequently fragmentary from a total system engineering viewpoint. Most had some emission test data. The lack of detailed system performance data--including driveability, reliability, maintainability, and safety data--appears in the case of many individual developers, and may be caused by a lack of indepth financing. Nonetheless, a number of these systems appear to have a sound technical approach for retrofit application.

The sources of comprehensive data were most frequently firms which are formally engaged in emission control products or in the automotive component field. Many companies were only in the initial stages of developing viable approaches to retrofit requirements and some were already marketing devices for use in controlling emissions. The main concern with some of these devices is whether they should be classed as emission control devices or, perhaps more appropriately, as means to enhance engine performance. In other cases, the products being marketed are viable emission controls awaiting legal enforcement of their use for wide scale retrofit application.

The detailed results of the data survey are presented in Volume V, Appredix V-1. These results provided a basic profile of the state of retrofit method technology from the retrofit developer. Detailed procedures of the data survey are presented in Volume IV.

Of 456 sources contacted directly for information on retrofit methods, 291 did not respond to the letter of inquiry. Of the 165 who did respond, 91 declined to participate, even though 40 were developers of retrofit devices. Of the 87 indicating interest in the program, only 33 returned the detailed data questionnaire sent them after the initial letter of inquiry.

It is also significant that among the 87 showing interest, 80 reportedly had retrofit devices in the form of hardware. However, of the 33 that returned data questionnaires, 26 had hardware to submit for evaluation.

These contacts were made on a worldwide basis. The data questionnaire packages received are presented in Volume V. Among the systems evaluated in this study, one was discontinued as a result of the developer requesting withdrawal from the program (Device 38).

Table 1-2 summarizes the results of the data survey. These results indicate that only 28 percent of the 92 developers who reportedly had hardware were aggressively developing their devices and were prepared to demonstrate them. The predominant percentage of the 26 hardware devices provided were in the exhaust emission control group. Although no evaporative emission control system was found for retrofit use other than in combination with other emission control techniques, a new model vehicle evaporative control system was evaluated for retrofit cost feasibility.

Table 1-2. DATA SURVEY RESULTS

RETROFIT SOURCE ITEM	QUANTITY	PERCENT OF TOTAL RETROFIT SOURCES
a. Total retrofit sources	469	100
b. Total sources contacted by Letter of Inquiry	456	97
c. Source data provided only by EPA	13	3
d. No response received to Letter of Inquiry	291	62
e. Declined to participate	91	19
f. Will participate	87	18
g. Have retrofit hardware	92	20
h. Total number of devices evaluated in retrofit program study	65	14

DEVICES EVALUATED ITEM	QUANTITY	PERCENT OF THE TOTAL DEVICES EVALUATED
a. Returned data questionnaire (refer to Vol. V, Appendix V-3)	33	51
b. Provided hardware	26	40
c. Devices previously tested by EPA	30	46
d. Devices already accredited for retrofit use	7	11

2 — RETROFIT
METHOD TECHNOLOGY

SECTION 2

RETROFIT EMISSION CONTROL TECHNOLOGY

To understand retrofit devices as a means of controlling the emission of pollutants from used cars, it is necessary first to know the pollutants to be controlled, the sources or causes of these pollutants, and the principle methods which can be used to control them. Such knowledge also is prerequisite to establishing a classification system by which to organize retrofit devices for study, and to evaluate the effectiveness and costs of the various devices to decide which may be better for a particular application.

2.1 POLLUTANTS ATTRIBUTABLE TO GASOLINE- AND GASEOUS-FUELED VEHICLES

The pollutants of concern in emissions from gasoline- and gaseous-fueled vehicles are carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxides (NOx). The effects of these pollutants on human health and welfare have been documented by EPA in References 108, 109, and 110. Carbon monoxide is an odorless, colorless gas that has long been associated with vehicle exhaust emissions as poisonous. Exposure to CO of 10 ppm for 4 hours can impair psychomotor functions in humans.

The hydrocarbons emitted by these vehicles cover a wide range of compounds of various molecular structure. Certain of these hydrocarbons are major causes of atmosphere pollution due to their high chemical reactivity in the formation of photochemical smog. (1) Of the more than 100 individual exhaust hydrocarbons identified, it is the more reactive unsaturated elements that account for most of the harmful emissions (Reference III).

The oxides of nitrogen, emitted as part of vehicle exhaust, are pollutants because they combine with the reactive hydrocarbons to produce photochemical smog. Of the 12 million tons of nitrogen oxides estimated to be emitted into the atmosphere each year in the U.S., approximately 50 percent are from motor vehicles (Reference 112).

2.2 VEHICLE SOURCES OF HC, CO AND NOx

Approximately 60 percent of the total hydrocarbons from uncontrolled vehicles and all of the CO and NOx are emitted from the exhaust. The remaining 40 percent of the emitted HC is divided approximately equally between the crankcase blowby emissions and the evaporative emissions from the fuel tank and carburetor (Reference 114).

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(1) The photochemical reactivity of hydrocarbons is measured on a relative basis by the rate at which nitrogen dioxide (NO_2) is formed in the presence of sunlight or infrared, using controlled amounts of hydrocarbon, nitric oxide, and nitrogen dioxide (Reference 111).

The presence of HC in the exhaust gas is an indication of incomplete combustion. Whereas incomplete combustion of HC has been attributed to several causes, the majority of the HC has its origin in an air-fuel mixture that is too rich, too lean, or too cool for complete oxidation to occur during the combustion or exhaust process (Reference 79). Insufficient oxygen supply could occur due to a rich fuel mixture or poor fuel mixing. A major HC source, related to a cool mixture, is the unburned gas in the quench zone of the combustion chamber. The temperature differential within an engine cylinder between the flame front of the ignited air-fuel mixture and the surrounding surfaces - such as the engine head, cylinder walls, and piston face - can be substantially different. The temperature of the gas layer near the surface areas of the combustion chamber is a major determinant as to whether fuel oxidation is complete or partial (Reference 79).

Another major source of HC is the unburned fuel that deposits in the combustion chamber crevices, such as in the piston ring grooves and valve seats. These deposits are attributable in part to the poor mixing characteristics of gasoline, which enters the combustion chamber in droplet form. These droplets accumulate in regions where the combustion flame is prevented from propagating. It has been estimated that in some cases up to 50 percent of the exhaust HC may be from the piston-ring crevices (Reference 30).

Both NOx and CO are products of the combustion process, whereas hydrocarbons are inherent as a major constituent of gasoline. CO, in general, is caused by the absence of sufficient oxygen to convert CO to CO_2, combined with insufficient reaction time under extreme engine operating conditions. An increase in oxygen, as with a lean air-fuel ratio, while decreasing CO, tends to enhance NOx formation, unless the peak temperatures conducive to NOx formation are prevented. If conditions are favorable, reactions of the HC and CO gases exhausted from the combustion chamber will continue in the exhaust ports, manifold and even in the tailpipe. The nature of reactions that may occur in the exhaust system is influenced by the amounts of carbon monoxide and hydrocarbons emitted. The extent of these exhaust reactions depends on the temperature distribution within the exhaust system (Reference 79).

2.3 PRINCIPLES OF RETROFIT METHODS FOR CONTROLLING VEHICLE EMISSIONS

The 65 retrofit devices studied were classified by emission source and retrofit type, in accordance with the classification structure shown in Table 2-1. Most of the retrofit types are based on the fundamental principles by which vehicle emissions may be controlled, and most of the accepted principles used in retrofit devices have already been incorporated on new model vehicles either as integral engine modifications or auxiliary equipment. Exceptions are the catalytic converter and the air bleed to intake manifold.

The basic operating principles and characteristics of the principle types of retrofit devices within each generic group of devices are summarized in the following sections.

2.3.1 Exhaust Emission Control Systems - Group 1

The air-fuel mixture ingested through the carburetor and intake manifold is first reacted and burned in the combustion chamber and then is reacted further in the exhaust system. These two major sequences of reaction define the two broad approaches to controlling exhaust emissions: (1) by minimizing the amount of

Table 2-1. CLASSIFICATION OF RETROFIT METHODS

GROUP	TYPE	SUBTYPE	TITLE
1			EXHAUST EMISSION CONTROL SYSTEMS
	1.1		Exhaust Gas Control Systems
		1.1.1	Catalytic Converter
		1.1.2	Thermal Reactor
		1.1.3	Exhaust Gas Afterburner
		1.1.4	Exhaust Gas Filter
		1.1.5	Exhaust Gas Backpressure
	1.2		Induction Control Systems
		1.2.1	Air Bleed to Intake Manifold
		1.2.2	Exhaust Gas Recirculation
		1.2.3	Intake Manifold Modification
		1.2.4	Carburetor Modification
		1.2.5	Turbocharger
		1.2.6	Fuel Injection
	1.3		Ignition Control Systems
		1.3.1	Ignition Timing Modification
		1.3.2	Ignition Spark Modification
	1.4		Fuel Modification
		1.4.1	Alternative Fuel Conversion
		1.4.2	Fuel Additive
		1.4.3	Fuel Conditioner
2			CRANKCASE EMISSION CONTROL SYSTEMS
	2.1		Closed System
	2.2		Open System
3			EVAPORATIVE EMISSION CONTROL SYSTEMS
	3.1		Crankcase Storage
	3.2		Canister Storage
4			EMISSION CONTROL COMBINATIONS

pollutants resulting from the combustion process and (2) by minimizing the amount of pollutants allowed to escape from the exhaust pipe. The first approach is that used in the induction and ignition control retrofit systems, and in the fuel modification systems. The second approach is that used in the exhaust gas control systems.

2.3.1.1 Exhaust Gas Control Systems - Type 1.1

Retrofit devices of this type have in common some means of acting upon the pollutants in the exhaust system to decrease the amount emitted to the atmosphere. The more sophisticated techniques, such as catalytic conversion, thermal reactor, and afterburning, accomplish this by chemically reacting the exhaust gas to convert CO, HC, and NOx to a nonpolluting form. Another exhaust gas control method is that represented by exhaust gas filtering, which physically removes particulate matter from the exhaust, but may not affect other emissions.

Catalytic Converter - This type of device is typically a high-temperature metal chamber that contains a catalyst material that promotes the oxidation of CO and HC to water and carbon dioxide. This type of system is called a single-bed oxidation catalyst. Dual-bed and tricomponent catalytic devices are also being developed for sequential and simultaneous (respectively) reaction of CO, HC, and NOx. However, none of these devices were submitted for retrofit evaluation or application.

The catalysts being used are both of the base and noble metal types. Extensive research and development is being performed to perfect both the catalysts and the container configuration. One of the catalytic converter types evaluated incorporates a pellet catalyst in a cylindrical metal container. Another approach is to use a monolithic coated substrate or honeycomb grid in a metal container. Most of the catalyst compositions are considered proprietary. Typical base metal catalysts are vanadium, chromium, manganese, iron, cobalt, nickel, copper, and zinc. These are usually combined as oxide compounds. Supports such as alumina and silica are used for structural strength (Reference 2).

Some of the base metal catalysts contain precious metals in trace amounts. These precious or noble catalysts are usually platinum or palladium, deposited on alumina or silica supports.

The catalytic converters are installed in the exhaust pipe as close as possible to the exhaust manifold. The reason for this is to prevent too much temperature loss in the exhaust gas before it enters the converter. Converter warmup time is a major factor in emission control effectiveness. Until the catalyst reaches its reaction temperature, the exhaust gas flows through the catalyst bed without any of the pollutants being converted. Normal operating range may be 1,200^{o} F or higher. The operating temperature also is a critical factor on catalyst durability. At the higher temperatures, some attrition of catalysts is usually encountered. This is generally not serious unless the catalyst also becomes contaminated, as from oil or particulate matter. When contaminated by oil, the catalyst may burn up.

To prevent overtemperature conditions, a thermal sensing system is sometimes incorporated. This system may consist of a thermal switch that diverts the exhaust gas through a bypass pipe around the converter. Converter chambers typically incorporate melt-out plugs that vent the exhaust through the converter body in the event of excessive temperature. To operate efficiently, oxidation catalytic converters require some excess of oxygen which can be provided by proper carburetor mixture or by an air pump operated off the engine auxiliary power system.

Since current catalysts are sensitive to leaded fuels, use of nonleaded fuel is an operational requirement for durability. Current technological developments in converters indicate that it will be about 1975 before catalytic systems are incorporated on new model vehicles (Reference 20). A satisfactory retrofit converter could be used on all vehicles up to the point of production use.

Thermal Reactor - This type of device is similar to a catalytic converter in that it reacts with the exhaust gas to change CO and HC to carbon dioxide and water. The oxidation process, however, is performed in a thermal environment produced and sustained within a specially designed exhaust manifold that replaces the conventional exhaust manifold.

There are two basic types of thermal reactors: rich and lean. The rich thermal reactor operates with a rich air-fuel mixture and requires secondary air injection. The lean thermal reactor operates with a lean mixture and does not require secondary air. For both the rich and lean thermal reactors, the reaction chamber is sized and configured for three primary objectives: to sustain residence time of the exhaust gas as long as possible to promote mixing, and to maintain the highest possible temperature.

When using the rich thermal reactor the carburetion must be more rich than normal. This inhibits NOx formation due to the lack of oxygen in the engine combustion chamber. For the lean thermal reactor, it is possible to operate at stoichiometric or leaner air-fuel ratios and use exhaust gas recirculation or vacuum advance disconnect to control NOx. In either case, the reactor must be installed next to engine exhaust ports and designed to heat up promptly on cold starts. The high operating temperatures up to 1,800°F, and thermal capacity require high-temperature materials of great durability. Major developmental problems have been encountered in designing reactor chambers that can withstand the prolonged thermal environment, particulate impact, possible flameups, and vibration.

The lean thermal reactor does not require secondary air injection, since it is operated on the fuel-lean side of stoichiometric with excess air. The lean mixture produces lower concentrations of CO and HC during combustion and, therefore, produces a lower reactor temperature than the rich-mixture thermal reactor.

Exhaust Gas Afterburner - This type of device operates on the same principles as the rich thermal reactor. The main difference is that the afterburner is installed downstream of the exhaust manifold, and does not depend on the hot exhaust gas for reaction temperature. The afterburner typically incorporates an ignition unit, such as a spark plug, to initiate combustion within the chamber. The fuel-rich exhaust gas is combusted in the presence of secondary air usually supplied by an air pump. The gases are circulated within the afterburner to oxidize CO and HC. As with the rich thermal reactor, NOx formation during combustion may be reduced by the rich fuel mixture.

Exhaust Gas Filter - This type of device is designed to control the emission for particulate matter from the exhaust. Currently, there are no Federal regulations for particulate matter from vehicles. Two devices incorporating this type of control (Devices 164 and 469) received a limited evaluation in the retrofit study. Thus far, no complete information has been available on the total particulate emissions rate from vehicles under realistic driving conditions (Reference 73). It is known that vehicle exhaust contains lead salts, carbon, iron rust, and semisolid or liquid particles such as tars and oil mists.

One approach to controlling exhaust gas particulates is to separate and retain the particulates in the exhaust system. This requires cooling the exhaust gas so that all particulates are solidified. Fine particles must be agglomerated for ease of separation. All particles then must be separated from the exhaust stream. This can be accomplished by direct filtration or by a cyclone separator.

Exhaust Gas Backpressure - The emission control principle of this type of device has not yet been established, based on known investigations. Exhaust backpressure in itself has an adverse effect on volumetric efficiency of an engine and on power (Reference 24).

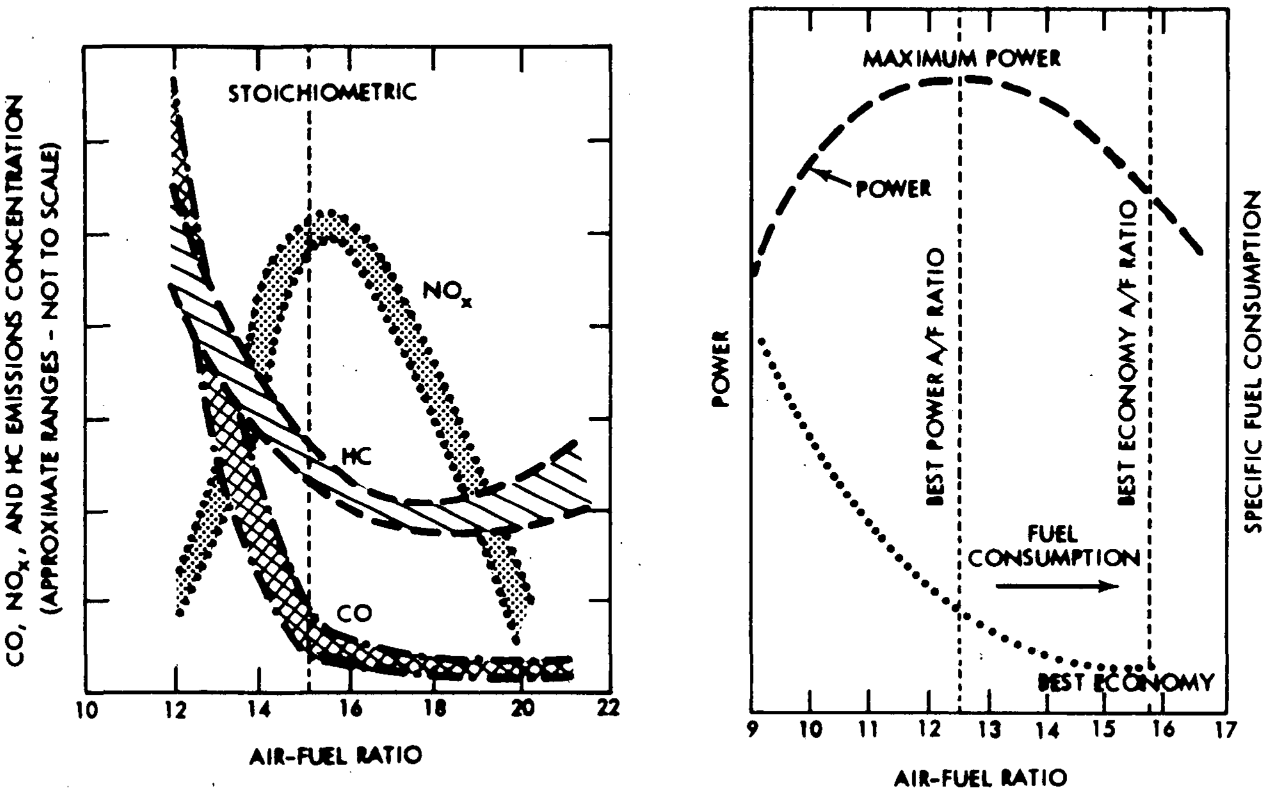
2.3.1.2 Induction Control Systems - Type 1.2

Modification of the induction of the air-fuel mixture to the combustion cylinder is one method of controlling the formation of pollutants during combustion. The other two methods are the ignition control and fuel conversion systems.

Air Bleed to Intake Manifold - As shown in Figure 2-1, CO, HC, and NOx concentrations in the exhaust of uncontrolled vehicles are directly influenced by the air-fuel ratio at which the engine is operated. At the stoichiometric air-fuel ratio (about 14.7:1), NOx is quite high, while CO and HC are relatively low. At air-fuel ratios between 17 and 19, concentration emission levels of all three pollutants are considerably lower than at stoichiometric. Current engine designs are limited to air-fuel ratios below 19:1 to avoid excessive power loss and rough engine operation due to lean misfire (Reference 2).

The air-bleed device as a retrofit approach is commonly implemented by means of a tube with an orifice (fixed or variable area) connected to the intake manifold. The device allows a metered amount of air to lean the carburetor mixture. Some air-bleed devices lean the air-fuel mixture at all engine speeds and load conditions. Other air-bleed devices operate at certain prescribed engine operating conditions, such as idle and deceleration.

Exhaust Gas Recirculation - As discussed in paragraph 2.2, the amount of the nitrogen oxides formed during the combustion process depends on the temperature of combustion. Higher temperatures yield more nitrogen oxides. The peak flame temperature of combustion can be lowered by introducing relatively inert substances into the air-fuel mixture. The exhaust gases from an engine provide a convenient source of such substances. Exhaust gases are essentially inert



(a) EFFECTS ON AIR-FUEL RATIO ON EXHAUST COMPOSITION

(b) EFFECT ON AIR-FUEL RATIO ON POWER AND ECONOMY

Figure 2-1. EFFECTS OF AIR-FUEL RATIO (REFERENCE 114)

and also contain substantial quantities of water, which has a cooling effect. The recirculation of part of the exhaust (usually from 10 to 15 per cent of the engine airflow) thus limits the combustion temperature and reduces the formation of nitrogen oxides.

In the retrofit devices evaluated, the amount of exhaust gas recirculated is controlled by an orifice or valve in the line leading from the exhaust to the intake manifold.

Many different EGR system designs have been employed by the various developers. The location of the recirculated exhaust gas pickup, the point of introduction of the recycled gas into the engine induction system, the metering devices, and their signal sources all can be varied greatly. In one system, the recycled gas was taken from the heat riser area of the exhaust manifold and metered directly to the intake manifold below the carburetor throttle plate. In another, the recycle gas was picked up downstream of the exhaust manifold, cooled, and introduced through a spacer plate above the carburetor throttle plate. For driveability and engine performance reasons, EGR is usually terminated at engine idle or wide-open-throttle conditions.

Intake Manifold Modification - Intake manifold modification types are based on the principle of reducing emissions by providing a more uniform air-fuel mixture to the combustion chambers and better atomization, vaporization, and diffusion of the mixture.

The typical approach reflected in the retrofit devices of this type consists in screen and deflection plate inserts between the carburetor throttle plate and the intake manifold, or between the manifold and the intake ports to the intake valves.

Carburetor Modification - Devices studied in this category reflect an alternative approach to optimizing the air-fuel ratio and air-fuel mixing qualities. These devices vary in complexity from relatively simple devices for improving air-fuel mixing to complete carburetor replacements.

Fuel Injection - This approach is based on the principle of improved air-fuel mixing to optimize combustion. Fuel injection would eliminate the conventional carburetor.

2.3.1.3 Ignition Control Systems - Type 1.3

Ignition Timing Modification - These systems represent another approach used to control exhaust emissions during the combustion process. The basic technique used in these devices is to retard the ignition timing or spark by disconnecting the distributor vacuum advance unit. This has the effect of lowering peak combustion temperature and, therefore, NOx formation is reduced. Retarding the spark also moves the combustion event closer in time to the exhausting of the combustion gases from the cylinder. Thus the exhaust gases are hotter and oxidation of CO and HC may continue in the exhaust manifold. Devices in this category are primarily NOx controls, and are sometimes used in combination with lean carburetion and reactors to encompass CO and HC control.

To guard against engine overheating, these devices usually incorporate a thermal switch in the cooling system that is interconnected with the vacuum line. When the coolant temperature reaches the thermoswitch actuation temperature, the vacuum is restored to advance the spark.

Ignition Spark Modification - This approach is based on prolonging the duration of the ignition spark. These systems are generally designed to provide higher secondary voltage for higher engine speeds and loads.

2.3.1.4 Fuel Modification - Type 1.4

Alternative Fuel Conversion - Retrofit methods evaluated in this category consist of the gaseous fuel conversions to compressed natural gas (CNG), liquified petroleum gas (LPG), or combination dual-fuel (gasoline and gaseous) systems.

LPG has been used as an automotive fuel for many years. Approximately 300,000 LPG vehicles are estimated to be in operation nationally. There are currently more than 2,000 natural-gas-fueled vehicles throughout the country. Thus far, these are mainly experimental operations. While this represents a small part of the automotive population, it indicates that the technical and economic problems associated with the use of natural gas in competition with gasoline-fueled vehicles have in some measure been resolved.

Gaseous fuels, by their lower molecular weights and lesser amounts of carbon, tend to produce fewer hydrocarbons that contribute to the formation of photochemical smog.

The emissions of CO and HC are minimized by operation further on the lean side, and this can be obtained without misfire with the use of gaseous fuels (Reference 30). One of the major problems associated with ignition and internal combustion engines is that of lean misfire, which is a limiting factor in lean carburetion of a conventional engine. Under certain conditions, misfire tends to occur both on the rich or lean side of stoichiometric ratio, but particularly on the lean. The gaseous fuels indicate a distinct advantage in regard to antiknock performance.

Fuel Additive - This approach has been associated over the years with engine performance improvement, as well as a means of decreasing engine maintenance requirements. Fuel additives are designed to remove or inhibit deposit levels in the carburetor and combustion chamber.

2.3.2 Crankcase Emission Control Systems - Group 2

Crankcase emissions from an uncontrolled vehicle may account for as much as 20 percent of the total HC emission. If these emissions are controlled, the hydrocarbons are ciciculated to the intake manifold. The crankcase emission control system provides a means of circulating air through the crankcase, mixing it with the blowby gases, which are recirculated through a metering positive crankcase ventilation (PCV) valve to the intake manifold for distribution on to the combustion chambers. Ventilation air is drawn either directly from the engine compartment (open system), or through the engine air cleaner through a hose (closed system), into the valve cover. The metering valve is typically a variable orifice valve controlled by intake manifold vacuum. A spring-loaded metering pin balances itself within the valve in response to the changing manifold vacuum. As the vacuum changes, the orifice area varies, and thereby controls the flow rate through the valve.

At idle conditions, the metering pin is at the minimum flow position and allows about 1 to 3 cubic feet per minute (cfm) flow capacity (flow capacity depends on engine application). As the engine load increases (12 inches of mercury intake manifold vacuum or less), the metering pin repositions itself in response to the combination of the spring force and vacuum force, and in turn allows increased flow capacity. A maximum flow of 3 to 6 cfm occurs at approximately 6 inches mercury manifold vacuum and then decreases as the vacuum becomes less, approaching wide-open throttle. If backfire occurs, the valve will completely close off the flow and prevent possible crankcase explosions.

After a period of operation, the PCV valve may become clogged with deposits, reducing and perhaps finally stopping all crankcase ventilation. Manufacturers of crankcase control systems recommend cleaning or replacing the metering valve periodically.

Because crankcase control systems are limited to blowby HC control, they are frequently used in combination with control devices for exhaust CO, HC, and NOx. These are generally compatible combinations. Care would have to be used in combining blowby control with an air-bleed-to-intake manifold device, because of the possibility of overleaning the carburetor mixture which could result in lean misfire under certain operating conditions.

2.3.3 Evaporative Emission Control Systems - Group 3

Evaporative emission control systems were not submitted for evaluation in the retrofit program. However, the feasibility of retrofitting a production system was evaluated. Gasoline tanks and carburetors are vented to the atmosphere on pre-1970 California vehicles and on pre-1971 vehicles nationally.

Evaporative losses at the carburetor occur almost entirely after shutting off a hot engine. The residual heat causes the fuel bowl temperature to rise to 150 - 200°F, causing substantial boiling and vaporization of the fuel. Fuel tank evaporative losses also occur while the car is parked, but could occur while running under severe conditions. Evaporative losses vary because of many factors and may be as much as 29 grams of fuel per soak period on a car without evaporative controls (Reference 122).

The vapor-recovery approach in the evaporative emission control system on new vehicles is based on using the crankcase as a storage area for vapors from the fuel tank and carburetor. During the hot soak period after engine shutdown, the declining temperature in the crankcase causes a reduction in crankcase pressure sufficient to induct vapors. During this period, evaporated vapors from the carburetor are drawn into the crankcase. Vapor formed in the fuel tank is carried to a liquid-vapor separator. The condensate returns to the fuel tank, and remaining vapors are drawn into the crankcase. When the engine is started, the crankcase is purged of vapors by the action of the positive crankcase ventilation system.

A sealed fuel tank with a fill-limiting device is required to ensure that enough air is present in the tank at all times to allow for thermal expansion of the fuel. A pressure vacuum relief gas tank cap is used to prevent excessive fuel tank pressure or vacuum.

In the absorption-regeneration evaporative control system, a canister of activated carbon traps the vapors and holds them until such time as they can be drawn back into the induction system for burning in the combustion chamber. During a hot soak period, vapor from the fuel tank is routed to a condenser and separator, and liquid fuel is returned to the tank. The remaining vapor, along with the fuel vapor from the carburetor, is routed to the canister filled with activated carbon which absorbs the fuel vapor. When the engine is started, fresh purge air drawn through the canister removes the trapped fuel vapor from the activated carbon and carries it to the combustion chambers. A sealed fuel tank with air trapping space that cannot be filled with fuel is required for thermal expansion. A vacuum and pressure-relief gas tank cap is also used with this system.

3 — EXHAUST CONTROL SYSTEMS

SECTION 3

GROUP 1 RETROFIT METHOD DESCRIPTIONS: TYPE 1.1 - EXHAUST GAS CONTROL SYSTEMS

As noted in Section 2, the emission of HC, CO, and NOx pollutants from the exhaust of gasoline-powered, light duty vehicles may be controlled basically in two ways: (1) by inhibiting formation of the pollutants during the combustion event; and (2) once they have formed, by changing their chemical composition to a nonpollutant form. The latter is the approach to vehicle emission control represented by retrofit devices classified as Type 1.1, Exhaust Gas Control Systems.

Most of the retrofit emission control devices in this category are characterized by a common mode of operation in which the exhaust gas pollutants formed during the combustion event are converted to a nonpolluting chemical form. These are typically devices which oxidize the CO and HC pollutants to carbon dioxide and water by either catalytic reaction, by thermal reaction, or by exhaust afterburning. Only one case was found where a strictly physical approach to retrofit exhaust gas control was being proposed; this was in the form of an exhaust gas filter. Filtering the exhaust gas would be expected to have no direct effect on the chemical makeup of the gas; however, it should remove particulate matter.

Another variation within the exhaust gas control group was that of a device which applies backpressure in the exhaust system. Increased backpressure might have an effect similar to exhaust gas recirculation in lowering combustion temperature and thereby inhibiting NOx formation; however, this was not an apparent characteristic of the backpressure device evaluated.

Of the 65 retrofit emission control devices for which data were obtained or developed, 12 were of the exhaust gas control type. Although devices of the exhaust gas recirculation type would appear to be part of the exhaust control group, they actually are in the emission control class which inhibits the formation of NOx during combustion and not in the class that treats the pollutant after formation. Devices of this type are more appropriately classified as induction controls, and therefore are described in Section 4.

The retrofit devices described in this section are listed in Table 3-1. As indicated by this table, several of the retrofit devices incorporate more than one approach to reducing emission of pollutants from the exhaust. These combination approaches are intended to do one of two things: either to extend CO and HC control to include NOx or to attain supplementary control of CO and HC in addition to some measure of NOx control. One combination approach, such as that of Device 93, combines the basic capability of a catalytic reactor for controlling CO and HC with the capability of exhaust gas recirculation to control NOx. With the Device 96 combination, the approach is to enhance the basic capability for controlling CO and HC by adding spark retard, which also inhibits NOx formation. Both of these may be considered system approaches to emission control requirements, in that they have capability for controlling all three pollutants. The system approach is typical of combination type devices.

Table 3-1. TYPE 1.1 - EXHAUST GAS CONTROL SYSTEM RETROFIT DEVICES

DEVICE NO.	NOMENCLATURE
CATALYTIC CONVERTERS - SUBTYPE 1.1.1	
62(1)	Catalytic Converter
93(1)	Catalytic Converter with Exhaust Gas Recirculation, Spark Modification, and Lean Idle Mixture
(1) 96(2)	Catalytic Converter with Distributor Vacuum Advance Disconnect
292(1)	Catalytic Converter
THERMAL REACTORS - SUBTYPE 1.1.2	
31	Thermal Reaction by Turbine Blower Air Injection
244(1)	Rich Thermal Reactor
463(1)	Rich Thermal Reactor with Exhaust Gas Recirculation and Spark Retard
468	Lean Thermal Reactor with Exhaust Gas Recirculation
EXHAUST GAS AFTERBURNER - SUBTYPE 1.1.3	
308	Exhaust Gas Afterburner
425	Exhaust Gas Afterburner
EXHAUST GAS FILTER - SUBTYPE 1.1.4	
164	Exhaust Gas Filter
EXHAUST GAS BACKPRESSURE - SUBTYPE 1.1.5	
322(1)	Exhaust Gas Backpressure Valve

(1) Previously tested by EPA.
(2) Emission and driveability data developed in the retrofit study test program.
(3) All data for devices having no footnote number adjacent to the device number were obtained through the retrofit development or production source.

In the descriptions which follow, combination devices of the exhaust gas control group are presented as part of the retrofit type most representative of the principal control concept. The major emission control combinations - those which integrate two or more of the principal retrofit group control approaches - are described in Section 9.

3.1 CATALYTIC CONVERTERS - RETROFIT SUBTYPE 1.1.1

As shown in Table 3-1, four retrofit devices incorporating catalytic oxidation of CO and HC pollutants as a basic approach to exhaust control were found to be under development. A data questionnaire response from the developer was received only for Device 96. Information on Device 292 was obtained from sales literature (Reference 12) distributed by the developer, and from a test report provided by EPA (Reference 10). Information on Devices 62 and 93 was obtained from EPA test reports (References 8 and 9).

3.1.1 Device 96: Catalytic Converter with Distributor Vacuum Advance Disconnect

Device 96 is a CO/HC-oxidation catalytic converter that, as an emission control system, encompasses NOx control by means of a distributor vacuum advance disconnect subsystem. This device is in limited production for test and evaluation, and was selected as one of the four representative devices to be tested on the used-car vehicle fleet of the retrofit program. Eleven test specimens of this device were subjected to 17 emission and driveability tests. Two specimens were subsequently subjected to a 25,000-mile durability test (refer to Volume IV for test procedures).

The developer of Device 96 is a manufacturer of catalytic materials. Although the developer has experimented with dual- and tri-component catalytic converters for control of NOx with CO and HC (as reported in Reference 2), the device configuration tested in the retrofit program incorporated only CO and HC basic catalytic conversion. Distributor vacuum advance disconnect was used to obtain supplementary HC oxidation in the exhaust manifold upstream of the reactor, and to inhibit NOx formation during combustion. In all, the developer identified four operational configurations of the device, incorporating components and operational provisions as follows:

Configuration	Catalytic Converter	Vacuum Advance Disconnect	Air Pump	Thermal Protection System
A	X	X		
B	X			
C	X	X	X	X
D	X		X	X

Vacuum advance disconnect is used when NOx control is desired with CO and HC control. An air pump is required when the carburetor cannot be tuned to a sufficiently high air-fuel ratio to provide the air needed for the oxidation process. Configuration A and C were the ones evaluated in the retrofit program. Both configurations were the same, except for the deletion of the air pump from Configuration A.

3.1.1.1 Physical Description

Device 96 consists of a catalytic converter that is installed in the engine exhaust system between the exhaust manifold and the muffler. The converter attaches directly to the exhaust manifold so as to process the exhaust gas at the highest possible temperature. Figure 3-1 shows the converter configuration tested in the retrofit program.

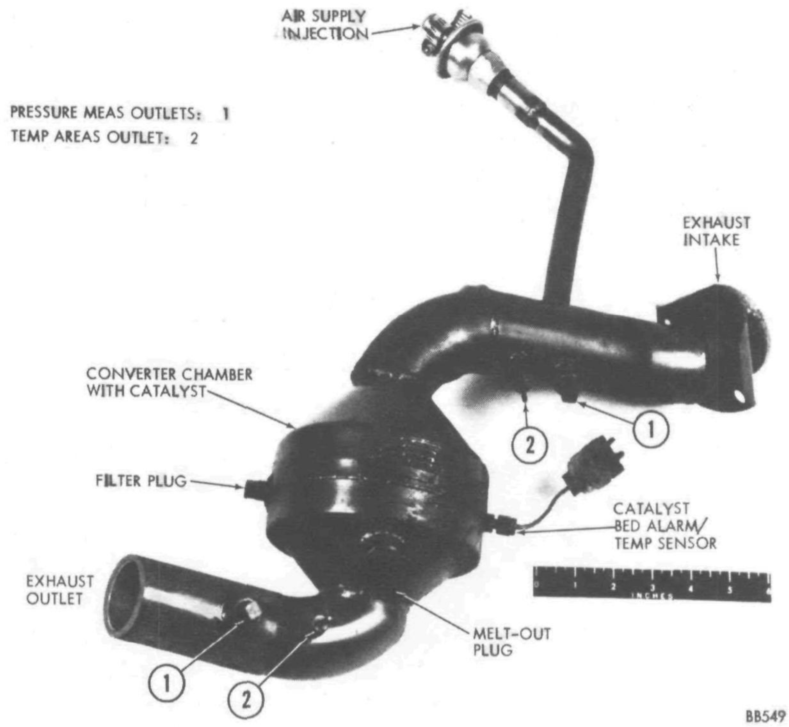


Figure 3-1. DEVICE 96 CATALYTIC CONVERTER CONFIGURATION TESTED IN RETROFIT PROGRAM - DEVELOPMENT MODEL

Figure 3-2a illustrates the installation of the converter on the 1965 Chevrolet, 6-cylinder, 194-cubic-inch-displacement (CID) vehicle used in the test program. An 8-cylinder engine would have a converter installed downstream from each exhaust manifold.

The converter chamber is circular in cross-section and is made of welded stainless steel. The chamber is 4.75 inches in diameter and 12 inches long for an 8-cylinder engine. The chamber contains a pellet-type catalyst bed, with the pellets retained by wire mesh screen. The catalyst bed consists of approximately 30 cubic inches of pellets coated with a platinum material. The bed is filled through a removable plug in the side of the chamber.

On older cars (pre-1968 and some 1968 cars) an air pump is usually required to supply the amount of air needed to support the oxidation process in the converter.(1) On later model cars, the carburetor can generally be tuned to a sufficiently high air-fuel ratio to provide the amount of air needed. A typical air pump installation is shown in Figure 3-2. The pump is mounted on the front of the engine where it can be belt driven from the crankshaft pulley.

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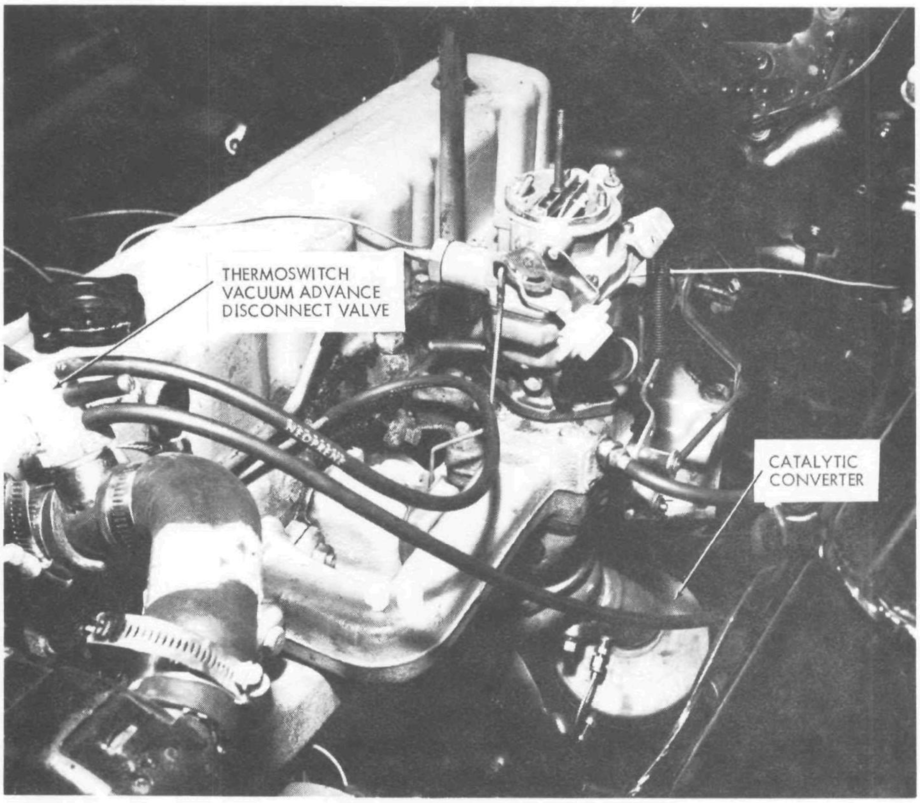
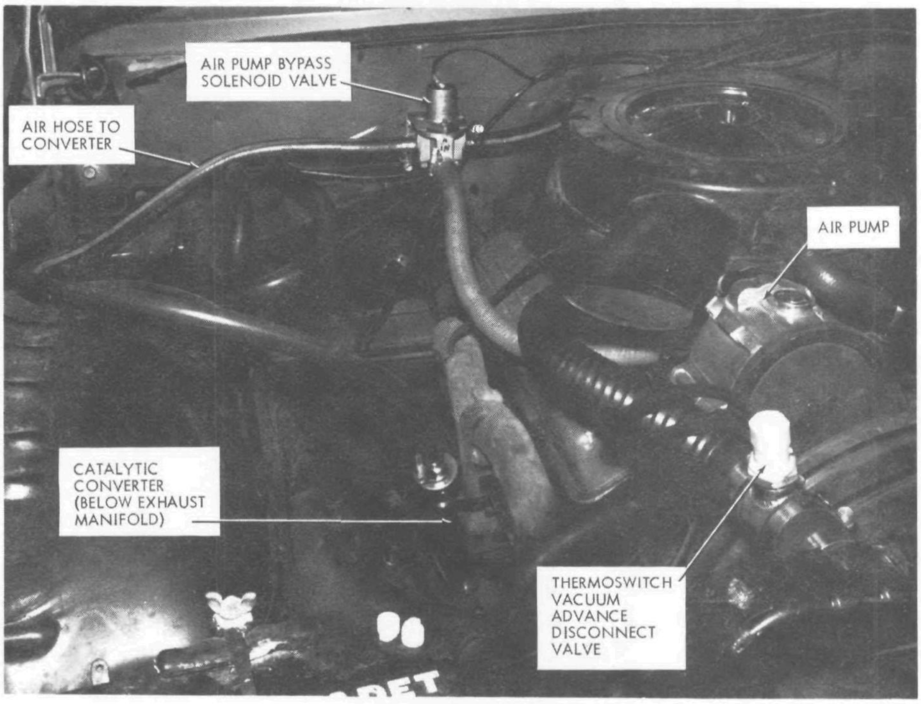
(1) According to the developer, use of a high capacity positive-crankcase-ventilation (PCV) valve may be an alternative, less expensive way of obtaining auxiliary air for the converter on older cars; the developer claimed a 50 percent emission decrease by use of an oversize PCV valve to provide air in place of an air pump.



(a) Installation of Device 96 - On 1965 Chevrolet 194-CID Test Vehicle



(b) Installation of Supplementary Air Pump for Device 96 on 1961 Chevrolet 283-CID Test Vehicle

Figure 3-2. DEVICE 96 CATALYTIC CONVERTER WITH VACUUM ADVANCE DISCONNECT INSTALLATION

To protect the converter from overheating under unusually high flow of CO and HC (which might occur if the carburetor or engine malfunctions), a melt-out plug is incorporated in the chamber. When temperature in the chamber rises above the the level at which the catalyst can operate without being damaged, the plug melts and the exhaust gas is vented directly into the ambient air. When an air pump is used to supply auxiliary air, a thermal protection system is required in addition to the melt-out plug. This system consists of a thermocouple installed in the converter, wired to an electronic control which is preset to a limit temperature and which energizes a solenoid to divert the air pump output away from the converter chamber when the limit temperature is exceeded.

To disconnect the standard distributor vacuum advance system, a thermoswitch, installed in the radiator water return line, is used. The vacuum advance hose is connected through the thermoswitch, which is normally closed, preventing the intake vacuum from actuating the distributor vacuum advance mechanism.

3.1.1.2 Functional Description

The function of Device 96 is to decrease CO, HC, and NOx pollutants in exhaust emissions. CO and HC react with oxygen in a catalytic platinum bed to produce carbon dioxide and water. Formulation of NOx is inhibited during the combustion event by use of retarded ignition timing.

A simplified block diagram of the overall catalytic converter and vacuum advance disconnect system is shown in Figure 3-3.

The NOx reduction is achieved by disconnecting the distributor vacuum advance. The thermoswitch installed in the distributor vacuum advance line keeps the vacuum advance disconnected during all engine operating modes, unless the engine coolant temperature rises to the point where the thermoswitch opens, allowing the vacuum advance to operate. In particular, at idle and mid-load ranges of engine operation, the temperature of the coolant may rise beyond the acceptable limit, because of the retarded ignition timing. The purpose of the thermoswitch is to sense engine overheating, through the coolant, and restore the vacuum advance to normal operation.

Normally, the thermoswitch disconnects the vacuum advance, and the cooler combustion event inhibits the formation of NOx. Because exhaust temperature increases, some HC is actually oxidized during exhaust. Since the carburetor is leaned out to as high an air-fuel ratio as the engine will accept to provide the air required for catalyst operation, the greater amount of air in the combustion chamber allows for more complete oxidation of CO and HC even before the catalytic converter part of the system is reached.

The higher exhaust gas temperature caused by high air-fuel ratio and ignition timing retard makes the converter more efficient. To oxidize CO and HC entering the converter as part of the exhaust, catalyst temperature in the range of 1,000 to 1,600°F is required, along with enough air to support oxidation. The temperature of exhaust gas entering the converter is from 900 to 1,400°F, with the ignition timing retard provided by the vacuum advance disconnect subsystem of Device 96. The air required to support oxidation comes from leaning out the carburetor to a high

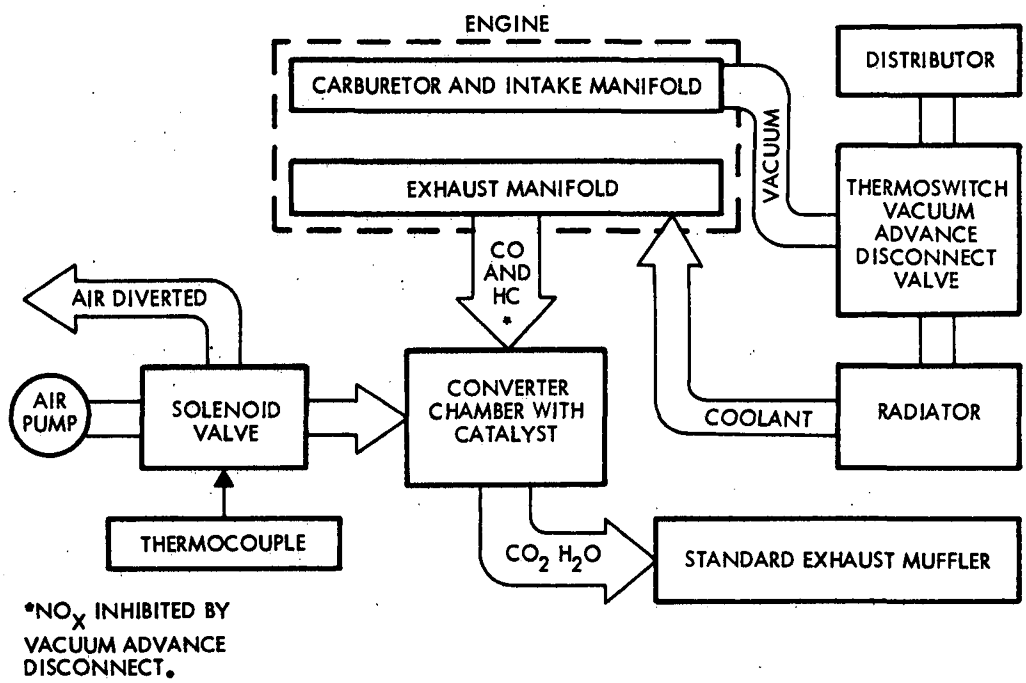


Figure 3-3. DEVICE 96 CATALYTIC CONVERTER WITH VACUUM ADVANCE DISCONNECT FUNCTIONAL DIAGRAM

air-fuel ratio, from the auxiliary air pump, if needed, or from both. As the exhaust gas flows through the catalyst bed, CO and HC are oxidized to carbon dioxide and water.

Since the temperature of the catalyst is in part determined by the amount of CO and HC being oxidized, unusual amounts of CO and HC can cause excessive temperature that may degrade, if not destroy, the catalyst. The thermocouple shown in Figure 3-3 monitors the temperature of the converter, so that, in the event of excess temperature, the air from the pump can be diverted by the air bypass valve until the temperature drops to an acceptable level. The air bypass valve has to be reset manually to restore the air pump to normal operation.

The melt-out plug in the converter chamber is provided as a backup overheat protection whether or not an air pump is used. Should the plug melt because of abnormal exhaust gas temperature, the exhaust is vented to the atmosphere through the opening. This produces a noise similar to a muffler that has a hole in it.

3.1.1.3 Performance Characteristics

Emission test results obtained in 17 tests of Device 96 using the 1972 Federal Test Procedure (Reference 3) are tabulated in Table 3-2.

Table 3-2. DEVICE 96 CATALYTIC CONVERTER WITH VACUUM ADVANCE DISCONNECT EMISSION REDUCTION AND FUEL CONSUMPTION PERFORMANCE (1)

VEHICLE YEAR/MAKE/CID	ANAHEIM TEST RESULTS								TAYLOR TEST RESULTS			
	POLLUTANT GRAMS/MILE						FUEL MILES/ GALLON		POLLUTANT GRAMS/ MILE			FUEL MILES/ GALLON
	HC		CO		NOx				HC	CO	NOx	
1965 Chev 194	*	*	*	*	*	*	*	*				
Without Device	11.09	8.12	85.06	75.39	2.87	1.72	12.3	15.7	(2)	(2)	(2)	(2)
With Device	1.65	3.93	18.42	17.01	0.67	1.45	15.7	13.2				
Percent Reduction	85.1	51.6	78.3	77.4	76.7	15.7	28.0	16.0				
1965 Ford 289	*	*	*	*	*	*	*	*				
Without Device	8.85	10.36	121.83	149.77	2.83	1.29	11.6	12.3	3.59	59.16	2.61	(3)
With Device	0.69	2.53	5.95	55.09	0.99	0.76	13.7	11.0	1.20	19.29	1.26	13.5
Percent Reduction	92.2	75.6	95.1	63.2	65.0	41.1	-18.1	11.0	66.6	67.4	51.7	(3)
1965 Plymouth 318		*		*		*		*				
Without Device	6.62	7.06	101.94	68.90	3.33	3.24	14.2	11.7	3.46	46.50	4.34	13.0
With Device	4.36	2.41	89.61	33.59	1.04	2.26	13.2	11.4	0.51	7.83	1.82	14.2
Percent Reduction	34.1	65.9	12.1	51.2	68.8	30.2	7.0	3.0	85.3	83.2	58.1	-9.2
1965 Chev 327	*	*	*	*	*	*	*	*				
Without Device	8.80	7.98	69.76	53.65	2.87	2.49	14.2	14.5	4.63	43.65	5.14	10.0
With Device	1.17	1.99	0.57	12.53	1.78	1.08	11.7	13.7	1.35	9.78	1.97	13.2
Percent Reduction	86.7	75.1	99.2	76.6	38.0	56.6	18.0	6.0	70.8	77.6	61.7	-32.0
1965 Ford 390									*	*	*	*
Without Device	6.73	8.37	74.88	104.45	1.90	2.56	12.1	11.4	4.08	64.45	2.83	14.0
With Device	4.00	5.16	56.80	76.38	0.64	1.84	11.7	10.4	0.29	0.30	1.20	15.4
Percent Reduction	40.6	38.4	24.1	26.9	66.3	28.1	3.3	9.0	92.9	99.5	57.6	-10.0
1961 Chev 283	*		*		*		*		*	*	*	*
Without Device	7.47	5.65	77.44	72.81	1.82	1.72	13.5	13.5	3.55	36.34	3.28	14.5
With Device	2.38	2.90	51.99	69.86	1.19	1.52	11.2	10.7	0.49	1.51	1.64	14.0
Percent Reduction	68.1	48.7	32.9	4.1	34.6	11.6	17.0	20.1	86.2	95.8	50.0	-3.4

POOLED MEAN PERCENT REDUCTION (4)	HC 68.4	CO 62.6	NOx 47.8	FUEL 1.0

(1) Emission results obtained by Olson Laboratories in tests performed under Contract 68-04-0038 using 1972 Federal Test Procedure (Reference 3). Fuel consumption was measured during these tests.

(2) No test.

(3) Test data invalid.

(4) Anaheim and Taylor results combined.

* With air pump.

As noted in Table 3-2, seven of the tests were performed with the device in Configuration A (without auxiliary air pump). The average emission reductions of CO, HC, and NOx with and without air pumps are summarized in Table 3-3.

Table 3-3. DEVICE 96 AVERAGE EMISSION REDUCTION PERFORMANCE

SYSTEM CONFIGURATION	PERCENT REDUCTION			PERCENT CHANGE FUEL MILES/GALLON
	HC	CO	NOx	
A (without air pump)	54.9	42.2	49.5	0.3
C (with air pump)	77.9	76.9	46.6	-1.8

The reductions shown for Configuration A are particularly significant in that they were obtained in the lower cost configuration, in which the air pump, which is relatively expensive (refer to paragraph 3.1.1.8), is not required.

The developer claims that tests have shown emission reductions of 50 percent with auxiliary air provided by an oversized PCV valve rather than an air pump. The developer states that this was accomplished "by replacing the PCV valve with one of larger capacity to lean out the mixture at cruise conditions and then adjusting the idle mixture adjustment screws to lean best idle" (Reference 4).

The results shown in Table 3-2 are further corroborated by cold-start emission tests to the 1972 constant-volume-sampling (CVS) Federal Test Procedure (Reference 3) reported by the developer. The results of these developer-reported tests are summarized in Table 3-4.

Table 3-4. DEVICE 96 EMISSION REDUCTION PERFORMANCE REPORTED BY DEVELOPER (REFERENCE 4) (1)

VEHICLE CONFIGURATION	POLLUTANT GRAMS/MILE		
	HC	CO	NOx
Without Device	7.48	95.5	Not Reported
With Device and Air Pump	0.65	1.3	Not Reported
Percent Reduction	91	98	---
With Device and No Air Pump	5.85	37.7	Not Reported
Percent Reduction	21.8	60.5	---

(1) Results obtained with 1965 Chevrolet, with 327-cubic-inch-displacement engine, using cold-start 1972 Federal Test Procedure, as reported in Reference 4. One test under each condition.

The developer of Device 96 has also been active in the development of a tricomponent catalytic converter (Reference 2). The tricomponent system has a three-way catalyst bed for simultaneous reduction of CO, HC, and NOx; thus disconnecting the distributor vacuum advance would not be required as a means of NOx control. EPA has performed emission tests on this system as reported in Reference 5, with results shown in Table 3-5.

The developer has determined in further investigations into the NOx reduction characteristics of this device that NOx reduction is optimum with the air-fuel mixture slightly on the rich side of the stoichiometric ratio.

Table 3-5. EMISSION TEST RESULTS OBTAINED BY EPA ON TRICOMPONENT CATALYTIC CONVERTER PROVIDED BY DEVICE 96 DEVELOPER (REFERENCE 5) (1)

TEST	POLLUTANT GRAMS/MILE			
	HC	CO	NOx	
			(2)	(3)
1	2.3	32	0.6	1.3
2	1.4	10	0.8	1.1

(1) Results obtained with 1970 Volkswagen, with 98-cubic-inch-displacement engine and automatic transmission using 1972 Federal Test Procedure. Stock fuel injection was modified to prevent fuel cutoff during deceleration and the catalytic converter was installed in place of the standard muffler (Reference 5).

(2) As measured by wet chemical modified Saltzman technique.

(3) As measured by electrochemical detection system.

3.1.1.4 Reliability

The principal components influencing the reliability of Device 96 are as follows:

a. Catalyst
b. Converter chamber
c. Air pump and drive belt
d. Thermoswitch and vacuum hoses
e. Air bypass solenoid valve and thermocouple.

The components listed above are comparable to existing automotive components which have life expectancies well in excess of 50,000 mean-miles-before-total-failure (MMBTF) - the useful life of light duty vehicle emission controls as specified in the Clean Air Amendments of 1970 (Reference 6) and the standard specified by California for retrofit device accreditation (Reference 7). Item b, the converter chamber, has been tested by the developer for 50,000 miles with no failure.

The catalyst is the critical component. Although prototype catalysts have been tested by the developer to 22,000 miles before significant attrition due to thermal exposure occurred, the catalyst used in Device 96 has not been tested for exhaust emissions beyond 10,000 miles. A minor decrease in the conversion efficiency of the catalyst occurred up to 4,000 miles, but no further loss in efficiency occurred to the 10,000-mile test limit. In Reference 4, the developer reports that the catalyst used in Device 96 was subjected to 50 thermal cycles to 1,825°F without any weight loss, and to 54 cycles to 1,900°F with 2.9 percent weight loss. These tests were performed with the converter on a Cooperative Fuel Research (CFR) engine. One CFR thermal test cycle consists of 15 minutes at peak temperature with full auxiliary air, 10 minutes with auxiliary air off, and 5 minutes with fuel off but with auxiliary air on to cool the catalyst bed. Fifty cycles is equivalent to 12.5 hours of operation at peak temperature.

The catalyst can be adversely affected by lead additives in the gasoline and by oil blowby, as well as by operation at excessive temperature. The effect of excessive temperature is attrition of the catalyst and the consequent loss of effective catalyst surface area for reacting with the incoming exhaust gas. The effect of lead additives is loss of catalyst activity either by chemical or physical interactions, or both, between the lead and the catalyst (Reference 2).

The developer of Device 96 has verified through tests that the emission reduction effectiveness of the device is greatly impaired when the fuel contains lead additives. The extent to which the catalyst tolerates occasional lead contamination, from fueling errors or from lead deposits that have accumulated in the engines and fuel lines of used cars, was investigated in the durability test program (1). Oil blowby due to worn piston rings can similarly affect the catalyst adversely, as indicated by the results of durability testing.

The resistance of the Device 96 catalyst to thermal attrition indicates that the device will have satisfactory reliability if maintained correctly and if unleaded fuel is used. Overall reliability of the device, however, is influenced by the condition of the vehicle's engine. If the engine is excessively worn so that oil consumption occurs, the catalyst can become ineffective, just as it would if used with leaded gasoline.

3.1.1.5 Maintainability

According to the developer, the only scheduled maintenance required on the device would be replacement of the catalyst at 25,000-mile intervals. A vacuum cleaner can be used to remove the old catalyst through the filler plug. Fresh catalyst can be poured into the canister through the same plug. The canister should be tapped as the new catalyst is added, so that the material settles evenly. This procedure has been performed routinely by the developer on development units of the device. As reported by the developer, the cost of a catalyst refill would be $15 and $20 for 6- and 8-cylinder engines, respectively.

Since an air pump is used and these normally incorporate an air filter, cleaning of the filter would be required at least once every 12,000 miles.

The only unscheduled maintenance would be the replacement of the melt-out plug should an engine malfunction cause excessive temperature in the catalyst chamber. Replacement is by simple insertion of a new plug.

To obtain maximum effectiveness from this catalytic converter, the vehicle engine must be maintained to preclude excessive blowby of engine oil into the exhaust system. This means that the engine oil and filter have to be changed in accordance with the regular schedule specified by the vehicle manufacturer to obtain maximum piston ring life; and that excessively worn rings have to be replaced.

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(1) The results of a 25,000-mile durability test that have been performed as part of the retrofit study program will be reported in Volume VI of this report. Every 2,500 miles, a full tank of leaded fuel (Premium) was used instead of the unleaded fuel (No-Lead) normally used to determine the effects of accidental use of leaded fuel in operational use and whether the catalyst recovers when use of unleaded fuel is resumed.

3.1.1.6 Driveability and Safety

No driveability or safety problems occurred in the 17 tests of Device 96 performed as part of the retrofit study.

3.1.1.6.1 Driveability Characteristics. Table 3-6 shows the driveability results obtained. The cold starting problems noted for Anaheim, California, Cars 1, 2, and 4 were attributed to the use of Indolene Clear Fuel. In subsequent driveability tests, commercial unleaded fuel was used and the starting problems did not occur.

The principal driveability effect of the device is some decrease in fuel economy. Fuel measurements during the emission tests of Table 3-2 indicate that fuel consumption is approximately 1 percent greater with the device installed.

The developer specified unleaded fuel without phosphorous additives for acceptable catalyst performance. The developer reported that in 190,000 miles of driving accumulated on 62 vehicles with the device installed that fuel consumption increased by as much as 2 percent. The developer attributes this increase to the use of distributor vacuum advance disconnect, which is the NOx control phase of the overall system. The developer reported that driveability characteristics were satisfactory throughout his tests.

3.1.1.6.2 Safety Characteristics. The design of the converter incorporates several safety features. The exhaust gas inlet cone and the main body of the catalyst chamber are insulated to protect the more sensitive areas of the engine compartment from the heat of the catalytic reaction. The exhaust gas outlet has a larger surface area than the inlet, so that more heat is dissipated downward, away from the car, than into the engine compartment. The converter chamber wall temperatures are generally not higher than exhaust manifold temperatures, for which adequate protection is usually found in most vehicle engine compartment areas.

A temperature sensitive melt plug is built into the outlet cone. This plug is designed to fail at a temperature low enough to protect the catalyst and converter body from the excessively high temperatures that might be generated in the converter if the engine ignition system malfunction or prolonged periods of high speed deceleration should feed fuel and air to the converter. Melting of the plug vents exhaust gases directly to the atmosphere. Should this happen, a noise level high enough to be heard by the vehicle operator is generated.

An overtemperature detection system is employed when an air pump is used. As part of this system, a thermocouple is incorporated in the chamber to sense catalyst bed temperature. During an over-temperature condition, the thermocouple signal actuates an air bypass solenoid valve that discharges the pump air to the atmosphere. If the temperature continues to rise, the temperature sensitive melt plug will provide an additional signal to the operator. As with the melt plug, the noise of the air dumping through this valve is audible to the vehicle operator. In most cases, the bypassing of the air will lower the temperature sufficiently until the excess air and fuel condition has passed. The bypass valve can be reset by a switch.

There has been no estimate of the amount of emissions that may be bypassed in this manner. If the vacuum disconnect continues to work, NOx reduction would not be affected; however, the thermoswitch in the engine coolant hose could reconnect vacuum advance should the engine get hot enough, eliminating NOx control.

Table 3-6. DEVICE 96 CATALYTIC CONVERTER WITH VACUUM ADVANCE DISCONNECT DRIVEABILITY TEST RESULTS

DRIVEABILITY CHARACTERISTICS	1965 CHEV. 194 CID	1965 FORD 289 CID	1965 PLY. 318 CID	1965 CHEV. 327 CID	1965 FORD 390 CID	1961 CHEV. 283 CID
	ANAHEIM, CALIF., DRIVEABILITY TEST RESULTS (1)					
	CAR NO. 1	CAR NO. 2	CAR NO. 3	CAR NO. 4	CAR NO. 5	CAR NO. 6
CRITICAL DRIVEABILITY	Decreased stall during cold start deceleration	No effect	No effect	Increased stall during cold start deceleration	No effect	No effect
GENERAL DRIVEABILITY	Increased start time, rough idle & stall during cold start idle; increased stumble during cold start deceleration	Decreased rough idle during hot start idle; increased start time during cold start	Decreased cranking time during cold start	Increased number of attempts to start during cold start, decreased stall during cold start idle	Detonation during hot start acceleration	Decreased number of attempts to start during cold start
0 - 60 MPH ACCELERATION TIME (SECONDS)	Increased from 19.6 to 22.6	Decreased from 12.8 to 12.2	Increased from 12.3 to 12.7	Increased from 12.5 to 13.0	Increased from 8.9 to 9.8	Decreased from 17.5 to 17.4
60 - 40 MPH DECELERATION TIME (SECONDS)	Increased from 21.1 to 22.4	Constant at 21.5	Decreased from 24 to 19.5	Increased from 23.0 to 26.8	Decreased from 29.4 to 24.1	Decreased from 27.2 to 24.3
GAS MILEAGE PER GALLON (1)	Average decrease of 5.33 percent (reference Table 3-2)					
	TAYLOR, MICH., DRIVEABILITY TEST RESULTS					
		CAR NO. 8	CAR NO. 9	CAR NO. 10	CAR NO. 11	CAR NO. 12
CRITICAL DRIVEABILITY		No effect	Increased stall during cold start acceleration	Improved cold start idle	No effect	No effect
GENERAL DRIVEABILITY		No change in driveability	Increased amount of hesitation during cold start and hot start - stretchiness on hot start acceleration	Decreased hesitation during cold start acceleration	Decreased number of attempts to start during cold start	Trace of hesitation during cold start acceleration
0 - 60 MPH ACCELERATION TIME (SECONDS)		Information not available	Information not available	Increased from 10.7 to 12.6	Increased from 9.7 to 11.8	Increased from 13.0 to 14.3
60 - 40 MPH DECELERATION TIME (SECONDS)		Information not available	Information not available	Decreased from 20.2 to 19.3	Decreased from 20.8 to 20.7	Constant at 24.1
GAS MILEAGE PER GALLON (1)	Average increase of 11.75 percent (reference Table 3-2)					

(1) Pooled mean decrease in miles per gallon equals 1.0 percent.

3.1.1.7 Installation Description

Prior to installing Device 96, the engine has to be tuned up to reduce exhaust emissions of CO and HC to a minimum. This tuneup must include diagnosis and repair of any engine components or systems affecting exhaust emissions. In particular, the engine cylinders should be checked for compression adequacy, to identify whether the piston rings should be replaced in order to preclude excessive oil blowby into the exhaust and consequent impairment of the catalyst. After the engine is tuned up and repaired as necessary, the thermoswitch is installed in the cooling system to disconnect the distributor vacuum advance, a converter chamber is installed at each exhaust manifold outlet and the air pump (if required) with its air bypass valve and catalyst overtemperature sensing system is installed.

A detailed description of the installation procedure is provided in Table 3-7, along with tools and special equipment required. This procedure is a summary of detailed installation instructions provided by the developer for a 1965 Chevrolet 327-CID Type C Kit. Installation can be accomplished in a normally equipped repair shop by the average mechanic. The average motorist would not have the necessary range of equipment or skill.

3.1.1.8 Initial and Recurring Cost

Table 3-8 summarizes the estimated costs for Device 96. From the information available, it is estimated that the initial purchase and installation costs for this device will be $175, including an air pump, for 8-cylinder cars; and $143.75 for 6-cylinder cars. If an air pump is not required, these costs would decrease approximately $85. The initial costs do not include the cost of the engine tuneup.

3.1.1.9 Feasibility Summary

When used in conjunction with initial engine tuneup and annual inspection, the Device 96 catalytic converter should provide an effective reduction in HC and CO emissions. Emission tests conducted during the retrofit study program, using 1961 and 1965 vehicles indicate that the converter should be used with an auxiliary air pump to obtain maximum emission reduction benefits. For the $85 initial cost difference for an air pump, some 25 percent improvement in emission reduction effectiveness is gained. Tests conducted in the retrofit program indicate an average improvement in HC emission reduction from approximately 55 to 78 percent and an average improvement in CO emission reductions from 42 to 77 percent when an air pump injection system is used.

Reduction of NOx emissions with this system results primarily from disconnect of the distributor vacuum advance and not from chemical reaction in the converter. The vacuum advance disconnect used with this system is disconnected in all operating modes, which may contribute to some slightly adverse driveability as noted in Table 3-6.

This device requires the use of unleaded fuel. Also, a major unknown factor is this system's ability to withstand accidental contamination by exhaust particulates, especially those encountered with leaded fuels. Information on this aspect of device performance, obtained from durability tests, are documented in Volume VI.

Table 3-7. DEVICE 96 CATALYTIC CONVERTER WITH VACUUM ADVANCE DISCONNECT: INSTALLATION PROCEDURE

MINIMUM AVERAGE SKILL LEVEL: AUTOMOTIVE MECHANIC		
INSTALLATION AND ADJUSTMENT PROCEDURE	TOOLS, EQUIPMENT AND FACILITIES	TIME (MIN.)
1. Diagnose engine to insure proper operation. Repair or replace all defective ignition and carburetor parts	Engine analyzer	15
2. Clean, flow test, or replace smog valve as required	Hand tools	15
3. Set dwell time on ignition points	Engine analyzer	5
4. Adjust spark timing	Engine analyzer	5
5. Set carburetor mixture and speed at idle	Engine analyzer	5
6. Install thermo-vacuum switch in radiator hose	a. Hand tools b. Thermo-vacuum switch	10
7. Top off radiator coolant	Radiator coolant	2
8. Remove existing distributor vacuum advance hose	Hand tools	2
9. Plug port on engine with rubber cap	Rubber cap	2
10. Install new vacuum hose to manifold to thermo-vacuum switch to distributor	Vacuum hose	3
11. Remove exhaust pipe from manifolds to muffler	Hand tools	10
12. Position Part 4 (exhaust pipe) into the muffler (do not clamp tight) (1)	Exhaust pipe clamps	5
13. Install Part 1 (left converter assembly)	Left converter assembly	5
14. Insert Part 3 (exhaust pipe extension) into Part 4	a. Exhaust pipe extension b. Clamps	5
15. Install Part 2 (right converter assembly) into Part 3 and the right manifold flange	Right converter assembly	5
16. Align the system to prevent any interferences and tighten all bolts and clamps	Hand tools	15
17. Check the system for exhaust gas leaks when the engine is running	None	5

(1) Part numbers refer to the developers detailed installation instructions (see paragraph 3.1.1.7).

Table 3-7. DEVICE 96 CATALYTIC CONVERTER WITH VACUUM ADVANCE DISCONNECT: INSTALLATION PROCEDURE (CONT)

MINIMUM AVERAGE SKILL LEVEL: AUTOMOTIVE MECHANIC		
INSTALLATION AND ADJUSTMENT PROCEDURE	TOOLS, EQUIPMENT AND FACILITIES	TIME (MIN.)
18. Remove fan pulley	Hand tools	5
19. Remove thermostat housing	Hand tools	5
20. Install different thermostat housing, spacer, and gaskets using cap screws supplied	a. Hand tools b. Thermostat housing spacer c. Gaskets	5
21. Install air pump mounting bracket and bend fuel line to clear	a. Hand tools b. Mounting bracket	10
22. Install elbow and gasket on air pump	a. Hand tools b. Elbow, gasket	5
23. Install air pump and tension adjusting bracket	a. Hand tools b. Air pump c. Tension adjusting bracket	10
24. Install water pump pulley and air pump belt	a. Hand tools b. Air pump belt	10
25. Install air pump pulley and adjust belt tension	a. Hand tools b. Air pump pulley	5
26. Connect radiator hose to thermostat housing	Hand tools	5
27. Mount bypass valve on fire wall using two sheet metal screws	a. Hand tools b. Electric drill c. Bypass valve d. Sheet metal screws	5
28. Connect 3/4" heater hose between air pump and bypass valve	a. 3/4" hose b. Clamps	5
29. Install antibackfire valves on air inlets of exhaust	Antibackfire valves	10
30. Connect equal lengths of 5/8" heater hose between the bypass valve and antibackfire valves	a. 5/8" hose b. Clamps	10

Table 3-7. DEVICE 96 CATALYTIC CONVERTER WITH VACUUM ADVANCE DISCONNECT: INSTALLATION PROCEDURE (CONCL)

MINIMUM AVERAGE SKILL LEVEL: AUTOMOTIVE MECHANIC		
INSTALLATION AND ADJUSTMENT PROCEDURE	TOOLS, EQUIPMENT AND FACILITIES	TIME (MIN.)
31. Check radiator hose and fuel line for leaks	None	3
32. Select location for mounting secondary air control. Minimum clearances: 6" on back, 2" on sides, 1/2" on bottom	None	3
33. Drill holes and mount bracket with sheet metal screws	a. Hand tools b. Electric drill c. Bracket d. Sheet metal screw	5
34. Assemble housing to bracket	a. Hand tools b. Secondary air control housing	10
35. Provide 1/8" diameter opening through firewall and run thermocouple through. Secure with 1/8" compression fitting	a. Electric drill b. Thermocouple	
36. Connect battery to terminals with 18-gauge or larger wire	18-gauge electric wire	5
37. Connect thermocouple to socket provided	Hand tools	5
38. To test, move switch so that alarm circuit engages and latches. Test reset by holding switch momentarily in reset position.	None	5
	Total Time	4.0 hrs

The developer has produced about 100 of these converters, but does not manufacture or distribute any of the other system components. These components are obtainable from existing manufacturers. For standardization and quality control of mass produced systems, the developer should market the device as an integral system package complete with all components and installation and inspection instructions.

In summary, this catalytic converter system appears to offer relatively exceptional control of all three emissions when an air pump system is employed. The relatively high initial installation cost detracts from its overall cost effectiveness for use in a used car retrofit program, unless for some air pollution control requirements, greatly reduced emissions are mandatory and cost is not a heavily weighted factor.

Table 3-8. DEVICE 96 CATALYTIC CONVERTER WITH VACUUM ADVANCE DISCONNECT INITIAL AND RECURRING COSTS

ITEM	DESCRIPTION	LABOR HOURS OR ITEM QUANTITY	COST - DOLLARS 8-CYL	COST - DOLLARS 6-CYL
Initial Cost:				
Material				
1. Device	a. Exhaust line converters	a. Two for 8-cyl (1) One for 6-cyl (1)	125.00	100.00
	b. Air pump	b. One		
	c. Catalyst bed overheat protection system	c. One		
	d. Vacuum advance disconnect system	d. One		
2. Miscellaneous	a. Hose b. Clamps c. Electric wire d. Brackets e. Sheet metal screws f. Gaskets g. Radiator coolant	As required	(Included in above)	
Labor				
1. Installation	As required by Table 3-7	3.5 hrs (8-cyl) 3.0 hrs (6-cyl)	43.75	37.50
2. Test and adjust	As required by Table 3-7	0.5 hr	6.25	6.25
		Total Initial Cost (2)	175.00	143.75
50,000-Mile Recurring Cost: (3)				
Material				
1. Replacement catalyst	Includes replacement cost	One refills (one every 25,000 miles)	20.00	15.00
2. Fuel increase	Unleaded fuel (4)	Based on \$0.03 per gallon cost increase and 1% fuel consumption increase over 12.5 miles per gallon for 8-cyl and 16 mpg for 6-cyl	135.20	105.62
Labor				
1. Air pump filter	Clean as required by manufacturer	0.25 hr/12,000 miles	12.50	12.50
		Total Recurring Cost	187.70	148.12
		TOTAL COSTS	362.70	291.87

(1) Converter cost is estimated by the developer at \$30 for a 6-cylinder engine and \$25 for an 8-cylinder engine. Chamber size is 5.75 by 4.4 inches for 6-cylinder engines and 5.25 (length) by 5.375 (diameter) for 8-cylinder engines.
(2) Approximately \$85 less if air pump is not required, based on labor and material for a complete air injection system installation.
(3) Recurring cost for 50,000-mile service life.
(4) \$0.38 per gallon.

3.1.2 Device 292: Catalytic Converter

The developer of Device 292 has been engaged since 1963 in the development and production of platinum metal catalyst converters for exhaust emission control of liquified-petroleum-gas (LPG) powered material handling vehicles (Reference 12). Over the past two years, with the move toward use of nonleaded fuels, the developer has renewed development efforts to adapt this converter to passenger cars.

Contacts with the developer indicated that he is more interested in new model vehicle applications of Device 292 rather than retrofit to used cars (Reference 13). Although a retrofit data survey questionnaire response was not provided by the developer, data were obtained through sales brochures (Reference 12) and an EPA test report (Reference 10).

3.1.2.1 Physical Description

In the LPG-fuel material handling vehicle configuration shown in Figure 3-4, Device 292 consists of two major components: a catalytic converter and a section of exhaust pipe containing an air filter and a venturi for mixing air with the exhaust gas upstream of the converter chamber. The device is manufactured in sizes varying from 3 inches in diameter and 9 inches long, to 6-3/8 inches in diameter and 12 inches long. A thermocouple, mounted in the converter chamber, is connected to a temperature indicator meter located on the vehicle control panel. The venturi pipe section is about 6 inches long and has a 3- by 3-inch air filter mounted on it.

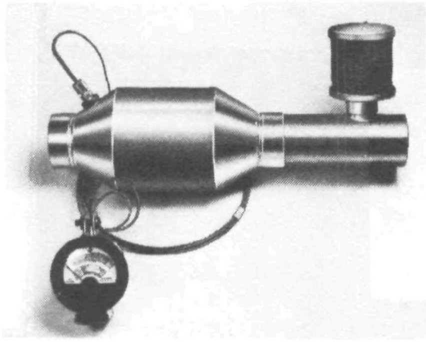

Figure 3-4. TYPICAL DEVICE 292 CONFIGURATION FOR LPG-FUEL MATERIAL HANDLING VEHICLE (REFERENCE 12)

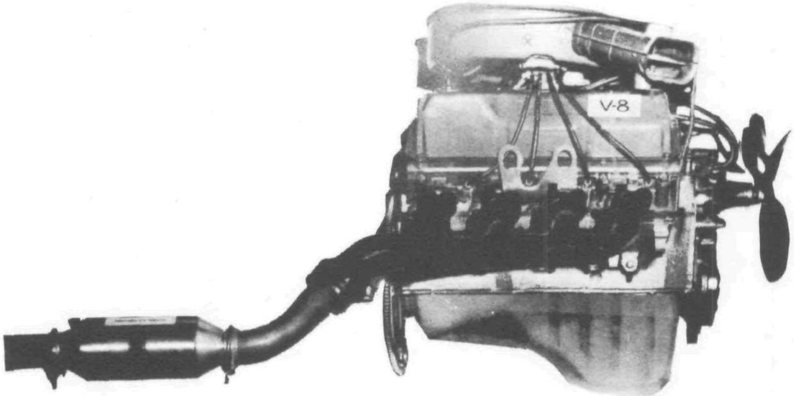

Figure 3-5. DEVICE 292 CONFIGURATION FOR GASOLINE ENGINE (REFERENCE 12)

Developmental versions of the device have been made in the configuration illustrated in Figure 3-5 for use with the gasoline engines of passenger cars. These configurations are approximately 6 inches in diameter by 20 inches in length. All versions of the device incorporate platinum catalyst. The catalyst bed is typically a ceramic honeycomb configuration.

3.1.2.2 Functional Description

Device 292 operates on the principle of oxidizing hydrocarbons and carbon monoxide by means of a platinum catalyst. Production versions of the device are presently manufactured for use with LPG-fueled engines for operation of forklift vehicles in enclosed spaces. Reference 12 states that the platinum catalyst used in the device is wholly incompatible with leaded gasoline.

Figure 3-6 illustrates the LPG configuration functionally. The functional description provided by Reference 12 is as follows:

> "Raw exhaust, containing carbon monoxide and other combustibles, enters exhaust tubing (1) furnished in each custom kit. The gases go through the venturi (2), bringing in air through the filter (3). Next, the exhaust gases, now mixed with air, are burned in the catalyst chamber (4). The purifying oxidation generates additional heat which is sensed by the thermocouple (5) and pyrometer (6) circuit to monitor the reaction. At outlet, the purified exhaust includes carbon dioxide and water vapor, the final conversion products."

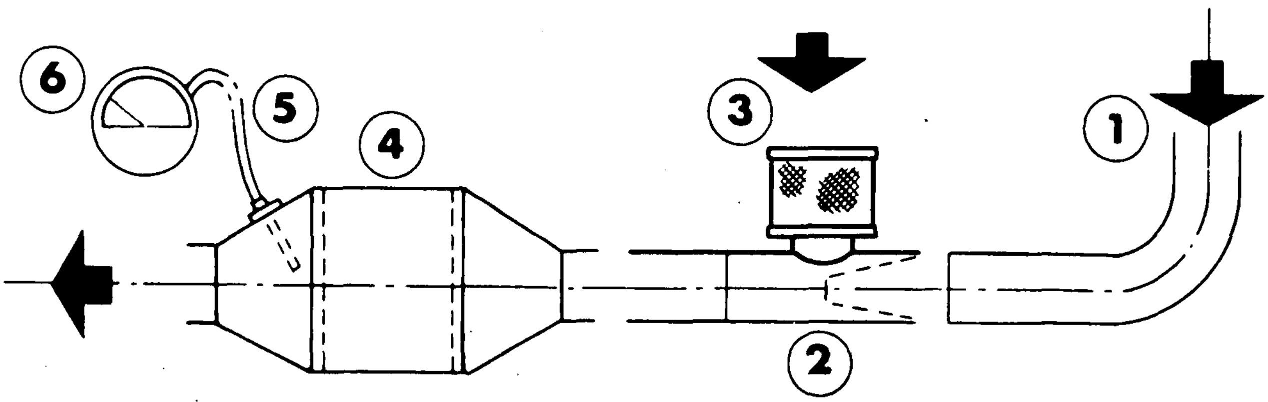

Figure 3-6. DEVICE 292 LPG CONFIGURATION CATALYTIC CONVERTER FUNCTIONAL DIAGRAM (REFERENCE 12)

The light duty vehicle configuration apparently functions in much the same way, except that an air pump may be required to inject auxiliary air rather than relying on venturi vacuum to draw in air through a filter, as for the configuration shown in Figure 3-6.

3.1.2.3 Performance Characteristics

Device 292 has been approved by the U.S. Coast Guard and the California Department of Industrial Safety for use on LPG-fueled material handling machinery operating in enclosed spaces. The device also has been certified by the State of California, Air Resources Board, in Resolution 69-22, for use on LPG fueled forklift trucks inside buildings.

The catalyst currently used in the device reacts only with CO and HC exhaust pollutants. The developer has indicated, however, that he is developing catalysts capable of controlling NOx as well. Table 3-9 shows emission test results obtained by the developer with the device installed on a forklift truck. The engine had 3,000 hours of operation at the time of device installation.

Table 3-9. DEVICE 292 LPG-FUEL EMISSION REDUCTION PERFORMANCE REPORTED BY DEVELOPER (REFERENCE 12)

TEST CONDITION (1)	POLLUTANT							
	HC (2) PPM		CH_4 (PPM)		C_2H_4 (PPM)		CO (%)	
	IN	OUT	IN	OUT	IN	OUT	IN	OUT
Idle	590	<50	320	<50	260	<50	3.54	<0.006
Governed Speed	110	<50	90	<50	250	<50	1.34	<0.006

Smoke in exhaust: None at steady speed, slight on acceleration.
Odor in exhaust: None.

(1) Reference 12 provided no indication as to number of tests performed to obtain measured emissions. The test vehicle was a 3,000-pound forklift with 162-CID engine.

(2) Calculated as n-hexane.

The developer reported in Reference 12 that the 1971 Ford Capri which won the 1970 Clean Air Race was equipped with his device as configured for light duty motor vehicles.

Emission test results obtained by EPA with the device installed on a standard Army M-151 1/4-ton truck and incorporating an auxiliary air pump are summarized in Table 3-10.

Table 3-10. DEVICE 292 CATALYTIC CONVERTER EPA EMISSION TEST RESULTS WITH AUXILIARY AIR PUMP (REFERENCE 10)

VEHICLE CONFIGURATION (3)	POLLUTANT (GM/MI)					
	HC		CO		NOx	
	CVS (1)	FTP (2)	CVS (1)	FTP (2)	CVS (1)	FTP (2)
Without Device	6.6	6.4	65.0	32.0	3.9	2.0
With Device	5.2	1.5	75.0	33.0	2.3	1.6
Percent Reduction	21.2	77.0	-15.4	-3.0	41.0	20.0

(1) Results of one test using 1972 Federal Test Procedure constant volume sampling (CVS) (Reference 3)

(2) Results of one test using 1970 Federal Test Procedure (FTP) (Reference 15)

(3) Test vehicle was a 1/4-ton M-151 Army standard truck with a 141-CID, 4-cylinder engine. The vehicle weighed 3,000 pounds

For these tests the vehicle muffler was replaced by the converter and auxiliary air was provided to the converter by a shop air system with airflow maintained at 2 cubic feet per minute.

3.1.2.4 Reliability

The developer stated that over 300 units of the device were in use on LPG-fueled fork-lift trucks as of August 1968 (Reference 12). He further stated that "Many installations on diesel-powered fork-lift trucks and mining machinery, monitored weekly, have shown consistent oxidation of contaminants including carbon monoxide during load cycles, even after 7,500 hours of operation. Table 3-11 shows the percentage of CO and HC decrease at test intervals over 48,300 miles obtained by the developer from a 1970 car, using the 1968 Federal Test Procedure (Reference 14).

Table 3-11. DEVICE 292 CATALYTIC CONVERTER EMISSION REDUCTION RELIABILITY REPORTED BY DEVELOPER FOR 48,300 MILES OF OPERATION (REFERENCE 12) (1)

	HC (PPM)			CO (PPM)		
MILEAGE	WITHOUT DEVICE	WITH DEVICE	% DECREASE	WITHOUT DEVICE	WITH DEVICE	% DECREASE
570	217	8	96	2084	286	86
4,852	185	35	81	2627	696	74
11,106	139	38	73	2250	170	92
16,393	199	43	78	1070	100	91
24,657	295	36	87	2080	90	95
33,500	165	34	79	3590	630	83
36,641	165	34	79	3590	140	95
48,300	130	23	82	1230	40	97

(1) Emission results obtained with 1970 Ford Torino (V-8) under 1968 Federal Test Procedure with device installed on one exhaust manifold. The Automobile Manufacturers Association (AMA) driving schedule was used.

These results indicate relative stabilization of the catalyst after the 4,852-mile emission test. Based on the data of Table 3-11, it appears that the reliability (MMBTF) of the device would be in excess of 50,000 miles, provided:

a. Only unleaded gasoline is used

b. Any new additives which might be substituted for lead are compatible with the platinum catalyst

c. Any auxiliary air is filtered to keep out particulate matter.

3.1.2.5 Maintainability

For the material handling vehicle version of Device 292, the developer used exhaust venturi vacuum to intake ambient air into the converter through an air filter. For retrofit applications to gasoline-fueled light duty vehicles, the developer would use an auxiliary air pump (Reference 13). Since the catalyst indicates a reliability of 50,000 miles (1), the only routine maintenance anticipated is cleaning or changing of the air intake filter. It is assumed that this maintenance would be performed every 12,000 miles which requires 15 minutes.

Replacement of the catalyst would be required at 50,000 miles (1), if vehicle service life extends beyond that point, or when indicated by a decrease in the reaction temperature beyond an acceptable limit, which might also be caused by a dirty intake air filter. It is assumed that a temperature sensing device would be incorporated in the reactor chamber with an indicator on the vehicle dashboard. Catalyst replacement time cannot be estimated because the installation requirements for an automotive retrofit kit configuration of the device has not been defined by the developer.

3.1.2.6 Driveability and Safety

No driveability data were obtained from the developer other than that reflected in Table 3-11. The developer indicated that more than 300 of the device configurations for material handling vehicle have been retrofitted satisfactorily, and that Device 292 configurations for light duty, gasoline-fueled vehicles were used on 26 of 37 entries in the 1970 Clean Air Race (Reference 12). No information was obtained on the temperature at which the converter functions. If it is significantly higher than the temperatures of a conventional muffler or exhaust manifold, then additional precautions might be required to preclude injury to personnel or damage to the vehicle.

If catastrophic structural failure or fouling of the catalyst system occurred, severely restricting exhaust gas flow, then a substantial or total loss of power could result. This could be potentially hazardous if the vehicle is being driven. It is assumed the converter chamber design would incorporate an exhaust relief provision to preclude premature (less than 50,000 miles) chamber burn-through which could result in venting of toxic fumes.

3.1.2.7 Installation Description

Device 292 installation consists in removing a straight section of the exhaust pipe as close to the exhaust manifold as possible, and replacing this with the converter. Information on air pump installation requirements was not obtainable. Table 3-12 delineates the installation procedure and identifies tools and special equipment required. Installation can be accomplished in a normally equipped repair or muffler shop by the average mechanic. Figure 3-7 shows a developmental installation of the device.

3.1.2.8 Initial and Recurring Cost

Table 3-13 summarizes the costs for Device 292, based on the information available. Use of an air pump and periodic replacement of catalyst could increase these costs by approximately $100.

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(1) This reliability is reported by the developer, but is not supported by current data within vehicle exhaust catalyst technology.

Table 3-12. DEVICE 292 CATALYTIC CONVERTER INSTALLATION PROCEDURE

MINIMUM AVERAGE SKILL LEVEL: AUTOMOTIVE MECHANIC		
INSTALLATION AND ADJUSTMENT PROCEDURE	TOOLS, EQUIPMENT AND FACILITIES	TIME (MIN.)
1. Remove a straight section of exhaust pipe about 18 inches long as close to the exhaust manifold as possible.	a. Oxyacetylene torch b. Car lift	30
2. Install the catalyst exhaust gas purifier in the exhaust pipe to replace the section removed.	a. Catalyst exhaust gas purifier b. Exhaust line clamps	30
	Total Time	1 hr

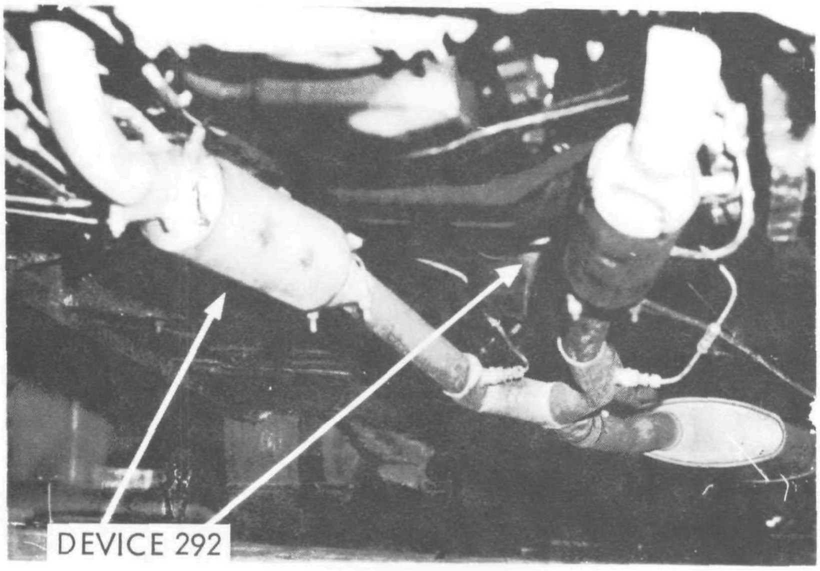

Figure 3-7. DEVICE 292 CATALYTIC CONVERTER LIGHT DUTY VEHICLE DEVELOPMENTAL CONFIGURATION (REFERENCE 12)

3.1.2.9 Feasibility Summary

Device 292 is not presently available for retrofit application to light duty motor vehicles. The developer has indicated that his interest is more in the new model vehicle field, than in used car retrofit (Reference 12).

Table 3-13. DEVICE 292 CATALYTIC CONVERTER INITIAL AND RECURRING COSTS

ITEM	DESCRIPTION	LABOR HOURS OR ITEM QUANTITY	COST (DOLLARS)
Initial Cost:			
Material			
1. Device	Catalyst exhaust gas purifier		$50 - $60
2. Miscellaneous	Exhaust line clamps		(Included in above)
Labor			
1. Installation	Table 3-12	1 hr	$12.50
2. Test and adjust			
		Total Initial Cost	$62.50-$72.50
50,000-Mile Recurring Cost: (1)			
Labor			
1. Air filter	Clean in accordance with manufacturer's specifications	0.25 hr/12,000 miles	$12.50
		Total Recurring Cost	$12.50
		TOTAL COSTS	$75 - $85 (2)

(1) Assuming no replacement catalyst or increased fuel consumption
(2) $160-$170 with air pump

Insufficient emission test data are available to reach conclusions as to Device 292's technical feasibility; however, the developer has successfully applied the basic Device 292 concept to the exhaust control of material handling vehicles equipped for LPG fuel, and developmental configurations of the automotive version have been used on specially equipped cars, with satisfactory emission reduction reported for CO and HC (Reference 12).

In the test performed by EPA to the 1972 Federal Test Procedure, CO increased (refer to Table 3-10). This is not characteristic of a catalytic converter, and on this basis it could be considered infeasible. Further development effort would be required to provide a Device 292 configuration suitable for retrofit application to light duty motor vehicles and to achieve a consistent CO and HC reduction effectiveness which would justify the cost of the device.

Because the developer's current interest emphasizes new model vehicles applications, it appears at this time that retrofit availability of the device will not be broadened beyond the existing retrofit configuration for material handling vehicles.

3.1.3 Device 62: Catalytic Converter

Device 62 is a catalytic converter for use in the control of CO and HC pollutants in vehicle exhaust gas. Insufficient data were obtained for a complete evaluation of this device. No response was received to the retrofit data survey questionnaire sent to the developer. The only data obtained were the results of emission tests performed by EPA in March 1971. The technical and performance characteristics summarized below are based on information in the EPA report on those tests (Reference 8).

3.1.3.1 Physical Description

This device is described in the EPA report as an exhaust HC and CO catalytic converter that replaces the standard vehicle muffler. The device requires auxiliary air supply for effective operation of the catalyst. The converter has an exhaust gas bypass system which routes exhaust gas around rather than through the converter if it overheats. In the EPA test, air was supplied by a shop air system. Air flow varied from 1.2 cubic feet per minute (cfm) at idle, to 1.8 cfm at cruise, and 3.6 cfm during acceleration.

3.1.3.2 Functional Description

This device was apparently designed to oxidize HC and CO exhaust emissions in a catalytic bed with auxiliary air supply. The operating principles of the device should be similar to those for the catalytic converters described in paragraphs 3.1.1 and 3.1.2, for the catalytic phase during which CO and HC are oxidized to carbon dioxide and water.

The exhaust bypass system was incorporated during the EPA test program to allow the catalyst to cool if the catalyst temperature exceeded 1,150°F, a test limit.

3.1.3.3 Performance Characteristics

EPA has conducted several emission tests on this device. The results of the 1970 Federal Tests (Reference 15) are shown in Table 3-14 for each test cycle. As shown by these results, the device indicates satisfactory reduction of HC for each cycle of 7-mode test. CO reduction improved as the test progressed, changing from an increase to a 50 percent reduction by the end of the test. HC and CO results for cycle 7 both show reduction on the order of 50 percent. By that time, the temperature of the catalyst had stabilized at 1,100°F.

The improvement in CO and HC oxidation capability of the converter as it reaches its operating temperature (1,100° to 1,150°F) is shown in Figure 3-8. This figure is based on the average percentage of emission reduction and the peak temperature of the catalyst for each cycle of the 7-mode test performed by EPA (Table 3-14), from the time the catalyst reached 500°F. This figure indicates that as the catalyst warmed up and reached its operating temperature, emissions of CO and HC decreased by approximately 50 percent, whereas NOx increased. These are typical emission reduction characteristics for a catalytic converter.

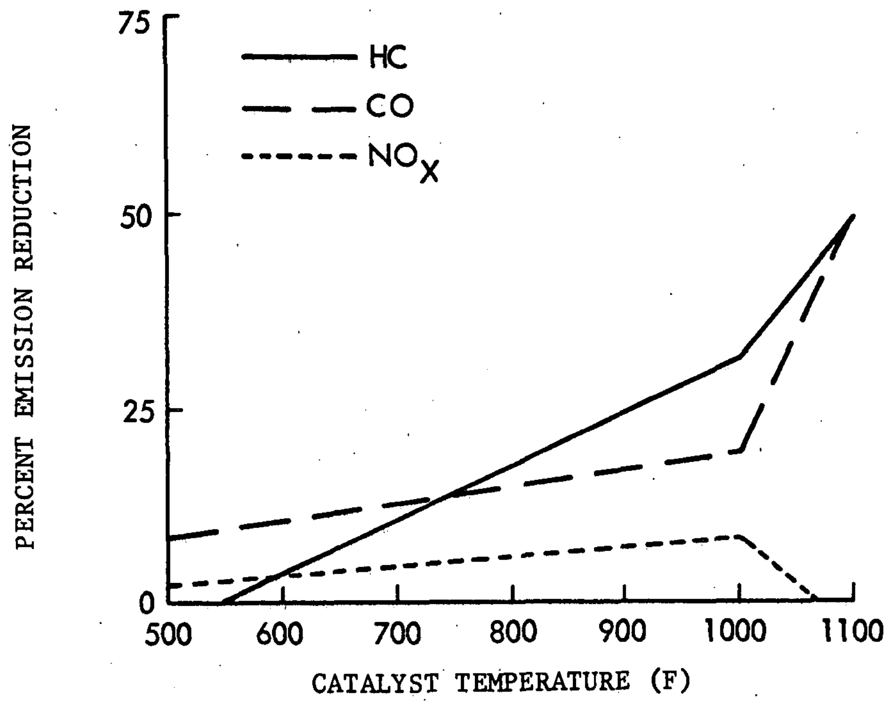

Figure 3-8. DEVICE 62 CATALYTIC CONVERTER EMISSION REDUCTION PERFORMANCE VERSUS CATALYST TEMPERATURE (REFERENCE 8)

Table 3-14. DEVICE 62 CATALYTIC CONVERTER EPA EMISSION TEST RESULTS (REFERENCE 8) (1)

TEST CYCLE	HC (PPM)		CO (PERCENT)		NOx (PPM)	
	WITHOUT DEVICE	WITH DEVICE	WITHOUT DEVICE	WITH DEVICE	WITHOUT DEVICE	WITH DEVICE
1	2,000	919	4.96	7.17	670	464
2	327	339	3.44	3.17	868	848
3	394	254	4.35	3.43	778	780
4	298	221	3.93	3.24	666	546
6	319	182	3.97	2.20	605	631
7	305	143	4.17	2.04	566	577
AVERAGE	607	343	4.14	3.54	692	641
PERCENT REDUCTION	44.0		14.5		7.0	

(1) Results obtained with a standard Army M-151 1/4-ton vehicle (4-cylinder engine with 141-cubic-inch displacement), using 1970 Federal Test Procedure (Reference 15); one set of tests with and without device installed.

3.1.3.4 Reliability

EPA was unable to complete tests of Device 62 under the 1972 Federal Test Procedure because the catalyst repeatedly overheated when subjected to that test. The Reference 8 EPA report states that:

> "The catalyst showed reductions after it reached temperature but achieving the temperature took a long time.
>
> "The overtemperature problem appears to be the catalyst beginning to burn at a temperature below the maximum rated temperature of the catalyst. The most effective temperature for reduction appears to be near the maximum temperature of the catalyst."

Since overheating did not occur during the 7-cycle test, it would appear that the catalyst of Device 62 is sensitive to the more rigorous driving regime of the 1972 Federal Test Procedure. This sensitivity during the latter test, as noted in the quotation above, may take the form of the catalyst actually burning before it reaches operating temperature. Since burning causes attrition of the catalyst, the catalyst may have low reliability for the overall range of driving operations to which it would be subjected during the service life of a vehicle.

To prevent burning of the catalyst during the EPA test program, an exhaust bypass line was incorporated. This bypass line circumvented the converter in the event of catalyst overheating. A similar provision may be required in the production design of Device 62. While such a provision would enhance the reliability of the device, it would detract from its overall emission reduction capability, since untreated exhaust would be vented to the atmosphere during catalyst overheat conditions.

3.1.3.5 Feasibility Summary

The lack of data on the component details of Device 62 precluded evaluation of its maintainability requirements, driveability and safety characteristics, installation procedure, and costs. From the results of the EPA test program, the device appears to be technically feasible for exhaust CO and HC control.

The tendency of the catalyst to burn, as when exposed to exhaust compositions resulting from vehicle operation under the 1972 Federal Test Procedure, could increase the cost of operating and maintaining the device unreasonably, if the device is used without regard to operating limits. To keep such costs down, the device might be restricted for use only under operating modes in which the conditions causing the catalyst to burn would not occur. If the alternative of bypassing the device when it overheats were used, then the overall emission control effectiveness of the device would be less.

Based on these considerations, Device 62 would appear to be usable in applications where some limitation as to operating modes is acceptable.

3.1.4 Device 93: Catalytic Converter with Exhaust Gas Recirculation, Spark Modification, and Lean Idle Mixture

Device 93 illustrates the combination of a catalytic converter with exhaust gas recirculation to achieve control of CO, HC, and NOx. Although the developer did not respond to the retrofit data survey questionnaire, data on the emission reduction performance of the device were obtained from an EPA test report (Reference 9). The following summary system evaluation is based on information obtained from that document.

3.1.4.1 Physical Description

As described in Reference 9, Device 93 consists of a catalytic converter with an auxiliary air pump, a special ignition system, and an engine modification for exhaust gas recirculation.
carburetor for high air-fuel ratio.

3.1.4.2 Functional Description

In the catalytic converter phase of system operation, Device 93 would oxidize CO and HC to carbon dioxide and water. Control of NOx is apparently accomplished by an engine modification which alters valve timing. This timing change apparently traps some of the exhaust gas in the cylinders as a residual carryover to the next combustion cycle. The effect of this would be similar to recirculating the exhaust gas from the exhaust system, as is the more customary way of implementing exhaust gas recirculation.

The special ignition system is designed to provide more electrical energy for spark propagation, so that the engine can be operated at high air-fuel ratios. High air-fuel ratio tends to decrease CO and HC, but increases NOx.

3.1.4.3 Performance Characteristics

The results obtained by EPA in emission tests of Device 93 are summarized in Table 3-15. Testing of the vehicle without the device installed was not possible, because of the valve timing modification to the cam.

Table 3-15. DEVICE 93 CATALYTIC CONVERTER WITH EXHAUST GAS RECIRCULATION, SPARK MODIFICATION, AND LEAN IDLE MIXTURE EPA EMISSION TEST RESULTS (REFERENCE 9) (1)

TEST CONDITION	POLLUTANT (GM/MILE)					
	HC		CO		NOx	
	COLD	HOT	COLD	HOT	COLD	HOT
Average of 6 Tests Using 1972 Federal Test Procedure (Reference 16)	0.9	0.1	9.1	0.73	1.4	1.2
One Test Using 1970 Federal Test Procedure (Reference 15)	0.3	0.1	1.0	0.1	1.0 (2)	0.9 (2)

(1) Results obtained with a 1967 Pontiac Tempest station wagon incorporating an overhead cam 6-cylinder engine.

(2) Combination test, consisting of nine repeats of the 1970 driving cycle using the 1972 mass sampling technique.

3.1.4.4 Feasibility Summary

Insufficient data as to the device's technical characteristics and performance capability preclude evaluating it for reliability, maintainability, driveability and safety, fuel consumption, installation requirements, and costs. The percentage emission reduction for the hypothetical case shown above indicates that the device would be effective for emission control of all three exhaust pollutants.

Although the emission reduction effectiveness of the device is significant, the device may be too costly to implement as a retrofit method. Specific cost information could not be developed because of the lack of information on the device; however, by comparing the device with the other catalytic converters evaluated, it would appear to be more costly in a retrofit application, because of the cam timing modification and the auxiliary air pump. Thus, the cost of Device 93 might be too unreasonably high to justify using it as a retrofit emission control device. Because of its apparently high emission reduction effectiveness, however, the device would be a candidate for further study to resolve its overall feasibility.

3.2 THERMAL REACTOR - RETROFIT SUBTYPE 1.1.2

Thermal reactors like catalytic converters, control exhaust emissions of CO and HC downstream of the combustion event by oxidation. The difference between the two approaches is in the process by which oxidation is accomplished. Thermal reactors accomplish oxidation by continued burning of the CO and HC compounds within a high-temperature chamber attached directly to the engine at the exhaust ports in the place of the conventional exhaust manifold.

As discussed in Section 2, there are two basic types of thermal reactors: the rich thermal reactor (RTR) and the lean thermal reactor (LTR). Among the four thermal reactor systems studied, three may be categorized as rich thermal reactors. There is only one device of the lean thermal reactor type known to be under development (Reference 70). The existence of this device was discovered too late in the study to obtain data from the developer; however, the technical characteristics of this device are summarized based on information in Reference 2.

The four devices described in this paragraph are identified in Table 3-1. Device 244 is also used in a combination control system that is designed to control particulates, as well as CO, HC, and NOx. This utilization of Device 244 is discussed in Section 9 (refer to Device 469).

In this report, thermal reactors are distinguished from catalytic reactors by referring to the latter as "converters." This is done for convenience in referring to one or the other of the devices by a short-form expression. Both types of devices are basically reactors for converting CO and HC to carbon dioxide and water. Only the means for achieving this reaction are different.

3.2.1 Device 244: Rich Thermal Reactor

Device 244 has been under development for the past six years, and reflects application of a systematic design, analysis, and test program (Reference 71). The concept of extending combustion time outside the combustion chamber by means of a thermal chamber is implemented in this device by a large-volume, insulated reactor that replaces the conventional exhaust manifold. The large volume appears to be a key design factor in the emission reduction effectiveness of a thermal reactor, because the length of time the exhaust gas can be contained in the reactor depends on volume: the longer the exposure time, the more oxidation can take place.

The device is of the rich thermal reactor type. It operates at air-fuel ratios ranging generally from 11:1 to 11.5:1 (Reference 71). The relatively enriched fuel mixture is required to achieve the gas temperatures that will support oxidation, and to provide enough fuel byproducts of combustion to sustain these temperatures by continued burning of the byproducts in the reactor chamber.

These rich air-fuel mixtures, though primarily intended to enable the reactor to operate, have the side benefit of inhibiting NOx formation during the combustion event. This benefit is attributable to the lack of oxygen availability and the lower flame temperature of such mixtures.

Because of the operating principles it incorporates, Device 244 would appear to have capability for controlling all three pollutants.

3.2.1.1 Physical Description

Figure 3-9 shows a cutaway view of one of the later models of Device 244. The assembly consists of an outer shell in which a tubular core is mounted with a shield to insulate the core from the outer shell. This configuration resulted from fundamental reactor design criteria established by the developer as a result of his development effort (Reference 71).

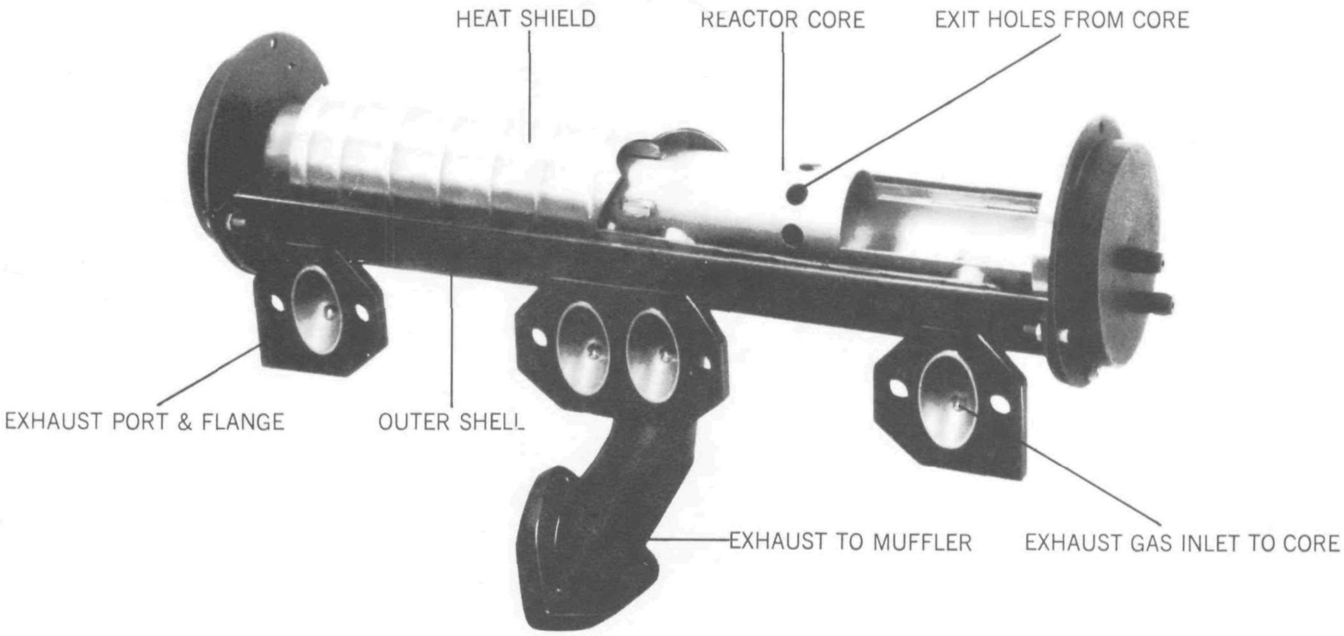

Figure 3-9. DEVICE 244 TYPE V THERMAL REACTOR PHYSICAL CONFIGURATION (REFERENCE 72)

The size of the reactor was based on the largest volumetric shell which would fit in an engine compartment without altering any of the major structural components of the vehicle. The reactor size meeting this criterion was a cylindrical shape with an external diameter of 4.5 inches and an overall length of approximately 22 inches.

The internal design was based on developmental studies which showed that an inner core was necessary to mix the exhaust gas with injected air. These studies showed also that the mixing function of the core could be implemented in two ways:

a. By incorporating baffles in the core to induce turbulent mixing.

b. By locating and sizing of inlet and outlet passageways to induce mixing by controlled gas flow within the core.

Based on emission tests, the second approach was found to be more effective. Subsequently it was found that further effectiveness could be achieved by placing shields around the core to provide additional heat insulation and mixing. This reactor configuration is known as Type III.

An auxiliary air injection system is used to supply the air needed to oxidize the exhaust gas. The air system is usually a Saginaw Steering Gear positive displacement pump driven by the engine. The air is supplied to the exhaust ports through a manifold with an individual air tube for each port. This is the system typically used on cars incorporating air injection as the means of exhaust control. A gulp-type air bypass valve is used to divert the injected air to the intake manifold during the initial period of deceleration. (1)

The material composition of the reactor is still being investigated (Reference 73), to determine a material capable of withstanding the oxidizing and corrosive thermal (1,400°-1,800°F) environment that exists within the reactor. Materials such as Incoloy 800 and 310 stainless steel are considered by the developer to be potential candidates as far as durability is concerned, but are relatively expensive because of the quantities of nickel they contain. For lower cost, iron-base, heating-element type alloys which typically contain 12 to 25 percent chromium and 3 to 6 percent aluminum are being investigated. The composition of some of the more promising of these alloys is shown in Table 3-16.

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(1) The bypass-type valve sometimes incorporated on air injection systems cannot be used with the reactor. Higher emissions would result during deceleration because this type valve, in bypassing to the atmosphere rather than the intake manifold, would not provide the extra air needed for combination of the overrich fuel mixture which develops during the initial periods of deceleration (Reference 71).

Table 3-16. COMPOSITION OF CANDIDATE ALLOYS FOR DEVICE 244 RICH THERMAL REACTOR (REFERENCE 73)

ALLOY	PERCENT	
	CHROMIUM	ALUMINUM
406	12	4
A	12	3
B	15	4
C	15	5.5
D	22	5.5

3.2.1.2 Functional Description

The basic purpose of Device 244 is to oxidize CO and HC compounds of the exhaust gas to carbon dioxide and water. Figure 3-10 shows the exhaust gas flow through the reactor during the oxidation process, along with the entry of air from the air injection system.

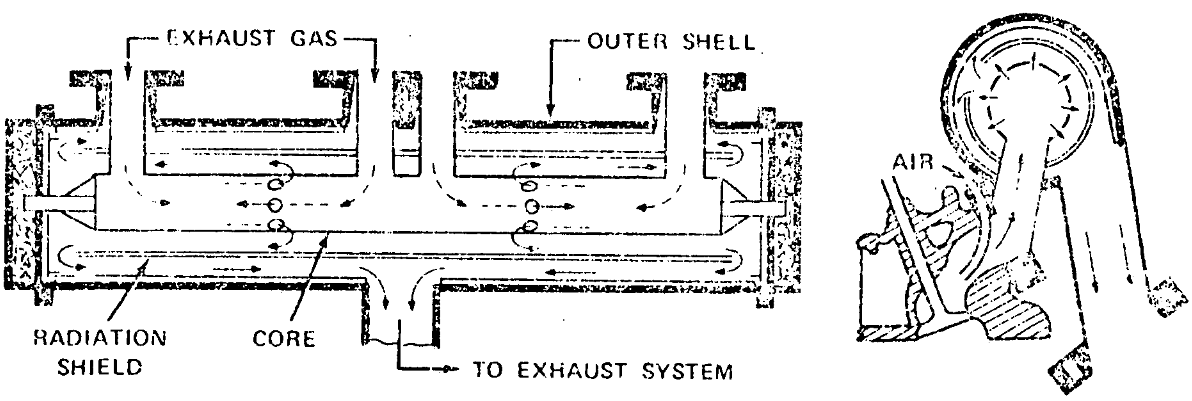


Figure 3-10. DEVICE 244 EXHAUST GAS FLOW THROUGH RICH THERMAL REACTOR (REFERENCE 71)

As the piston nears bottom dead center on the power stroke, the exhaust valve begins to open. Then, as the piston moves up on the exhaust stroke, the exhaust gas is mixed with the injected air and expelled through the exhaust port directly into the reactor inlet tube. The reactor inlet tube is connected to the reactor core, into which the air and exhaust gas flow.

Upon entering the core, the air and gas from adjacent inlets have a common set of exit ports by which to leave the core. As the gases meet at these exit ports, the intermixing process, which began in the engine cylinder, is accelerated. The core and exit ports are sized so as to restrict the passage of the gases to the extent that excessive exhaust backpressure does not develop. The objective is to hold as much of the gases as possible within the core as long as possible so as to subject them to thermal oxidation.

The principal source of heat for the reactor is from the oxidation process itself. The high concentrations of CO and HC resulting in the exhaust gas from the rich fuel mixture are readily oxidized at the right temperature. As they leave the combustion chamber, oxidation is already in process. As CO and HC convert to carbon dioxide and water, heat is liberated. The core, heat shield, and outer shell insulation are designed to have minimum thermal capacity. As the hot fuel-rich gases mix with air within the chamber, oxidation is initiated and the heat liberated is retained by the inner reactor components. With balanced reactor volumetric capacity gas flow, and heat insulation, an optimum oxidation temperature of about 1,650°F is maintained.

The gas temperature has to be maintained above a minimum level ranging between 1,200° to 1,400°F, for effective oxidation of the unburned exhaust CO and HC (Reference 71). To prevent the temperature of the exhaust gas entering the reactor from being below this minimum, particularly during cold-start idle and low speed cruise, retarded spark at idle and off-idle is used with thermostatic control to resume spark advance when the engine coolant is above 140°F. This has been found to warm up the reactor faster.

When Device 244 is installed on engines which use exhaust gas to heat the intake manifold to promote fuel vaporization during cold start, the flow of the exhaust gas is changed so that the gas goes to the reactor first and then to the intake manifold. This is to make sure that the exhaust gas entering the reactor is at its hottest, rather than cooled down from circulating first through the intake manifold.

The flow of exhaust gas from the reactor to the intake manifold is illustrated in Figure 3-11. To make this modification, the passageway through the cylinder head between the exhaust valve and the intake manifold is blocked. Exhaust gas to warm the intake manifold is then routed from the exit of the reactor to the manifold.

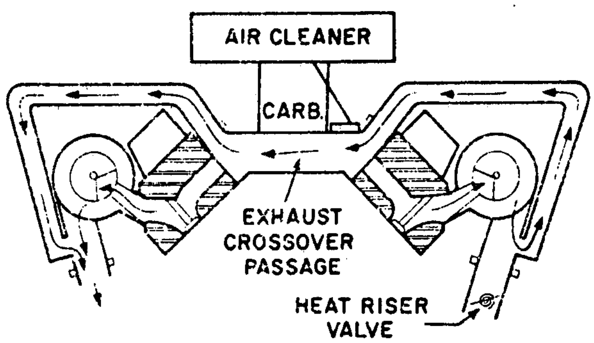


Figure 3-11. DEVICE 244 RICH THERMAL REACTOR AND INTAKE MANIFOLD HEAT INTERFACE (REFERENCE 71)

The amount of air required by the reactor from the air injection system varies according to the degree of engine warmup and operating mode. During cold start, when the air-fuel mixture is particularly rich because the choke is operating, more air is required than when the engine is warmed up and the air-fuel ratio is near stoichiometric. The developer has found that the standard air injection system has to be operated at a pump-to-engine rpm ratio of 1.25 to 1.50 to achieve an optimum compromise between the different air supply requirements of the cold and the hot engine.

Since the engine has to have extra air in the intake manifold at the start of deceleration to prevent backfiring of the residual, unmixed fuel, the gulp-type antibackfire valve is required when the standard air injection system is used. This valve injects air to the intake manifold during deceleration. The air injected during this diversion is mixed with the remaining fuel in the intake manifold, and the resulting air-fuel mixture is then drawn into the cylinder for normal combustion. This prevents the reactor from being loaded up with unmixed fuel during deceleration at a time when the air injection system is unloading and, therefore, not supplying air to the reactor. As discussed later in paragraph 3.2.1.4, if too rich a fuel mixture enters the reactor when it is at operating temperature, the mixture could ignite, damaging the reactor.

To complete its flow through the reactor (Figure 3-11), the air and exhaust gas mixture, still undergoing oxidation, flows out of the inner core through the exit ports into the annular space between the core and its concentric heat shield. This narrow passageway reduces the gas volume-to-surface-area ratio to expose as much of the exhaust gas as possible to thermal oxidation. The gas then flows through the annular space between the heat shield and the concentric outer shell, and exits into the exhaust pipe.

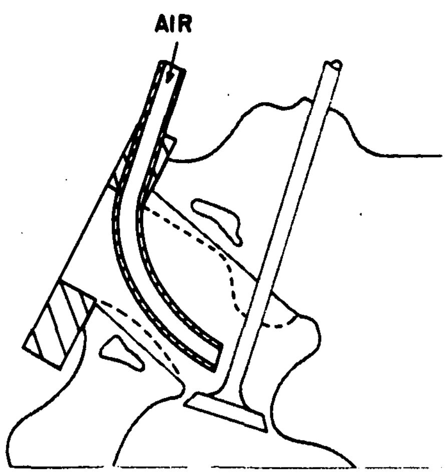
Thus, in operating principle, the inner core functions as a mixing chamber and the passages between the core, the heat shield and the outer shell functions as a thermal zone for the oxidation process. Because of the 1,000°F heat differential between the core-heat-shield assembly and the insulated outer shell, the inner assembly is designed so that it can expand and contract without stressing itself or the shell. As noted in Figure 3-10, the heat shield is attached to the core, which in turn is mounted inside the shell by pins at each end. During thermal expansion or contraction these pins slide freely in the shell end-cap bearings into which they fit. Similarly the inlet tubes from the exhaust port to the inner core are loose fitted into the core so that they can expand and contract and so that the core can as well.

The developer has also found that the effectiveness of a thermal reactor is influenced by the distance the exhaust gas has to travel before it enters the reactor and by the insulating properties of the passageway. In general, the longer the passageway, the cooler the exhaust gas will be when it enters the reactor, and the lesser the gas is oxidized. Special exhaust port inserts are used to insulate the exhaust gas from the water-cooled exhaust port passage of the engine. Figure 3-12 shows two inserts which eliminate the projecting air injection tube of the standard auxiliary air supply system, and a third insert that simply insulates the passageway. Each of the three systems was effective in providing further emission decrease, particularly CO. These decreases were accompanied by an increase of 25° to 70°F in the average temperature of the reactor core (Reference 71).

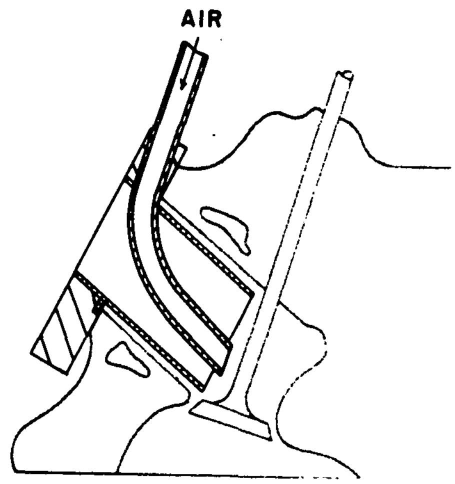
3.2.1.3 Performance Characteristics

The developer has performed many emission tests on Device 244 and has participated in HEW/NAPCA test programs. Figure 3-13 illustrates in general the emission reduction characteristics of a thermal reactor. The CO and HC emission levels of the vehicle with the standard air injection system operating, but without the reactor installed, are shown for comparison. (1) Both tests were performed to the 1970 Federal Test Procedure (Reference 15). An 83 percent reduction in HC and a 67 percent reduction in CO are indicated by use of the thermal reactor.

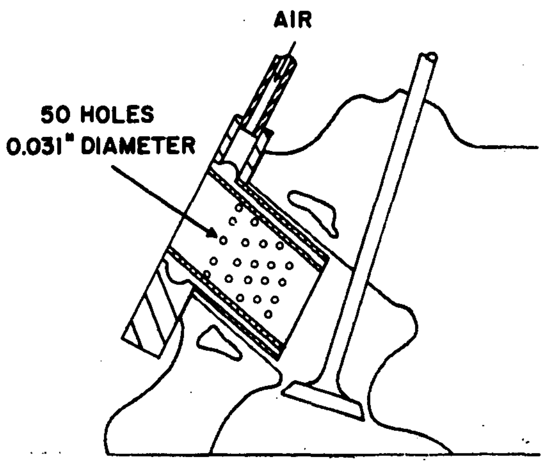
(1) The vehicle was reported as being a standard sedan equipped with an 8-cylinder, 300-CID engine with 2-barrel carburetor and automatic transmission, representative of a high percentage of total U.S. vehicle production (Reference 71).



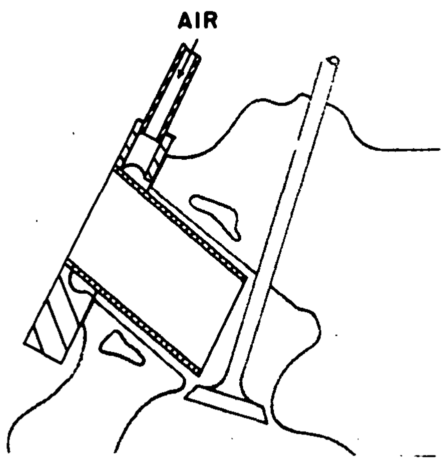
(a) Standard air injection



(b) Single-wall insulation



(c) Double-wall insulation with annular injection



(d) Single-wall insulation with annular injection

Figure 3-12. DEVICE 244 RICH THERMAL REACTOR EXHAUST PORT INSERT ALTERNATIVE CONFIGURATIONS (REFERENCE 71)

The drop in emissions indicated by both systems from the first to second test cycles is attributable to the warming up of the engine. The ability of a reactor to control exhaust emissions is measurable in part by how fast it can warm up so that the oxidation process can begin. Temperature measurements made during the 1970 Federal Test Procedure indicate that the core temperature reaches minimum oxidation temperature (1,200°F) less than one-third of the way through the first 7-mode cycle, from a cold start.

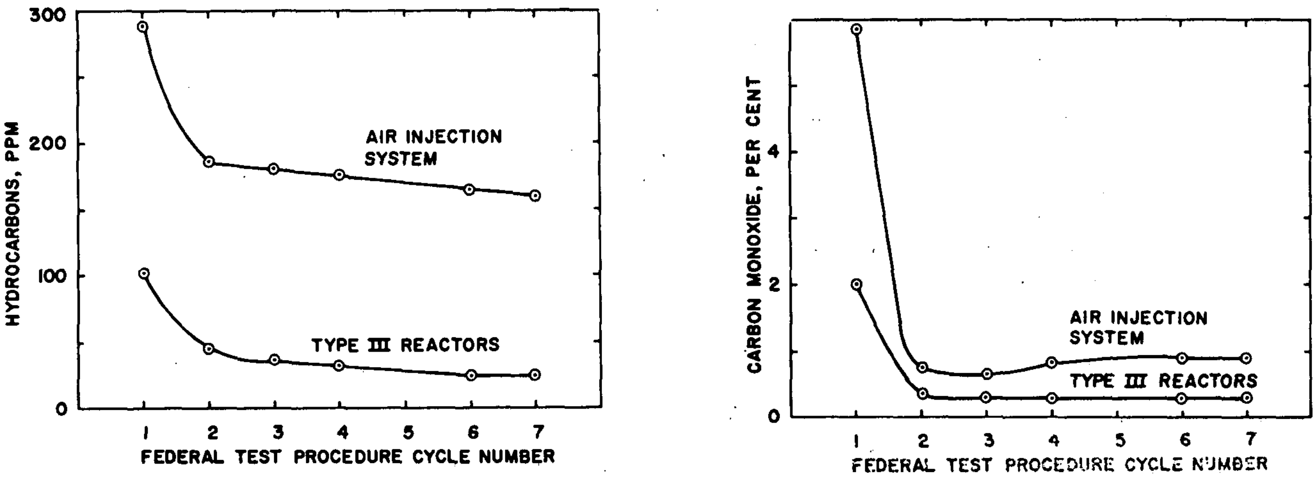


Figure 3-13. DEVICE 244 RICH THERMAL REACTOR EMISSION REDUCTION CHARACTERISTICS COMPARED TO STANDARD AIR INJECTION (REFERENCE 71)

Figure 3-14 shows the core temperature profile for the 7-mode cold start tests. The high temperature peak that occurred during the first cycle appears to be due to the oxidation of the larger amounts of CO and HC which result from the choke-enriched fuel mixture during cold start. The choking, although causing higher emissions, also provides the rich mixture which heats up the reactor quickly.

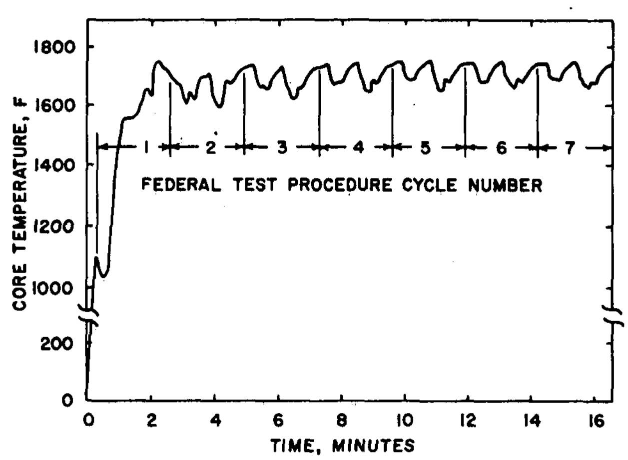


Figure 3-14. DEVICE 244 RICH THERMAL REACTOR TEMPERATURE PROFILE FOR ONE 7-MODE CYCLE (REFERENCE 71)

Emission tests performed by HEW/NAPCA with Device 244 used in combination with exhaust gas recirculation, carburetor modifications, special exhaust systems, and particulate traps indicated average emission levels meeting 1974 Federal Standards of 3.4 gm/mi HC, 39 gm/mi CO, and 3.0 gm/mi NOx. The average percentage reductions for this device configuration were 80 percent HC, 44 percent CO, and 65 percent NOx, when tested using nine Federal emissions-test cycles and the constant volume sampling technique (References 16, 74, and 75). This device configuration is described in Section 9, as an emission control combination (Device 469).

3.2.1.4 Reliability

Reactor durability may be a significant factor in the overall cost effectiveness of Device 244. The service life of a reactor has been found to depend largely on whether the core heat shield and insulation can withstand the oxidizing, erosive environment that exists within the reactor during operation (References 2 and 71). Tests by the developer have indicated that none of the commercially available alloys have adequate oxidation resistance. Superalloys were found to be more satisfactory, but expensive for application to an automotive exhaust reactor.

The principal manifestation of reactor degradation is the erosion of the core in the area opposite the exhaust gas inlet. The mechanism of the erosion appears to involve oxidation of the surface of the metal, followed by erosion of the oxidized area as a result of particulate matter impingement at high velocity (Reference 71). The solution to the problem, according to the developer, may be to change the geometry of the inlet passages to prevent high velocity impingement and to use erosion resistant coatings in the local areas of the core most subject to oxidation and erosion.

Erosion-resistant materials which have indicated sufficient oxidation resistance for extended life are those which have had a layer of nickel aluminide applied by the plasma-jet spraying technique, followed by aluminum dipping. The aluminum dipping appears to provide adequate oxidation resistance and the plasma-jet spray application of nickel aluminide enhances this resistance.

Design configuration changes by the developer to decrease the erosion attributed to exhaust impingement have included deletion of the baffles in the core. These were found to be located at the point of maximum erosion. Also, revision of the exhaust port and reactor inlet tube passageways has been considered, to eliminate concentrated impingement of the exhaust gas on the core (Reference 71). Patches of oxidation resistant material also are being used to protect the impingement area.

While the oxidation and erosion problem appears to depend mainly on the inherent susceptibility of the reactor core metal to oxidation, the presence of lead in the gasoline apparently can increase this susceptibility in the low-cost alloy steels at the high temperatures at which reactors operate. These steels usually have insufficient strength to withstand long-term exposure to the reactor's thermal environment. With the high-temperature materials such as Inconel 601, the presence or absence of lead appears to make no difference (Reference 2).

The oxidation/erosion effects of leaded fuels appear to be directly related to temperature and the amount of lead. Materials testing with different fuel compositions of lead, halide, and phosphorous have indicated that less erosion occurs with nonleaded gasoline, but that the magnitude of erosion increases with increased temperature. As shown by Figure 3-15, the rate of increase for low-lead gasoline and gasoline with 3 gm/gallon lead is approximately the same.

The significance of the data reflected in this figure is that at temperatures approaching 1,700°F, alloy weight loss from erosion does not appear to be particularly sensitive to fuel composition (Reference 2). As shown by Figure 3-16b, under normal cruise conditions the reactor core temperature could be limited to 1,750°F, with throttle- and vacuum-controlled air diversion incorporated. This form of control would divert injected air from the exhaust system during vehicle operating modes in which the air-fuel mixture is richer than usual. Since these modes are associated with high cruise speeds and high loads when exhaust emissions might be high, the effect of air diversion on the emission reduction effectiveness of the reactor should be determined before using this approach to reactor temperature control.

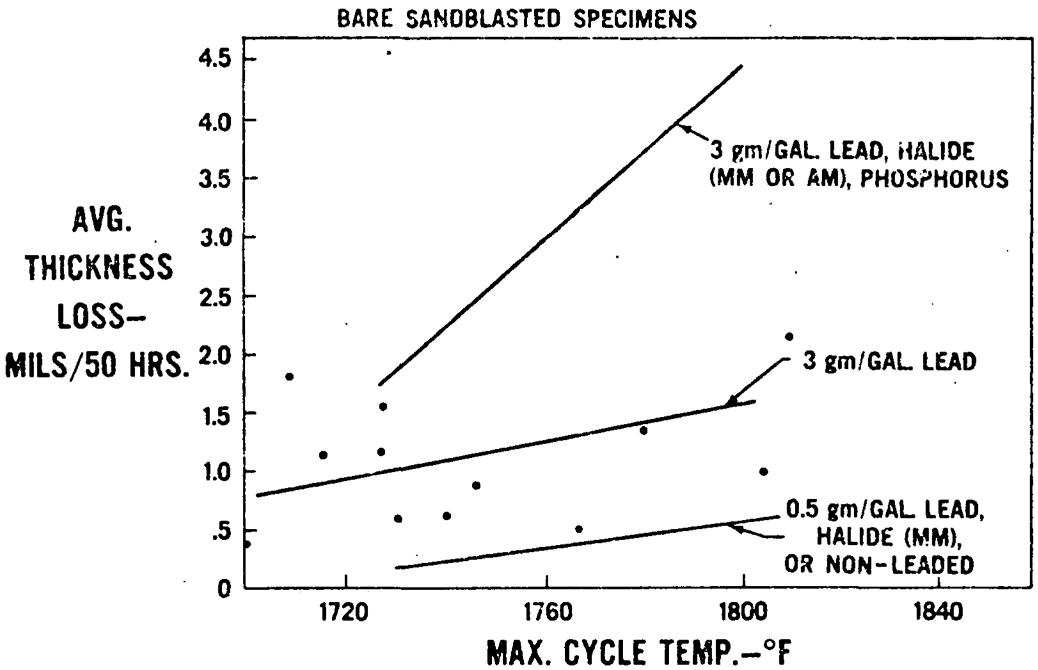
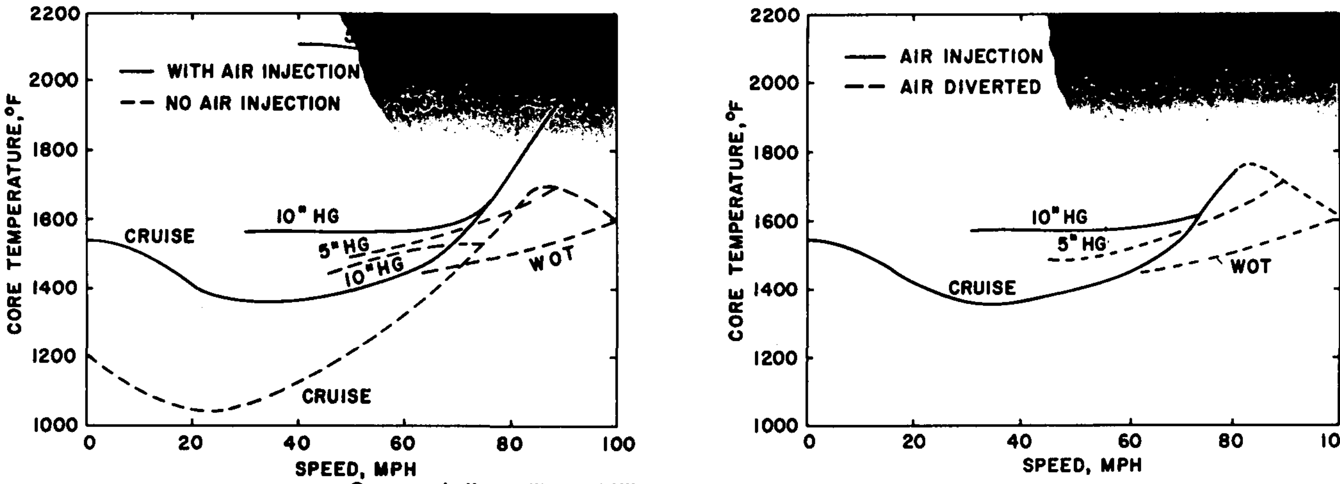


Figure 3-15. EFFECT OF FUEL VARIABLES ON AVERAGE THICKNESS LOSSES OF OR-1 ALLOY DURING CONTINUOUS THERMAL CYCLING (REFERENCE 2)



Grey area indicates "Light-Off" limits of Car Make A equipped with Type I exhaust manifold reactor system. Intermittent or trace "Light-Off" occurs in the light grey zone while severe "Light-Off" occurs in the darker grey zone.

(a) With and Without Air Injection

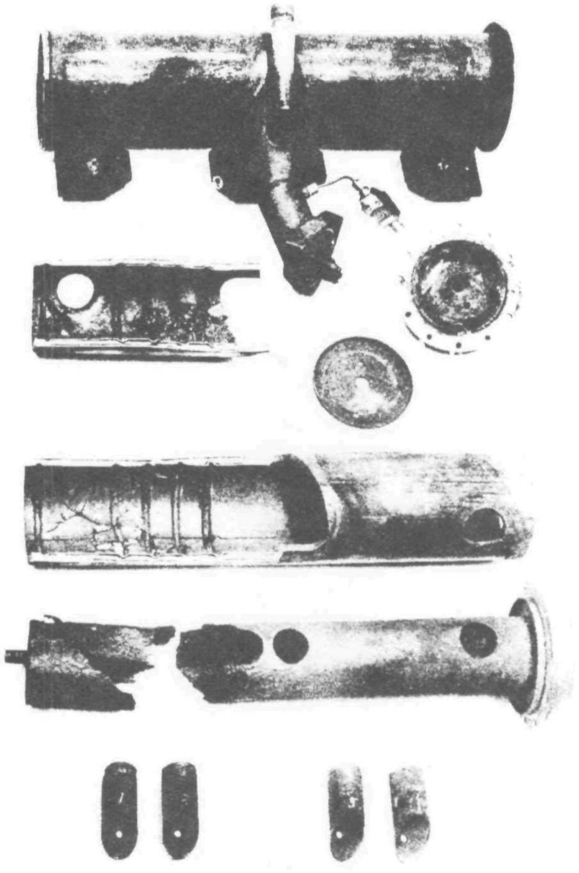
(b) With Air Injection Diverted Above 80 mph and Below 7 Inches Hg.

Figure 3-16. DEVICE 244 RICH THERMAL REACTOR CORE EQUILIBRIUM TEMPERATURES FOR VEHICLE OPERATING MODES (REFERENCE 71)

The preceding reliability factors concern reactor durability under high temperature operation. Another potential reliability problem is that of reactor light-off. "Light-off" is the condition which exists when the air-exhaust mixture within the reactor actually begins to burn as a result of engine misfire or a particularly rich fuel mixture. As noted in Reference 71, light-off generally is associated with large volume, highly efficient reactors. Since temperatures in excess of 2,400°F can be reached quickly with light-off, this condition must be prevented or catastrophic failure of the reactor may occur.

Figure 3-16 indicates the core temperatures and engine modes at which light-off could occur, given a misfire. As indicated by this figure, light-off is dependent on the vehicle operating modes in which the fuel mixture is rich; and on the reactor being operated with air injection during those modes. The combination of wide open throttle or heavy engine loading with air injection to the reactor provides the conditions for light-off to occur.

Figure 3-17 shows the condition of a Device 244 reactor after one hour of sustained light-off at 70 mph. Disassembly of the reactor after the test revealed that the core had failed catastrophically and that the insulating liner was severely damaged. A large section of the core had melted, indicating that temperatures exceeding 2,500°F, the nominal melting point of the core metal (Alloy F), must have occurred (Reference 71).



Cores and insulating liner of Type I exhaust manifold reactor installed on Car Make A after one hour of operation at 70 mph, wide-open throttle with "light-off" induced by shorting two spark plugs.

Figure 3-17. CONDITION OF DEVICE 244 RICH THERMAL REACTOR COMPONENTS AFTER ONE HOUR OF LIGHT-OFF (REFERENCE 71)

The reliability of the reactor is susceptible to a variety of other engine malfunctions, such as a stuck choke, a stuck power enrichment valve, or other carburetor malfunctions which could cause rich fuel mixtures and high temperatures. Distributor timing over-retarding and leaking exhaust valves could load up the reactor with excess fuel as well. According to the developer, some form of controlled air injection rate appears to be the means by which most of these excess-temperature related factors could be controlled (Reference 71).

It is the developer's position that the Device 244 thermal reactor has the reliability to control emissions for 100,000 miles of normal operation, but that reactor reliability still has to be proved trouble-free under the wide variety of tests used by vehicle manufacturers. It would appear therefore that any use or accreditation of the Device 244 reactor for retrofit would be contingent on restricting vehicle operation to the reliability constraints of the device, or on partially deactivating the device during the critical driving modes.

3.2.1.5 Maintainability

Assuming that the device is operated within the limits prescribed for reliability, it should require no planned maintenance of the reactor itself. Since an air pump is required and these usually have an air filter it is assumed that cleaning of the filter would be required once every 12,000 miles. The amount of time required to clean the filter is estimated to be 0.25 hour.

Preventing any particulate matter from entering the exhaust system is necessary, because of the susceptibility of the reactor core to erosion from the high velocity impingement of particulates (refer to paragraph 3.2.1.4).

3.2.1.6 Driveability and Safety

3.2.1.6.1 Driveability. The developer has reported that there are no driveability problems that would be apparent to the average driver; however, some decrease in vehicle acceleration time has been measured (Reference 71). The developer attributes this to the greater pressure drop in the exhaust gas across the reactor, than occurs with the standard exhaust manifold system. This pressure drop has been measured as being 2.5 times more than that of the standard manifold.

The effect of this pressure drop is to increase exhaust backpressure. This reduced maximum power output of the engine of the developer's test vehicle by as much as 6 percent at the 4,500-rpm rated engine power. Acceleration of this vehicle with different configurations of the reactor system is shown in Table 3-17. The reactor caused an increase of about one second (8%) in the 0-to-60-mph acceleration time.

The developer attributes the increased backpressure to the increase in the gas volume and temperature resulting in the reactor from the injection of air and the consequent oxidation process. The developer's approach to improving acceleration with the reactor installed has been to divert air from the reactor during acceleration and to replace the standard muffler with a resonator to improve exhaust flow.

Other than the acceleration loss, the reactor apparently has caused no driveability problems. Cold starting and driving and general hot driveability have been satisfactory.

3.2.1.6.2 Fuel Economy. An increase in fuel consumption has been measured in vehicle tests with the reactor installed. This is attributed to the rich carburetion generally associated with thermal reactors of the Device 244 type.

Table 3-17. DEVICE 244 RICH THERMAL REACTOR DEVELOPER ACCELERATION TEST RESULTS (REFERENCE 71)

Car Make A (1)
Wide-open-throttle, Level Road

	Acceleration Time in Seconds			
	0-50 mph	0-60 mph	30-60 mph	50-70 mph
Standard Manifolds Without Air Injection	9.4	13.3	8.5	9.1
Standard Manifolds With Air Injection	10.3	14.4	9.3	9.9
Type I Reactors Without Air Injection	10.0	14.1	9.0	9.4
Type I Reactors With Air Injection	10.8	15.4	9.4	10.2
Type I Reactors With Air Injection, Air Diverting Valve, and Resonator in Place of Muffler	9.4	13.3	8.7	9.2

(1) Defined by the developer as 1965-67 standard 2-door sedans, with V-8 engine of approximately 300 CID, 2-barrel carburetor. automatic transmission, and power steering.

Table 3-18 shows the results of fuel consumption tests performed by the developer. The "rich" carburetor caused a 17 percent decrease in miles per gallon using the 1970 Federal Test Procedure. The "lean" carburetor caused a 6 percent decrease in miles per gallon. The "lean" carburetor, however, had higher emissions of 60 ppm HC and 0.80 percent CO. This loss in fuel economy would increase the recurring operational costs with the device, as noted in paragraph 3.2.1.8.

3.2.1.6.3 Safety. There appear to be no safety problems with Device 244. Temperature measurements reported by the developer indicate that the exterior surface of the reactor is less hot than the standard exhaust manifold under comparable conditions. The temperature at the reactor outlet is greater than the standard exhaust manifold (1,430° to 1,600°F versus 1,140° to 1,260°F). This temperature, two feet down the exhaust pipe, decreases to where it is about the same as the temperature of a standard exhaust system.

The developer indicated that the higher temperature should increase the life of the muffler and tail pipe, which usually fail due to cold corrosion (Reference 71).

Table 3-18. DEVICE 244 RICH THERMAL REACTOR DEVELOPER FUEL CONSUMPTION TEST RESULTS (REFERENCE 71)

Car Make A (1)

Tests on Clayton Emission Test Dynamometer
Fuel A

Emission Control System	Fuel Economy, mpg				
	Cyclic*	15**	30	45	60
Dynamometer Set to 12 HP at 50 mph					
None (Standard 1967)	15.7	24.3	24.4	20.0	16.8
1967 Air Injection System	15.0	22.6	27.6	21.3	17.0
Reactors+ with Air Injection System Carburetor	15.3	21.3	25.2	21.1	18.2
Reactors+ with "Rich" Carburetor (2)	13.4	14.5	22.8	20.0	14.2
Reactors+ with "Lean" Carburetor (3)	14.6	16.5	26.0	22.1	19.5
Dynamometer Set to 26 HP at 50 mph					
None (Standard 1967)	14.4	21.6	20.4	16.1	11.1
1967 Air Injection System	13.9	21.0	20.7	15.4	10.2
Reactors + with Air Injection System Carburetor	14.1	16.3	21.3	16.1	10.6
Reactors+ with "Rich" Carburetor	11.4	14.1	17.9	14.7	11.3
Reactors+ with "Lean" Carburetor	13.7	18.5	24.2	17.2	11.1

* Federal Emission Test Cycle ** Steady Speeds, mph + Type III Reactors

(1) Defined in Table 3-17
(2) 11.0:1 air-fuel ratio
(3) 11.5:1 air-fuel ratio

3.2.1.7 Installation Description

A typical installation of Device 244 is shown in Figure 3-18. The installation of this device consists basically of the following phases:

a. Replacing the standard exhaust manifold with the thermal reactor manifold (two for 8-cylinder engines).

b. Installing the correct engine-rpm-drive ratio air pump (1.25:1 or.1.50:1) and air injection manifold (if not already standard equipment for the vehicle being converted).

c. Blocking the exhaust passage to the intake manifold and connecting the reactor manifold heat line to the intake manifold.

d. Adjusting the carburetor to 11.0:1 air-fuel ratio.

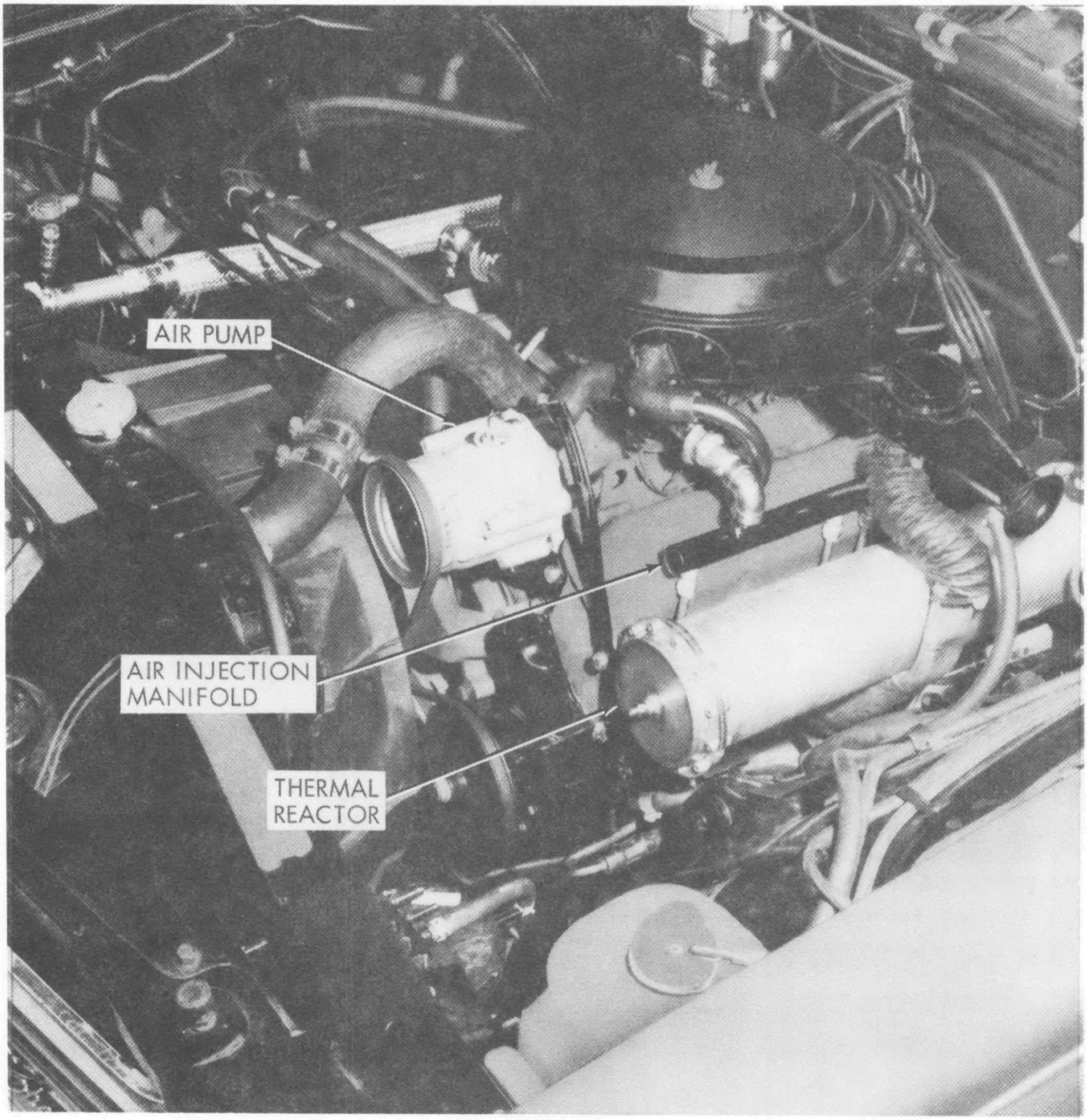


Figure 3-18. DEVICE 244 THERMAL REACTOR INSTALLATION (REFERENCE 72)

Table 3-19 lists the installation steps generally required to implement these phases, along with the tools and the amount of time required, assuming an eight-cylinder vehicle. The installation should be made by an experienced automotive mechanic. The installation of an air injection system is assumed to be a requirement.

Table 3-19. DEVICE 244 RICH THERMAL REACTOR INSTALLATION PROCEDURE

MINIMUM AVERAGE SKILL LEVEL: AUTOMOTIVE MECHANIC		
INSTALLATION AND ADJUSTMENT PROCEDURE	TOOLS, EQUIPMENT AND FACILITIES	TIME (MIN.)
1. Remove existing exhaust manifold	Hand tools	45
2. Remove intake manifold	Hand tools	30
3. Install air injection manifold	Electric drill, tap, and hand tools	180
4. Install air pump bracket and pump (verify correct ratio pump pulley for a 1:25:1:50 pump to engine pulley ratio)		90
5. Block intake manifold exhaust gas circulation passageway	Plate, drill, tap and hand tools	15
6. Install exhaust port insulation	Hand tools	15
7. Install thermal reactor manifolds	Hand tools	45
8. Replace intake manifold		30
9. Connect air pump hose to injection manifold and reactor hose to intake manifold	Hand tools	10
10. Adjust carburetor to 11.0:1 air-fuel ratio and test.	Hand tools and engine analyzer	15
11. Inspect exhaust system for leaks		5
	Total Time	8.0 hrs

3.2.1.8 Initial and Recurring Costs

Table 3-20 sets forth the initial and recurring costs estimated for Device 244 based on the installation requirements defined in Table 3-19 and the increased fuel consumption which the device indicates. Initial costs for a six-cylinder vehicle would be about $175 less than the average eight-cylinder vehicle, because only one reactor manifold would be required. Recurring costs would be about the same.

Table 3-20. DEVICE 244 RICH THERMAL REACTOR INITIAL AND RECURRING COSTS

ITEM	DESCRIPTION	LABOR HOURS OR ITEM QUANTITY	COST (DOLLARS)	
Initial Cost:				
Materials:			6 Cyl	8 Cyl
1. Kit	Thermal reactor with air injection system (Two for 8-cylinder engine and one for 6-cylinder engine)		125.00	250.00
2. Miscellaneous	Brackets, hoses, fasteners	As required by kit	25.00	25.00
Labor:				
1. Installation	Table 3-19	8 hrs for 8-cylinder engine 4 hrs for 6-cylinder engine	50.00	100.00
Total Initial Cost (1)			200.00	375.00
50,000-Mile Recurring Cost:				
Material:				
1. Fuel	15 percent average increase in consumption over the national average of 12.5 mpg at 10,000 miles per year for 50,000 miles	500 gallons X $0.35 per gallon	210.00	
2. Filter	Inspect/clean	0.25 hr	3.13	
Total Recurring Cost			213.13	
Total Cost			413.13	588.13

(1) $85 less if an air injection system is not required.

3.2.1.9 Feasibility Summary

Although Device 244 has been demonstrated as an effective means of reducing vehicle exhaust emissions of CO and HC, it currently appears to require more development before it can be considered technically feasible. Its susceptibility to internal oxidation and erosion would possibly impose restrictions on vehicle operating modes, if the device were incorporated. The alternative of limiting device operation by leaner fuel mixtures and by air diversion would require a determination as to how much emission reduction effectiveness would be lost, before such restrictions could be accepted from an emissions standpoint.

The high initial and recurring costs are perhaps the decisive factors in evaluating the device for its retrofit feasibility. Unless the initial costs were reduced substantially, the device would be difficult to justify on a cost effectiveness basis. If the device were limited to later model vehicles with air injection systems, the initial cost would still be high for a retrofit device. It would appear that only a major redesign based on new breakthroughs in low-cost reactor materials would lower the initial costs to a reasonable level.

Because of the device's high costs and its questionable reliability under all vehicle operating conditions, this device would appear to be questionable as a retrofit candidate at this time.

3.2.2 Device 463: Rich Thermal Reactor with Exhaust Gas Recirculation and Spark Retard

Device 463 combines exhaust gas recirculation (EGR) and spark retard to control NOx with post-combustion thermal reaction to control CO and HC. The reactor is the product of extensive developmental effort, as reported in Reference 101, and also has been tested by EPA (Reference 102). The following system description is based on these data sources.

3.2.2.1 Physical Description

The reactor subsystem is shown in Figure 3-19. The reactor consists of a replacement exhaust manifold and an air-exhaust mixing chamber. The manifold incorporates

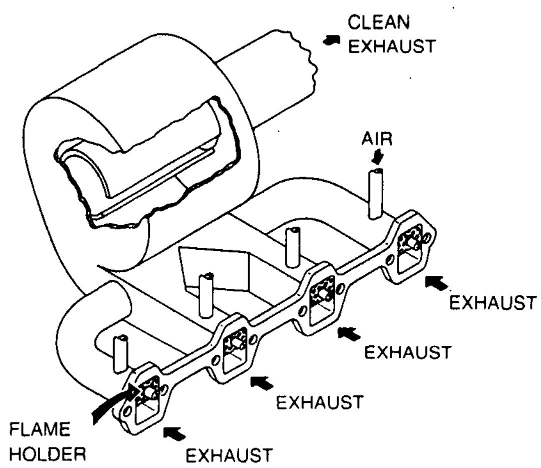


Figure 3-19. DEVICE 463 RICH THERMAL REACTOR MODEL II CONFIGURATION (REFERENCE 101)

flame holders opposite each exhaust port. The flame holders are made of stainless steel sheet perforated with 1/8-inch-diameter holes and extending halfway across the exhaust port. The manifold also incorporates air injection tubes which extend through the flame holders.

The reactor section is of a torus configuration that is 5.5 inches in diameter and 3.0 inches wide. The volume of the torus is 71 cubic inches and the surface-to-volume ratio is 1.35.(1) The reactor is made from Type 310 stainless steel.

(1) The reactor shown in Figure 3-19 is a second generation model. This model was designed to reduce surface-to-volume ratio. This was done to reduce flame quenching and heat losses at the reactor walls, and thereby enable the reactor to warm up faster (Reference 101).

For V-8 engines, a reactor is installed on each cylinder bank. In the developer's tests, each reactor was insulated with about 1/2 inch of refractory felt coated with asbestos cement. Air to the reactors was supplied through balanced air injection manifolds by a single automotive air pump driven by the engine. Pump speed was approximately 2.5 times engine speed.

The engine spark timing is set at the manufacturer's specification; but vacuum advance is inactivated, unless the exhaust pipe temperature indicates that the reactor is warmed up and the speed is above 20-25 mph cruise.

Exhaust gas recirculation of approximately 12 percent of engine intake air is used. The exhaust gas is taken near the muffler and routed through a finned cooling tube to the carburetor above the throttle plate. A diaphragm valve connected to the vacuum advance line controls the EGR; thus, EGR is off when the vacuum advance is off. The exhaust gas crossover normally used to heat the intake manifold is blocked on one side to equalize the temperature of the two reactors.

An automatic choke was designed by the developer to disengage the choke when reactor temperature indicates that the reactors are warmed up and also when the throttle is opened. A fast idle cam modification is also used. This provides a fast idle speed of 1,700-1,900 rpm in neutral after starting, but disengages upon the first throttle movement. Fuel rich carburetion is provided by enlarged idle, off-idle, and main jets.

3.2.2.2 Functional Description

The basic function of the reactor subsystem is to provide the air and thermal environment in which the CO and HC constituents of the exhaust gas can be oxidized to carbon dioxide and water. As noted for Device 244 (paragraph 3.2.1), the effectiveness of a thermal reactor in producing the high temperature (1,400-1,900°F) needed to support oxidation is influenced by the speed with which the reactor can heat up during engine cold start operations, when emissions are usually high. The purpose of the flame holders is to stabilize the flame at the exhaust outlet during engine startup when the choke is used. The stabilized flame causes the oxidation process to be initiated and thereby reactor warmup is accelerated. The flame holder grid creates eddies which heat the grid locally, igniting the fuel rich exhaust gas. When the choke is disengaged, the flame goes out because the air-fuel ratio returns to normal; but by this time the reactor is warmed up.

Figure 3-20 shows the reactor warmup time with and without the flame holders. The gas temperature was recorded at the exhaust outlet using the 1968 Federal Test Procedure (Reference 14). The developer reported that without the flame holders, flameout occurred when the car was put in gear and again during the acceleration from 15 to 50 mph (Reference 101).

According to the developer, most of the thermal reaction takes place as the gases swirl through the reactor. The gases enter the torus and flow around it to exit through a slot in the central plenum and thence into the exhaust pipe. The slot is positioned so that the gases must flow at least halfway around the torus and also so that a portion of the gas goes past the slot to mix with incoming gas. The back-mixing is intended to initiate reaction in the incoming gas and to mix the injected air.

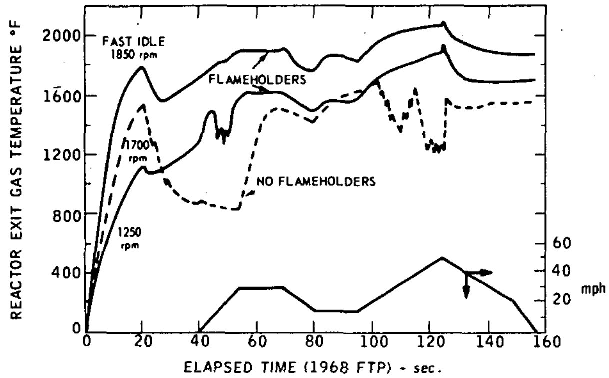


Figure 3-20. EFFECT OF FLAME HOLDERS ON DEVICE 463 RICH THERMAL REACTOR WARMUP TIME DURING 1968 FEDERAL TEST PROCEDURE (REFERENCE 101)

The distributor vacuum advance is disconnected below 20-25 mph, so as to speed reactor warmup and to enhance oxidations at low speed and idle when emissions are high. This also tends to reduce NOx because of the lower peak flame temperature during combustion.

Exhaust gas recirculation is used to provide NOx control whenever the vacuum advance is operating. EGR was not used below 20-25 mph because, according to the developer, it increased CO and HC. It was not desired during warmup, because it prevented the warmup flame from being established quickly.

Fuel rich carburetion is used to speed reactor warmup and to sustain reactor oxidation temperature. As is typical of rich thermal reactors, an excess of CO and HC in the exhaust is required for the oxidation process to be effective.

3.2.2.3 Performance Characteristics

The developer found that the reactor was fully operational within 40 seconds after a cold start. An operating temperature of 1,500°F was found adequate to reduce CO and HC so that very little of these pollutants are emitted with the exhaust gas. Exceptions occur when the engine is choked and there is insufficient air, or when very high exhaust flow rates occur before the exhaust pipe is hot enough to sustain the reaction (Reference 101). Although the developer reported no vehicle baseline emission data, average emission levels measured with the 1972 Federal Test Procedure (Reference 3) met the 1975 emission standards, as shown in Table 3-21.

The results of emission tests performed by EPA were much the same, except that CO exceeded the 1975 standard. These results are shown in Table 3-22.

3.2.2.4 Reliability

The developer reported (Reference 101) that 1,950°F, which was reached at 60 mph cruise speed, is considered the upper limit for reactor durability. In the experimental configuration tested, no overtemperature control was used. The developer stated, however, that it would be necessary to have such control to protect the reactor from the excessive temperatures that engine malfunction could cause. Malfunction examples are a stuck choke or persistent spark plug misfire, which could

Table 3-21. DEVICE 463 RICH THERMAL REACTOR EMISSION LEVELS COMPARED TO 1975 STANDARDS (REPORTED BY DEVELOPER IN REFERENCE 101)

EMISSION LEVEL	POLLUTANT (GM/MI)		
	HC	CO	NOx
1975 Standards	0.46	4.7	3.0
Device 463 (1)	0.08	3.7	0.72

(1) Average of four tests performed to the 1972 Federal Test Procedure (Reference 3) on a 1968 Chevrolet Bel Air with 307-CID V-8 engine.

Table 3-22. DEVICE 463 RICH THERMAL REACTOR EMISSION LEVELS REPORTED BY EPA (REFERENCE 102) (1)

EMISSION TEST	POLLUTANT (GM/MI)		
	HC	CO	NOx
2 June 1971	0.2	6	0.6
23 June 1971	0.1	5	0.6
24 June 1971	0.1	5	0.6

(1) Results obtained by the 1972 Federal Test Procedure (Reference 3) with Device 463 on a 1971 Ford LTD with a 351-CID V-8 engine and automatic transmission.

supply too much fuel to the reactor, causing excessive heat. The developer's approach to preventing this problem would be to divert the air supplied to the reactor by the air injection system.

The effects of fuel properties have not been studied by the developer. The performance data were obtained with commercial fuels.

3.2.2.5 Maintainability

Assuming that the reactor has adequate service life reliability, there should be no maintenance required on this part of the overall Device 463 system. If the air pump has an air filter, it would require cleaning about every 12,000 miles. Such maintenance should not exceed 0.25 hour.

3.2.2.6 Driveability and Safety

The developer reported that the combined effects of EGR, exhaust backpressure, and rich air-fuel ratio increase the time to reach a given speed. Backpressure increase caused by the reactor is indicated by Table 3-23.

Table 3-23. DEVICE 463 RICH THERMAL REACTOR EXHAUST BACKPRESSURE REPORTED BY DEVELOPER (REFERENCE 101)

	CRUISE SPEED (MPH)				
VEHICLE CONFIGURATION (1)	IDLE	30	40	50	60
Device 463 with Muffler (Inches H_2O)	6	20	40	69	110
Muffler Alone (Inches H_2O)	4	11	22	38	72
Percent Increase	33	45	45	45	35
(1) 1968 Chevrolet Bel Air with 307-CID V-8 engine.					

These results indicate an average 40.6 percent increase in backpressure. The effect of this on acceleration, when combined with EGR and rich air-fuel mixture, is shown in Table 3-24. The developer reported, however, that from a subjective standpoint the vehicle equipped with Device 463 had acceptable driveability.

Table 3-24. DEVICE 463 RICH THERMAL REACTOR VEHICLE ACCELERATION TIME INCREASE REPORTED BY DEVELOPER (REFERENCE 101)

PERCENT INCREASE IN WOT ACCELERATION TIME (1)			
0-25 MPH	0-40 MPH	0-50 MPH	0-60 MPH
5.6	9.0	17.2	20.5
(1) 1968 Chevrolet Bel Air with 307-CID V-8 engine.			

As with most retrofit systems which use a rich fuel mixture to decrease NOx, some loss of fuel economy may be expected. The developer noted that rich engine operation is essential to a thermal reactor; and that the use of fuel in excess of that required by the reactor represents a fuel economy debit solely for the reduction of NOx. In developer tests of the reactor, the fuel mixture was enrichened to the maximum ratio that reactor operating temperature would allow. With this maximum rich fuel mixture, the NOx emissions were low, but fuel consumption was high. The average increase measured for fuel consumption in turnpike and city driving was 19.9 percent (Reference 101).

No data on the safety of the Device 463 reactor were reported.

3.2.2.7 Installation Description

A complete evaluation of the Device 463 installation requirements was not possible on the basis of available data. The reactor apparently is a complete replacement assembly for the standard exhaust manifold. Figure 3-21 shows one of the two reactors installed on a 1971 Ford LTD. The torus size was scaled in proportion to the engine cylinder displacement (351 CID) for this vehicle by increasing the width from 3 to 3.5 inches.

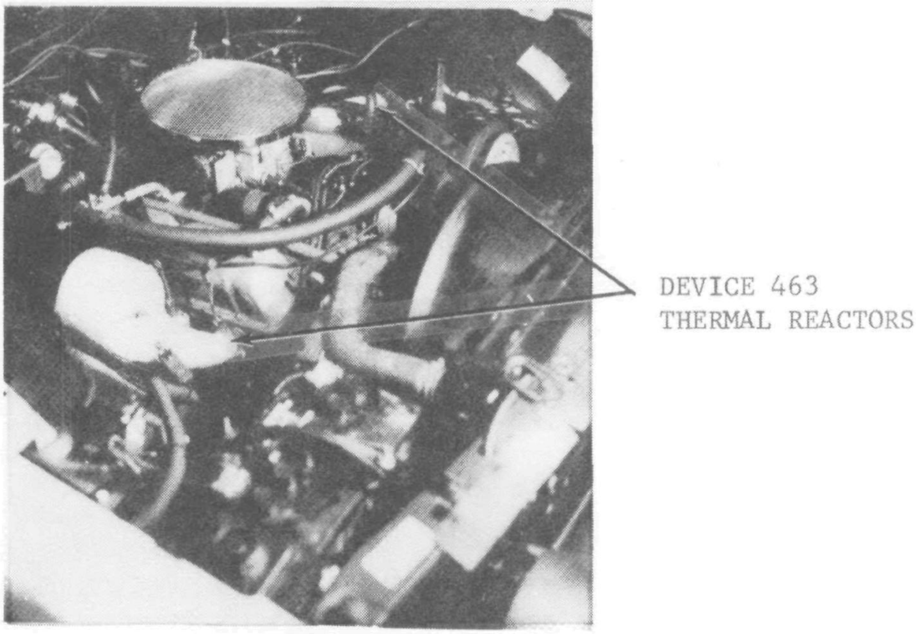


Figure 3-21. DEVICE 463 RICH THERMAL REACTOR INSTALLATION ON 1971 FORD LTD 351-CID ENGINE (REFERENCE 101)

3.2.2.8 Initial and Recurring Costs

System costs for Device 463 could not be estimated because of the lack of complete system information.

3.2.2.9 Feasibility Summary

Device 463 is apparently still in the development stage and requires additional testing to verify its overall technical feasibility, particularly its reliability. The emission tests reported thus far indicate that the device effectively and consistently reduces exhaust emissions of CO, HC, and NOx. Whether this effectiveness can be achieved reliably and within a reasonable cost would have to be determined through further development effort. The large penalty indicated in fuel economy may be a decisive factor offsetting technical feasibility, unless NOx control is decreased to the point where the increase in fuel consumption is acceptable.

On older model-year vehicles, the overall system costs may still be prohibitive, because of the requirement for adding an air injection system. The cost of such systems is approximately $85. On later model-year vehicles which already incorporate air injection, the existing air pump could be used with the reactor. In most cases, however, carburetor modification would be required to provide the rich fuel mixture needed for reactor operation. Reactor cost would have to be lower than may be possible, if overall system costs, including EGR and solenoid valves, are to be acceptable. It would appear that such costs could only be absorbed in a new model-year basis. Thus, the device may not be economically feasible for retrofit to used cars.

The rich thermal reactors described in the preceding paragraphs indicate the major problems in attempting to control CO and HC exhaust pollutants by high temperature oxidation. In summary, these problems include the substantial penalty in fuel economy that results from the need for a rich fuel mixture to initiate and sustain high temperature oxidation, the additional cost penalty that results from the need for an auxiliary air supply to support the oxidation process, and the questionable reliability of reactor materials under the oxidation environment produced by the fuel and the high temperature.

3.2.3 Device 468: Lean Thermal Reactor with Exhaust Gas Recirculation

Device 468 attempts to eliminate the problems associated with rich thermal reactors by means of a thermal reactor that operates on a lean air-fuel mixture. The indicated advantages of this lean thermal reactor (LTR) are that it operates at temperatures that are 200 to 300°F below those of a rich thermal reactor, it can be operated without an auxiliary air supply, and it avoids the fuel economy losses which appear to be characteristic of the rich reactor. These advantages result from the high air-fuel ratios at which the reactor is designed to operate.

Device 468 has undergone vehicle testing by the developer, and is the only design of a lean operating system for which configuration and performance details were available. Although the developer was not located during the retrofit method survey, design and performance information was obtained from a report on the effect of lead additives on emission control systems (Reference 2).

3.2.3.1 Physical Description

The Device 468 system consists of the LTR for CO and HC control, an exhaust gas recirculation (EGR) system for NOx control, and modified carburetion for engine operation at a lean fuel mixture of approximately 17.5 air-fuel ratio. Spark advance is adjusted for the best compromise between low exhaust emissions, vehicle driveability, and fuel consumption.

As reported in Reference 2, the reactor is a cylindrical assembly consisting of a three-layer shell. The inner layer is an open-tube liner made of 310 stainless steel. The second or intermediate layer is insulating material. The outer layer casing is made of 310 or 430 sheet stainless steel.

The LTR combines with EGR for the control of NOx during combustion. The lean air-fuel operation of the reactor requires a special carburetor that provides high velocity air-fuel intake and mixing. Use of small, dual, or staged venturies is being investigated to strengthen the fuel metering signals and to improve the air and fuel mixing. Consideration has also been given by the developer to use of electronic fuel injection.

Spark retard is generally used as a supplementary NOx control and also to increase exhaust gas temperature for the oxidation process in the reactor.

3.2.3.2 Functional Description

At the 17-19:1 air-fuel ratios under which the LTR-EGR device operates, CO and HC concentrations in the engine exhaust are inherently much lower than with the rich thermal reactor (RTR) or with conventional carburetion. Because of these lower concentrations, reaction temperatures are not as high as with the RTR. Oxidation of CO and HC in the LTR is accomplished between 1,400-1,600°F.

Because of its lower operating temperatures, the LTR-EGR device has less of a durability problem, and less expensive materials can be used in manufacturing the reactor core and gas mixing baffles. The low operating temperatures necessitate, however, that the reactor be designed for minimum heat loss, so as not to limit the oxidation process.

To achieve satisfactory engine performance at the high air-fuel mixture and its distribution from cylinder to cylinder has to be precisely controlled. This is the function of the special carburetor mentioned previously.

3.2.3.3 Performance Characteristics

Table 3-25 shows the results of Device 468 emission tests reported by the developer and summarized in Reference 2. For comparison, Table 3-26 shows emission results for the device when operated with auxiliary air injection during cold start. These results indicate that the device without air injection may be able to meet 1974 Federal emission standards. Percent reduction from vehicle baseline emission levels were not reported.

The developer reported (Reference 2) that the cold start phase of the 1972 Federal Test Procedure contributes most of the CO and HC pollutants, and almost half of the NOx. Estimates are that 78 percent of the HC, 68 percent of the CO, and 48 percent of the NOx occur during this phase. The relatively low overall emission levels shown in Tables 3-25 and 3-26 would indicate that the LTR warms up quickly to oxidation temperatures.

3.2.3.4 Reliability

The results of developer tests indicate that overtemperature protection of the LTR is not required, as it is with the RTR. Tests have been run with three spark plugs disconnected without increasing reactor temperature, though with CO and HC increase. A 50,000-mile service life (MMBTF) has not been demonstrated, but indications are that the device could achieve this standard.

The basic nature of a lean reactor system indicates less difficulty in obtaining satisfactory durability than with a rich reactor system. Exhaust gas entering the reactor from the lean engine contains about 100 ppm HC, 0.1-0.4 percent CO, and approximately 2-4 percent O_2 (without an air pump); therefore, little chemical heat is generated in the reactor and its ultimate temperature is determined by the extent to which the heat in the exhaust gas is not lost by radiation. This enables the lean reactor to operate in a temperature range of 1,400° to 1,600°F, even under high-speed turnpike conditions. This is a temperature range that good-quality stainless steels should tolerate well. Tests by the developer indicate that the lean reactor is not subject to destructive temperature excursions, even (as noted above) with a continuously misfiring spark plug. Thus, durability should not be seriously decreased by situations in which engine malfunctions occur.

A developer-modified 1966 Pontiac was driven throughout the United States for over 20,000 miles while being used for a series of demonstrations. Modifications were similar to those in cars now in use with the LTR-EGR, except that the car was not equipped with EGR and had a less effective thermal reactor. Another Pontiac incorporating EGR and improved thermal reactors accumulated over 30,000 miles in various types of service including cross-country trips. This car was reported by the developer to have demonstrated excellent durability characteristics and emission reduction stability.

The developer provided a modified 1970 Pontiac to the California Air Resources Board in November 1970 for testing and use in general fleet service. The durability test mileage of this vehicle at the last reported test point was 12,000 miles. The emissions of this car had good stability, as shown in Table 3-27.

Table 3-25. DEVICE 468 EMISSION TEST RESULTS WITHOUT AIR INJECTION (REFERENCE 2)

Vehicle Description	Modifications
1971 Plymouth Fury III	3-Venturi Carburetor
360 CID Engine	EGR System
Automatic Transmission	Exhaust Manifold Reactor
Power Steering	Exhaust Port Liners
Power Brakes	Evaporative Loss Controls
Air Conditioning	Exhaust Cooler Units

1972 CVS Procedure (Single-bag tests)

Run Date	HC gm/mi	CO gm/mi	NO_x gm/mi
2-26-71	1.00	8.0	1.6
3-2-71	0.74	7.3	1.7
3-8-71	0.92	7.6	0.86
3-24-71	0.82	10.0	1.5
4-8-71	1.00	10.0	1.23
Avg.	0.89	8.6	1.37

1975 CVS Procedure (Three-bag tests)

	HC gm/mi	CO gm/mi	NO_x gm/mi
	0.52	6.2	1.37

Table 3-26. DEVICE 468 EMISSION TEST RESULTS WITH AIR INJECTION (REFERENCE 2)

Vehicle Description	Modifications
1970 Pontiac LeMans	3-Venturi Carburetor
400 CID Engine	EGR System
Automatic Transmission	Exhaust Manifold Reactor
Power Steering	Exhaust Port Liners
Power Brakes	Evaporative Loss Controls
	Exhaust Cooler Units
	Particulate Trapping Device
	Air-Injection Pump (Operates During Choking Period)
	Transmission Modifications (Modulator and Governor)

1972 CVS Procedure

Run Date	HC (gm/mi)	CO (gm/mi)	NO_x (gm/mi)
4-5-71	0.74	7.3	1.40
4-6-71	0.75	7.0	1.60
4-19-71	0.74	5.3	1.70
4-20-71	0.78	6.2	1.70
4-21-71	0.84	6.2	1.48
4-22-71	0.82	5.9	1.45
6-3-71	0.88	6.5	1.45
6-24-71	0.73	6.8	1.40
Avg.	0.79	6.4	1.52
12-18-70	0.64	9.1	1.09

1970 7-Mode Procedure

Run Date	HC (ppm)	CO (%)	NO (ppm)
4-8-71	19	0.21	226
4-13-71	20	0.20	200
4-14-71	23	0.21	197
Avg.	20.7	0.21	208
Equivalent gm/mi	0.26	5.0	0.81

Table 3-27. DEVICE 468 LTR-EGR DURABILITY EMISSION TEST RESULTS (REFERENCE 2) (1)

DATE	APPROXIMATE MILES	POLLUTANTS (GM/MI)		
		HC	CO	NOx
11-19-70	0	0.60	8.34	0.72
1-26-71	3,000	0.47	7.87	0.48
4-1-71	6,000	0.51	8.11	0.77
5-18-71	8,000	0.42	8.8	0.79

(1) 1970 equivalent mass method measurements by the California Air Resources Board.

The LTR-EGR tests performed by the developer have been with fully leaded fuels and no adverse effects have been observed on the thermal reactor. The developer has indicated that deposits in the EGR system can be expected to result from the decomposition of fuel and lubricant additives, from tars and carbonaceous matter produced during combustion, and from ferrous oxides from exhaust system parts. In addition, water condensate could be an important factor in promoting deposits. The developer has found that self-cleaning EGR orifice designs (plungers, specially coated surfaces, or flexible snap-rings) in areas of likely deposit buildup are practical for preventing deposit plugging and loss of EGR effectiveness. The more advanced modulating EGR system now used on lean reactor cars was found to be free of such deposits after 12,000 miles of service on the car tested by the California Air Resources Board. This EGR system was tested successfully for 30,000 equivalent miles on the dynamometer (Reference 2).

Materials testing data on leaded fuels indicate that corrosion effects due to lead halides and/or phosphate compounds in the exhaust are temperature related. Figure 3-15 indicates that, at temperatures approaching 1,700°F, corrosive weight loss rates are not sensitive to fuel composition. This provides a rational basis for the developer's claim that the lead composition of fuel has no impact on the Device 468 LTR. The developer has found that 430 stainless steel (with zero nickel content) has a useful service life in the lean reactor of about 30,000 miles. The same material had a life of only 17 hours when tested on the dynamometer at 100-mph vehicle speed with retarded spark to increase exhaust temperature. Under the same dynamometer conditions, a duplicate reactor fabricated of 310 stainless steel (20 percent nickel) showed no deterioration for more than 200 hours (equivalent to 20,000 miles). Therefore, the developer has concluded that 310 stainless steel should provide a tenfold improvement over the 30,000-mile road service obtained with stainless steel.

3.2.3.5 Maintainability

With the requirement for an air pump eliminated, Device 468 should require no periodic servicing other than that associated with the EGR subsystem and normal vehicle maintenance. Carburetor idle adjustment could be performed during regular engine tuneup and therefore would not be a special requirement of the device. The EGR subsystem would require about 40 minutes of service every 12,000 miles.

3.2.3.6 Driveability and Safety

The developer has reported (Reference 2) that acceptable driveability is achieved with the lean air-fuel mixtures required for LTR-EGR operation, because it is possible to operate the engine at a high-compression ratio. Since this enables tetraethyl lead (TEL) fuel to be used with the LTR-EGR, it does not apprently have the fuel economy penalties that would otherwise result from lowering the compression ratio to use low-octane fuels.

The developer has reported fuel economy test results for the aforementioned Plymouth and Pontiac LTR-EGR cars (Tables 3-25 and 3-26). Two test routes were used to measure fuel economy under consumer driving conditions, with characteristics as follows:

a. <u>City and Expressway Route</u>: a 27.7-mile loop, 10 stops per loop, with average speed of 36.7 mph.

b. <u>City Route</u>: an 18.4-mile loop, 40 stops per loop, with average speed of 23.4 mph.

Table 3-28 shows the results obtained on these test routes with the lean reactor cars and their unmodified production counterparts. The economy losses apparently occurred because of the substantial amounts of EGR used. Earlier versions of lean reactor cars without EGR indicated little or no loss in fuel economy in comparison with the corresponding unmodified car.

3.2.3.7 Installation Description

The specific installation requirements for this device could not be defined, because the system data obtained were incomplete with respect to the detailed system description.

3.2.3.8 Initial and Recurring Costs

These costs could not be estimated for the same reason stated in paragraph 3.2.3.7. Because it would apparently incorporate low cost materials, would not require an air pump, and may not have exorbitant fuel economy penalties, Device 468 possibly would be considerably less expensive than an RTR approach to exhaust emission control.

There are no apparent safety problems indicated by the technical characteristics of this device.

3.2.3.9 Feasibility Summary

The effective emission reduction capability indicated by Device 468, combined with its possibly acceptable initial and recurring costs, suggest that it should be considered for further test and analysis as a candidate retrofit method.

Table 3-28. DEVICE 468 LTR-EGR FUEL CONSUMPTION COMPARED TO CONVENTIONAL CARS (REFERENCE 2)

Item	City Route	City and Expressway
Average Speed	23 mph	36 mph
Stops per Mile	2.17	0.36
1971 Plymouth Fury III, 360 CID		
Standard Car	11.1 mpg	16.7 mpg
Modified Car		
Car A	11.0 mpg	14.5 mpg
Car B	11.1 mpg	14.7 mpg
Economy Loss	0.5%	12.6%
Avg	6.6%	
1970 Pontiac LeMans, 400 CID		
Standard Car	11.5 mpg	14.9 mpg
Modified Car	10.6 mpg	13.5 mpg
Economy Loss	7.8%	9.4%
Avg.	8.6%	

3.2.4 Device 31: Thermal Reaction by Turbine Blower Air Injection

Device 31 is a turbine driven air pump designed to replace the conventional air injection pumps used to supply air to exhaust manifolds, thermal reactors, and catalytic converters for the oxidation of CO and HC. The device incorporates a variable displacement, centrifugal pump driven by a small (3-inch-diameter) impulse turbine. Impulse turbine power is derived from air drawn through the turbine by intake manifold vacuum.

This appears to be a well developed device. The developer has conducted sufficient tests to demonstrate that the turbine driven air pump, when used with an exhaust manifold air injection system, for control of HC and CO exhaust emissions, performs as well as conventional air pumps.

The device was evaluated solely on the basis of developer provided data. No comparison of relative costs was provided by the developer.

3.2.4.1 Physical Description

As shown in Figure 3-22, the device has a turbine section (right side) and centrifugal pump section (left side) contained in an integral assembly. The 3-inch-diameter turbine wheel and centrifugal impeller are rigidly mounted on a common shaft supported in between by a single duplexed pair of miniature ball bearings. The entire turbine/blower assembly weighs approximately 1.75 pounds.

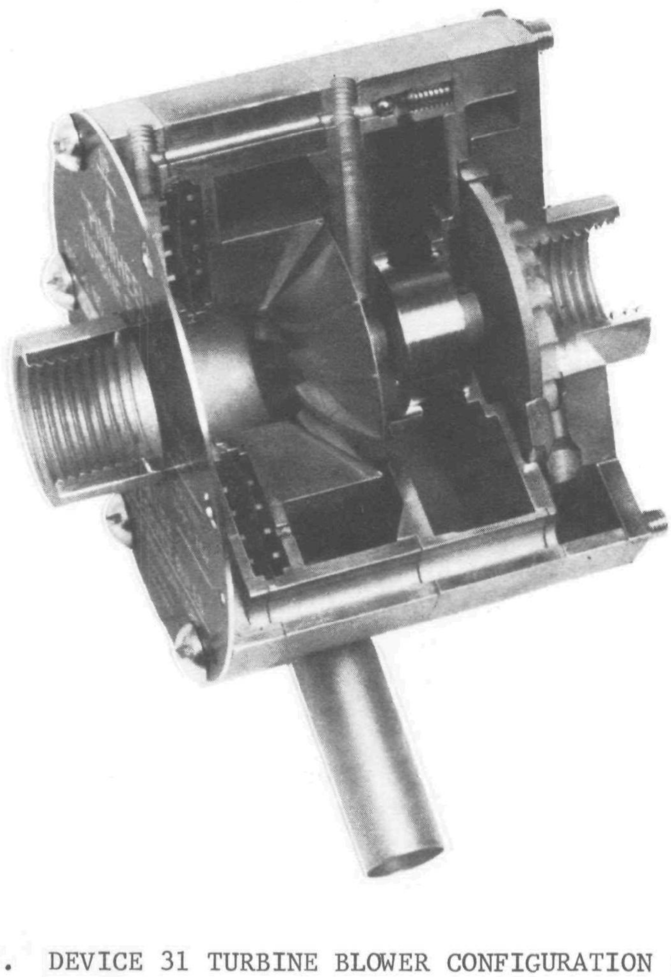


Figure 3-22. DEVICE 31 TURBINE BLOWER CONFIGURATION (DEVELOPER PHOTO)

3.2.4.2 Functional Description

Figure 3-23 shows a typical installation of Device 31. Three ports are provided in the pump housing: (1) an air inlet entering axially from the right, (2) a vacuum outlet, and (3) a blower air outlet discharging tangentially in line with the impeller. Inlet air to the blower and turbine is first passed through an air filter. Turbine air is drawn from the air inlet immediately upstream of the impeller and ported along axial passages in the housing wall to an annular plenum chamber. From the plenum chamber air is drawn through a tangentially oriented, tubular nozzle to impinge on turbine buckets. The blower discharge is equipped with a check valve which is essential to blower performance as well as a safety device to prevent exhaust backflow if backfiring should occur.

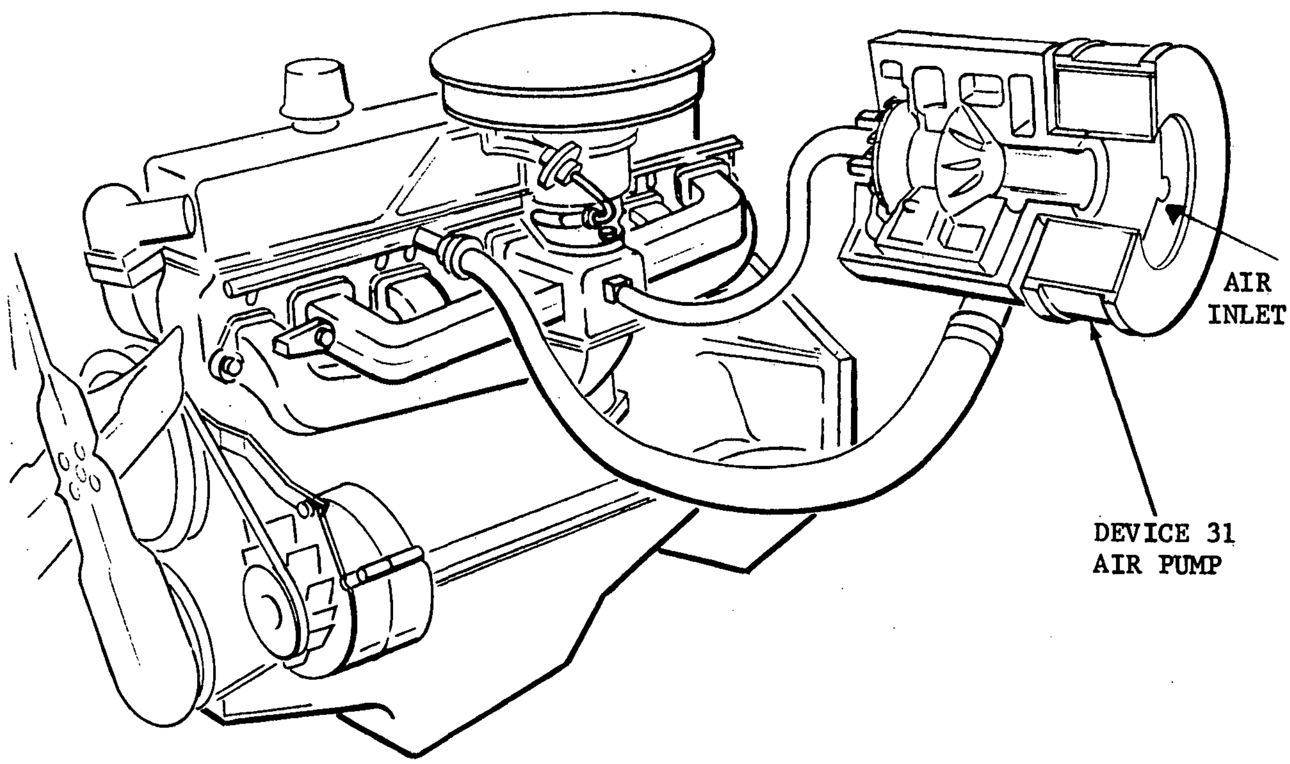


Figure 3-23. DEVICE 31 AIR INJECTION SYSTEM CONFIGURATION (DEVELOPER SKETCH)

Figure 3-24 shows the air pumping characteristics of the device with the engine operating at a constant 1,800 rpm, while intake manifold vacuum was varied. This figure indicates that blower output varied almost directly with intake manifold vacuum. A maximum blower output of about 10 cubic feet per minute was achieved at 24 inches of mercury intake manifold vacuum. Blower output ceased at about 6 inches of mercury intake manifold vacuum even though at approximately 15 inches of mercury intake manifold vacuum, blower outlet pressure equaled exhaust manifold pressure. Blower output flow at the latter vacuum was about 5 cfm and did not become zero until exhaust pressure was over five times blower output pressure. This is explained

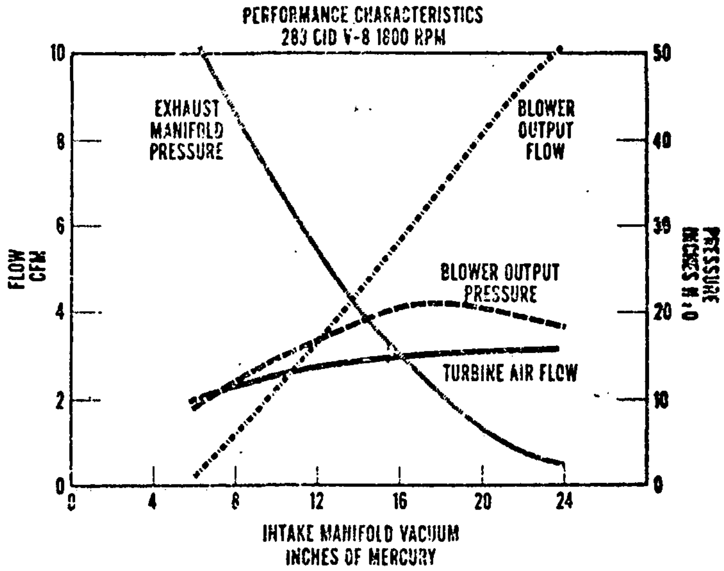


Figure 3-24. DEVICE 31 TURBINE BLOWER AIR PUMPING CHARACTERISTICS (DEVELOPER DATA)

by the developer as a combination of pressure variations in the exhaust and the action of check valves in the device. The exhaust pressure undergoes high and low fluctuations. The check valves permit blower output air to enter the exhaust during exhaust pressure fluctuations in which the exhaust pressure is lower than that of the pump.

Figure 3-25 shows the air pumping capability of the turbine blower, expressed as percent of engine inlet air (carburetor air plus turbine air).

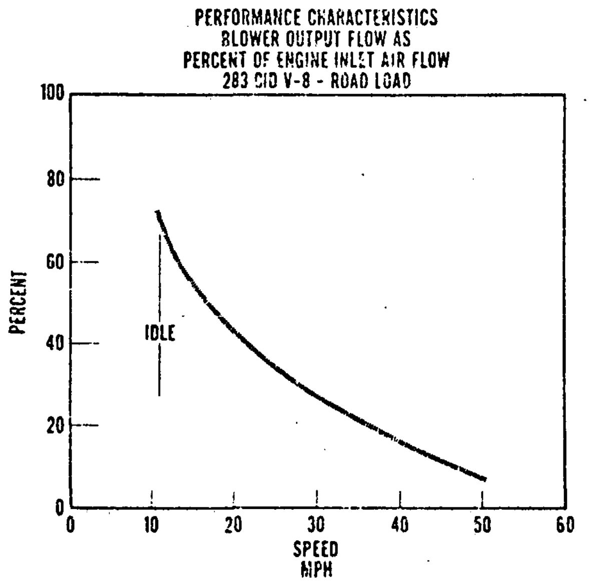


Figure 3-25. DEVICE 31 TURBINE BLOWER OUTPUT AS PERCENT OF ENGINE INLET AIRFLOW (DEVELOPER DATA)

3.2.4.3 Performance Characteristics

The emission control performance capability of air injection systems using the turbine blower was evaluated by the developer by comparing the results of cold start dynamometer tests on air injection system equipped cars, first with the turbine blower supplying the air, then with the standard pump supplying the air. The procedure consisted in performing hot cycles with the vehicles in the as-received condition, both with and without air. From the without-air tests idle CO and speed were noted. The turbine blower vacuum line was then connected to the intake manifold and the idle CO and speed set to their original values to compensate for the introduction of turbine air into the intake manifold.

Cold start emission tests were performed, first with the turbine blower supplying air and the standard pump discharging to atmosphere, and then with the standard pump supplying the air and the turbine-blower discharging to atmosphere. Six air-injection-equipped 1966 and 1967 model automobiles, with engine displacements ranging from 164 cubic inches to 428 cubic inches, were tested in this manner. Three of the cars had six-cylinder engines and one had a manual transmission. Odometer readings varied between a few miles and 15,000 miles.

Results of the evaluation tests showed nearly identical emission control with either the standard pump or the turbine blower supplying the air. Emission test results were as shown in Table 3-29.

The average HC and CO emission test results from six vehicles during the course of a 7-mode, 7-cycle comparison test are plotted in Figure 3-26. The vehicles were equipped with an exhaust manifold air injection system. Emission trends are shown for air injection systems equipped with both turbine blower and conventional air pump. No significant differences in emissions result from substitution of the turbine air pump.

Table 3-29. DEVICE 31 TURBINE BLOWER AND CONVENTIONAL AIR PUMP SYSTEM EMISSION TEST RESULTS (DEVELOPER 7-MODE DATA)

TEST CONDITION	STANDARD PUMP SYSTEM		TURBINE BLOWER SYSTEM	
	HC (ppm)	CO (%)	HC (ppm)	CO (%)
Warmup Cycles 1-4	297	1.33	300	1.51
Hot Cycles 6 and 7	237	0.92	236	0.91
Weighted Average (1)	258	1.06	258	1.12

(1) Average of six cars.

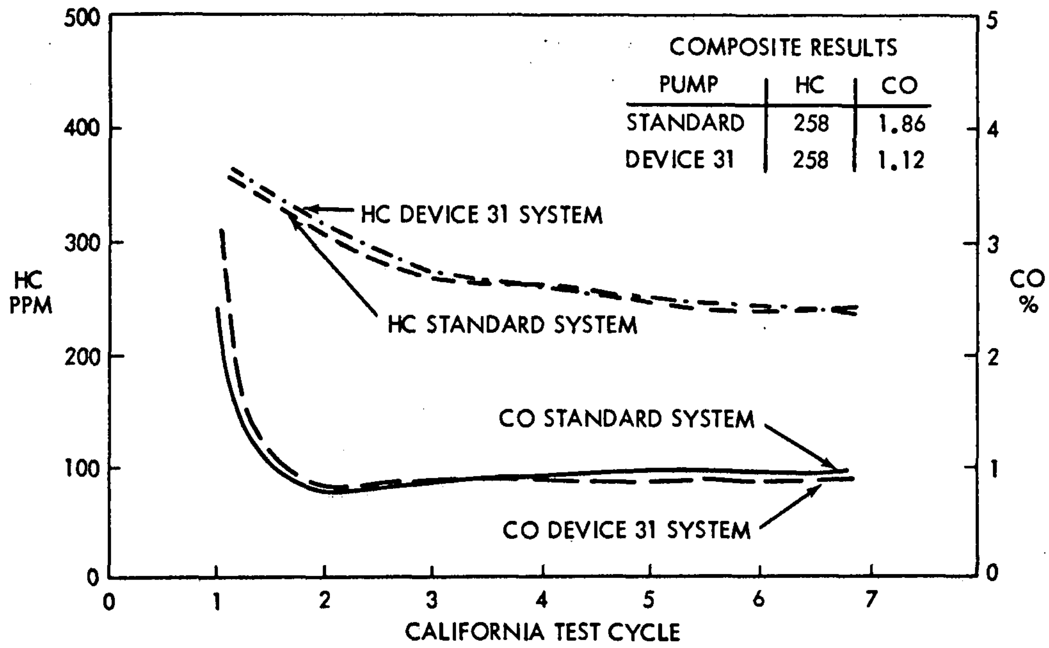


Figure 3-26. DEVICE 31 TURBINE BLOWER EMISSION TEST COMPARISON WITH CONVENTIONAL AIR PUMP SYSTEM (DEVELOPER DATA)

3.2.4.4 Reliability

The device is an air driven turbine as compared to the belt driven pump it replaces. Provided appropriate bearings have been selected, and their lubrication system properly designed, the reliability of the device should exceed that for belt driven pumps because the device bearings are symmetrically loaded as opposed to the radial loading for a standard belt type pump. Assuming such consideration has been given the bearing and lubrication system, it is estimated that the device reliability (MMBTF) would exceed 50,000 miles.

3.2.4.5 Maintainability

The only anticipated routine maintenance is changing or cleaning of the air filter every 12,000 miles, plus an inspection of hoses and turbine blower attachments to the engine. Changing or cleaning the filter could be accomplished within 15 minutes provided the device is readily accessible. The bearings might require lubrication if not designed for a minimum of 50,000 miles without maintenance. The developer noted that there is no requirement for lubrication, because the pump contains a sealed bearing system. Overall maintenance and corrective action at 12,000-mile intervals should not exceed 0.5 hour.

3.2.4.6 Driveability and Safety

No safety hazards were identified. However, engineering estimates based on the developer's data indicate that rotational velocities could exceed 20,000 revolutions per minute. Therefore, a critical design review should be performed prior to full-scale production to assure that there is no safety hazard resulting from explosive disintegration of the turbine or impeller.

This device was not tested for driveability and the developer supplied no driveability data. Therefore, no evaluation could be made as to the effects of this device on vehicle driveability.

3.2.4.7 Installation Description

The Device 31 installation on cars not already equipped with an air injection system consists in drilling holes in the engine exhaust manifold so that air may be injected into the exhaust system immediately adjacent to the exhaust valves, installing air injection nozzles and manifold, installing a turbine blower to provide air for injection, and drilling a hole in the intake manifold to provide air flow for the turbine section of the blower. On later model-year vehicles with a conventional air pump, the existing pump would be replaced with a Device 31 turbine blower.

Table 3-30 lists the installation requirements. Installation could be accomplished by a skilled mechanic in a normally equipped repair shop. Figure 3-27 shows a typical installation for a 6-cylinder engine.

3.2.4.8 Initial and Recurring Costs

Table 3-31 summarizes the costs for this device. From the information available, it is estimated that the cost for installing this device, including material, would be approximately $142.50 for a complete air injection system.

Recurring costs would be insignificant, based on the assumption that the only maintenance required would be the cleaning of the air filter.

3.2.4.9 Feasibility Summary

This device is considered technically feasible as an air source for exhaust air injection systems. The device appears to be well engineered and designed; however, no information regarding durability is available. It is questionable if this device is feasible for retrofit application because of the relatively high installation costs for an unequipped vehicle.

Table 3-30. DEVICE 31 TURBINE BLOWER AIR INJECTION SYSTEM INSTALLATION PROCEDURE

MINIMUM AVERAGE SKILL LEVEL: AUTOMOTIVE MECHANIC		
INSTALLATION AND ADJUSTMENT PROCEDURE	TOOLS, EQUIPMENT AND FACILITIES	TIME (MIN.)
1. Drill and tap holes in engine exhaust manifold adjacent to exhaust valves.	a. Hand tools b. Electric drill c. Tap	120
2. Secure air injection nozzles into holes in exhaust manifold.	a. Hand tools b. Air injection nozzles	45
3. Connect injection manifold to air injection nozzles	a. Hand tools b. Air injection manifold	30
4. Attach mounting bracket to engine	a. Hand tools b. Mounting bracket	10
5. Attach turbine blower to mounting bracket	a. Hand tools b. Turbine blower	10
6. Attach 3/4" hose from the blower output to the air injection manifold through check valves	a. Hand tools b. Hose clamps c. Hose d. Check valves	10
7. Drill and tap hole in intake manifold near base of carburetor	a. Electric drill b. Tap	15
8. Secure connector in hole in intake manifold	a. Hand tools b. Connector	5
9. Attach hose from turbine outlet to intake manifold	a. Hand tools b. Hose c. Hose clamps	10
10. Reassemble engine accessories	Hand tools	45
	Total Time	5.0 hrs

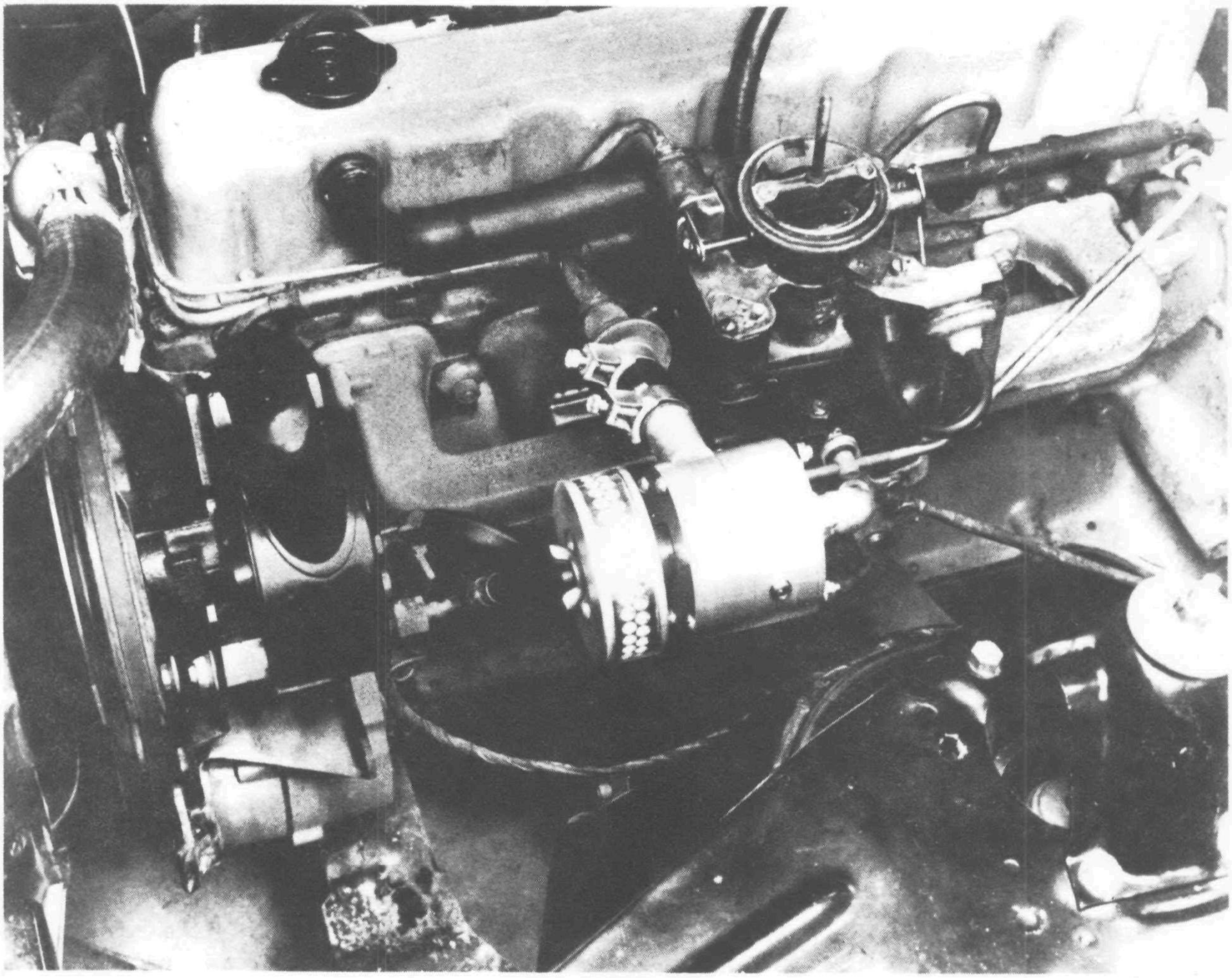


Figure 3-27. DEVICE 31 TURBINE BLOWER AIR INJECTION SYSTEM INSTALLATION (DEVELOPER PHOTO)

Table 3-31. DEVICE 31 TURBINE BLOWER AIR INJECTION SYSTEM INITIAL AND RECURRING COSTS

ITEM	DESCRIPTION	LABOR HOURS OR ITEM QUANTITY	COST (DOLLARS)
Initial Cost:			
Material			
1. Device	a. Air injection nozzles and manifold		
	b. Turbine blower		80.00
	c. Check valves		
2. Miscellaneous	a. Mounting bracket		(Included in above)
	b. Hose and hose clamps		
	c. Connector		
Labor			
1. Installation	Table 3-30	5 hrs	62.50
2. Test and adjust			
Total Initial Cost			142.50
50,000-Mile Recurring Cost:			
Material	(None assumed to be required)		
Labor			
1. Air filter and turbine installation	Cleaning and inspection	1/2 hr every 12,000 miles @$12.50 per hr	25.00
Total Recurring Cost			25.00
TOTAL COSTS			167.50

3.3 EXHAUST GAS AFTERBURNER - RETROFIT SUBTYPE 1.1.3

The afterburner approach to exhaust gas control is based on the same principle of operation as the thermal reactor: CO and HC are oxidized to carbon dioxide and water under a sustained combustion temperature environment. With the afterburner, however, this process occurs downstream of the exhaust manifold rather than in the manifold. Whereas the thermal reactor takes advantage of the hot exhaust gas to sustain the necessary temperature for oxidation, the afterburner requires an auxiliary ignition system, since the exhaust gas has cooled below the oxidation point by the time the gas reaches the afterburner.

To achieve combustion in the afterburner, the air-fuel ratio may have to be lowered so that more fuel is present in the exhaust gas. This is the same approach used in a rich exhaust gas reactor, as described in paragraph 3.2.1, to increase reaction temperature. If lower air-fuel ratio is used, then NOx emissions concurrently decrease because of the lower availability of oxygen and cooler engine-cylinder combustion temperature of a rich fuel mixture. With rich fuel mixture, some form of air injection is required, so that sufficient air is present to support combustion of the mixture in the afterburner.

Two afterburner devices were evaluated, Devices 308 and 425. The developers in both cases responded to the retrofit data survey questionnaire (refer to Volume V, Appendix 3). Device 308 operates without requiring any change in the air-fuel ratio, whereas Device 425 requires a rich fuel mixture.

3.3.1 Device 308: Exhaust Gas Afterburner

A single prototype unit of this device has been fabricated by the developer and installed on 1966 and 1967 Chevrolets. The developer provided the results of several emission tests conducted at idle, 30 mph, and 50 mph by the Arizona Department of Health, Division of Air Pollution Control. The emission reduction effectiveness was determined by testing with and without the afterburner ignition functioning.

3.3.1.1 Physical Description

The prototype unit is shown in Figure 3-28. The afterburner chamber consists of a 4.5-inch-diameter cylindrical steel section, 4.75 inches long. The cylinder is closed at each end by caps with exhaust pipe inlet and discharge holes.

A spark plug and grounding electrode are sidewall mounted opposite each other, so that they project radially inward to provide a spark gap of approximately 0.5 inch between the electrodes on the chamber centerline, approximately 1 inch downstream of the exhaust inlet. A circular plate, ringed with holes, is located transversely in the chamber, downstream of the spark system.

The spark plug is connected through a high voltage wire to a coil that, in turn, is connected to one side of a dual-point distributor plate and condensers incorporated in the standard engine distributor in place of the standard single-point distributor plate.

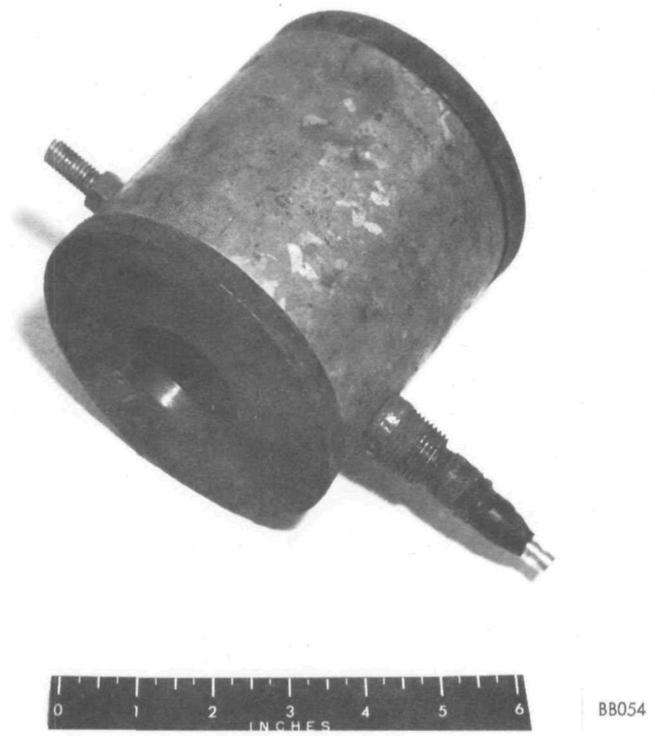


Figure 3-28. DEVICE 308 EXHAUST GAS AFTERBURNER SHOWING SPARK PLUG (RIGHT SIDE) AND DIAMETRICALLY OPPOSED ELECTRODE (LEFT SIDE)

3.3.1.2 Functional Description

Device 308 provides a chamber or accumulator through which exhaust gas flow is restricted while being subjected to a continuous ignition spark stimulus under all engine operating conditions. One set of the dual points and their condenser controls the coil of the standard engine ignition system, and the second set controls the coil of the afterburner ignition system. The objective of the continuous spark is to expose the center of the exhaust gas stream to high temperature, with the intent of oxidizing unburned CO and HC to carbon dioxide and water.

Since the afterburner spark plug operates off the engine distributor, a high voltage spark is directed across the exhaust gas entering the afterburner, whenever the engine is operating. The developer specifies that the engine be tuned to the vehicle manufacturer's specifications, with no emphasis on lean or rich carburetion (refer to Volume V, Appendix 3, Device 308 questionnaire response).

3.3.1.3 Performance Characteristics

Exhaust emission test results were reported by the developer, based on tests of a 1967 Chevrolet with and without the afterburner operating. The results are summarized in Table 3-32.

Table 3-32. DEVICE 308 EXHAUST GAS AFTERBURNER EMISSION TEST RESULTS REPORTED BY DEVELOPER (REFERENCE 18) (1)

TEST CONDITION (2)	POLLUTANT		
	HC(PPM)	CO(PERCENT)	NOx(PPM)
Idle			
Without Device	150	2.8	150
With Device	200	2.5	150
Percent Reduction	-33	10	0
30 MPH			
Without Device	160	1.4	300
With Device	150	1.5	250
Percent Reduction	7	-7	17
50 MPH			
Without Device	120	0.9	500
With Device	150	1.1	450
Percent Reduction	-25	-22	10

(1) Results obtained by Arizona State Department of Health, Division of Air Pollution Control, under steady state engine rpm noted, with and without device operating on a 1967 Chevrolet sedan with a 327-cubic-inch-displacement engine and automatic transmission.

(2) One set of tests, each condition.

These results show no significant reduction of emissions. The device appears to perform more as an NOx control than as a CO and HC control. This may be attributable to exhaust backpressure caused by the transverse plate in the afterburner chamber; this backpressure may induce some exhaust gas recirculation, which would have the effect of lowering combustion temperature and inhibiting the formation of NOx. This concept of device operation assumes that the device was not installed in the exhaust system of the test vehicle when the "without device" emission data were obtained.

3.3.1.4 Reliability

The device uses a standard automotive ignition coil, one half of a standard set of dual ignition points (the other half is used for engine ignition), and a single-electrode spark plug. Mean-miles-before-total-failure would exceed 50,000 miles provided the points and spark plug are replaced or maintained in accordance with the manufacturer's recommendations.

3.3.1.5 Maintainability

The ignition points utilized by the device, associated capacitor, and the spark plug will require the same maintenance as the points, capacitor, and spark plugs used for engine ignition. The afterburner high voltage line might require more frequent replacement than the engine ignition wires, depending on physical location, because of increased exposure to road hazards and exposure to exhaust pipe heat. The following preventive maintenance requirements are assumed to be required at the mileages noted, to achieve the reliability potential of the device:

a. Inspect spark plug gap every 12,000 miles and adjust electrode as required.

b. Replace breaker points every 12,000 miles (1).

c. Inspect spark plug lead every 12,000 miles.

d. Inspect afterburner chamber every 12,000 miles.

3.3.1.6 Driveability and Safety

Driveability data provided by the developer (Volume V, Appendix V-3) indicate that the device has no adverse effect on the vehicle's general driving quality. No information was provided as to the effect of the device on vehicle acceleration, deceleration, or gas mileage. No special type of fuel is required.

There are no apparent safety hazards for the vehicle operator or for the vehicle.

3.3.1.7 Installation Description

The installation of this device consists in cutting out a 5-inch section of exhaust line, inserting the afterburner into the exhaust line, replacing the standard single-set distributor points with a set of dual points, installing a second ignition coil, and electrically hooking up the points, coil, and afterburner. The developer specifies that the device should be installed as close to the exhaust manifold as possible. Adjustment consists in tuning the engine to the automobile manufacturer's specifications.

The developer estimates that installation of the complete system should take about one hour. Table 3-33 itemizes the installation procedure and identifies the tools and special equipment required. Installation can be accomplished in a normally equipped automobile repair shop by the average mechanic.

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(1) Based on information obtained from automotive repair personnel at Olson Laboratories, points should be replaced for the average vehicle at approximately 12,000 miles. The only maintenance cost attributable to the device would be the cost of the breaker point set used by the device (approximately $3.00).

Table 3-33. DEVICE 308 EXHAUST GAS AFTERBURNER INSTALLATION PROCEDURE

MINIMUM AVERAGE SKILL LEVEL: AUTOMOTIVE MECHANIC		
INSTALLATION AND ADJUSTMENT PROCEDURE	TOOLS, EQUIPMENT AND FACILITIES	TIME (MIN.)
1. Cut exhaust line between exhaust manifold and muffler and remove approximately 5-inches of exhaust line.	Oxyacetylene torch	10
2. Install afterburner in exhaust line and secure with clamps.	a. Hand tools b. Afterburner c. Clamps	20
3. Remove ignition distributor points and replace with a set of dual points.	a. Hand tools b. Dual ignition c. Distributor points	9
4. Install another coil in the engine compartment.	a. Ignition coil b. Electric drill c. Clamp d. Sheet metal screws	15
5. Connect wires from extra set of distributor points to extra coil to afterburner.	a. Hand tools b. Wire	6
6. Tuneup engine.	Engine analyzer	15
	Total Time	1.15 hr

3.3.1.8 Initial and Recurring Costs

The developer estimates that the device would cost $35. Table 3-34 summarizes the installation costs for this device. From the information available, it is estimated that the cost for installing this device, including material, would be $70.62.

3.3.1.9 Feasibility Summary

The test and design information provided by the developer indicate that this device is not technically feasible with respect to emission reduction effectiveness. The emission data provided indicate that the device does not implement the exhaust afterburner principles of operation with respect to CO and HC oxidation. No significant exhaust pollutant decrease is indicated in the data supplied by the developer.

Table 3-34. DEVICE 308 EXHAUST GAS AFTERBURNER INITIAL AND RECURRING COSTS

ITEM	DESCRIPTION	LABOR HOURS OR ITEM QUANTITY	COST (DOLLARS)
Initial Cost:			
Material			
1. Device	Afterburner (with spark plug)		35.00
2. Miscellaneous	a. Clamps b. Dual ignition points c. Ignition coil d. Sheet metal screws e. Electric wire		20.00
Labor			
1. Installation	Table 3-33	1.00 hr	12.50
2. Test and adjust	Table 3-33	0.25 hr	3.12
		Total Initial Cost	70.62
50,000-Mile Recurring Cost:			
Labor			
1. Inspections	a. Spark plug gap and ignition lead b. Afterburner chamber c. Break points	0.5 hr/12,000 miles	25.00
2. Install		0.3 hr/12,000 miles	15.00
Material			
1. Breaker points	One-half of a dual set	$2.50/12,000 miles	10.00
		Total Recurring Cost	50.00
		TOTAL COSTS	120.62

3.3.2 Device 425: Exhaust Gas Afterburner

Device 425 represents a system approach to the afterburner concept for controlling vehicle exhaust emissions. The afterburner creates and sustains a thermal reaction environment for the oxidation of CO and HC to carbon dioxide and water, by combustion within the chamber. Lower air-fuel ratio is required to support the combustion process in the afterburner and this richer air-fuel mixture inhibits NOx formation during the engine combustion cycle.

This system has been under development since 1968. Five prototype models have been developed, and one of these models (covered by U.S. Patent No. 3,601,982) has been selected for production (refer to developer's data survey questionnaire response, Volume V, Appendix V-3).

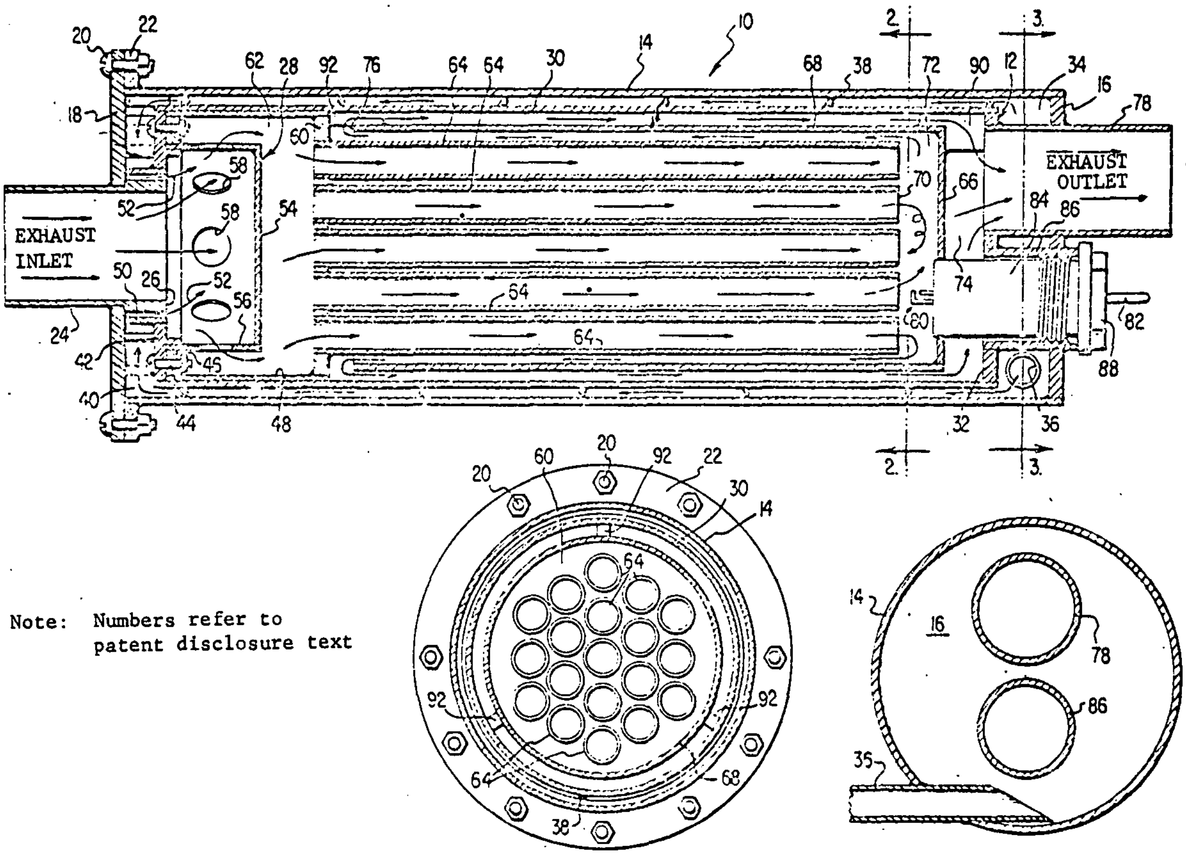
3.3.2.1 Physical Description

Device 425 consists of a combination acoustic muffler and afterburner, an air pump, and an electronic controller to meter air flow and ignite the afterburner. Figure 3-29 shows a cross-sectional view of the afterburner unit. The afterburner unit is 6 inches in diameter and 24 inches long. It incorporates a special spark plug to initiate the combustion process. It is installed in place of the muffler. Because of the heat generated, the unit is heavily insulated, and a finned tailpipe is used. The air pump is of the same type now utilized to inject air into the exhaust manifold on many late model cars. A special carburetor may be required to obtain the desired low air-fuel ratio.

3.3.2.2 Functional Description

Device 425 operates on the principle of burning excess HC and CO in the exhaust gas after it is exhausted from the engine. Nitrogen oxides are controlled by utilizing a rich air-to-fuel mixture. The following description of the device was provided by the developer:

> ". . . The device is designed as concentric inner and outer housings of a combined acoustical muffler and afterburner. A wire, filling the approximate one-eighth of an inch of space between the inner and outer housings is spiraled around the inner housing to lengthen the passageway for incoming fresh air so as to maximize the heat transfer between the hot combuster wall and the incoming fresh air. Fresh air enters the rear end of the device and is forced around and between the inner and outer housings. At the front end of the device the fresh air is mixed with the exhaust of the engine consisting of carbon monoxide, hydrocarbons and nitrous oxides. This mixture which is at an initial temperature of about 400 degrees Fahrenheit, then enters tubings which carry the mixture to the rear of the unit. At this point the mixture is ignited and quickly reaches a combustion temperature of about 1,350 degrees Fahrenheit. The now burning mixture returns to the front end of the unit and then is channeled to the outer edge of



Note: Numbers refer to patent disclosure text

Figure 3-29. DEVICE 425 EXHAUST GAS AFTERBURNER
(U.S. PATENT NO. 3,601,982)

the tube bank where it is transversed to the exhaust end of the unit. Thus, the mixture of chemicals and fresh air are burning during three passes from the entrance of the exhaust manifold to the exhaust end of the unit. Burning is attained by creating a stoichiometric mixture of chemicals and fresh air. A small, inexpensive electronic controller adjusts the amount of fresh air so that the right amount is introduced based on the RPM of the engine which creates a finite volume of exhaust. The fresh air, as stated, enters the unit at the rear and while transversing the spiraled wall, tends to cool the outer housing and is pre-heated to avoid a quenching effect when the fresh air is mixed with the exhaust.

In order for thermal reactors to burn 100% of the burnable pollutants, enough pollutants must be available to quickly catch on fire and maintain a burnable temperature. Six percent or more of carbon monoxide will burn in a chain reaction. Less than six percent must have enough heat to burn each individual module. This effectiveness cannot be attained with the lean carburetors now being installed on vehicles. An air/fuel ratio of approximately 11.5/1 is desired. However, this rich mixture tends to greatly reduce the creation of nitrous oxides which are more toxic to the human body than is carbon monoxide. Nitrous oxides cannot be removed by burning. . ."

3.3.2.3 Performance Characteristics

Table 3-35 presents the emission test results reported by the developer for Device 425. In tests performed by the Ethyl Corporation (Reference 19) with the device installed on the same vehicle; average emissions of 16.5 ppm HC, 0.24 percent CO, and 131 ppm NOx were obtained for four hot cycles under the 1968 Federal Test Procedure (Reference 14).

Table 3-35. DEVICE 425 EXHAUST GAS AFTERBURNER EMISSION TEST RESULTS REPORTED BY DEVELOPER (1)

TEST CONDITION	POLLUTANT	
	HC(PPM)	CO(PERCENT)
Without Device	500.29	9.37
With Device	17.18	0.26
Percent Reduction	97	97

(1) Results reported by developer for one cycle of the 1968 Federal Test Procedure with and without the device installed on a 1969 Chevrolet 6-cylinder, manual transmission vehicle equipped with a General Motors certified air pump and a special Rochester carburetor with 11.5:1 air-fuel ratio (refer to Device 425 data questionnaire response, Volume V, Appendix 3). Tests performed by a department store Diagnostic Center, Seven Corners, Virginia.

3.3.2.4 Reliability

Device 425 should meet a 50,000-mile MMBTF life standard, provided that the production design incorporates suitable components and materials, and that the device is maintained satisfactorily throughout its service life. The system components affecting the reliability of Device 425 consist of the air-injection pump, the electronic control unit, and the combustion chamber with spark plug ignition device. The developer noted that the air pump could be the standard automotive belt-driven pump now used on many vehicles. Assuming proper maintenance, including that pertaining to filtration of input air, pump reliability should exceed 50,000 mean-miles-before-total-failure. This estimate is applicable to pumps having rotary blowers with graphite sealing vanes and sealed bearings.

The developer did not define the electronic control unit (ECU) sufficiently for reliability evaluation; however, it can be deduced that it performs at least the following functions:

a. Provides a high voltage pulse to the spark plug ignition device. (1)

b. Provides airflow volume control.

c. Provides an indication to the motorist that the system is or is not functioning.

It is anticipated that an ECU which can provide the required functions can be developed and manufactured with a reliability in excess of 50,000 mean miles before failure.

The specific type of special spark plug which would be used was not identified; it is assumed that it would be replaced during routine vehicle maintenance to preclude failure so as not to jeopardize the 50,000-mile system service life. In the recurring cost estimation of Table 3-37, it was assumed the spark plug would be replaced once at 25,000 miles.

Operating in a temperature range of 1,350-1,500F, with low air-fuel ratio, Device 425 is analogous to a rich thermal reactor. Therefore, the corrosive effects of high temperature and rich fuel mixture may be a consideration in the material composition of the device. As discussed in paragraph 3.2.1, test data obtained so far on the effect of fuel and temperature on reactor materials indicate that leaded fuels have a significant corrosive effect on reactor metals at temperatures over 1,700°F. Since Device 425 is reported by the developer to operate in the 1,350°-1,500°F range, corrosion due to leaded fuel should not be a problem if suitable materials are used in the construction of the device.

With regard to the material composition of the afterburner, the developer stated:

> "The Thermal Reactor operates at very high internal temperatures. Accordingly, it must be constructed out of metals which will not be affected by the internal heat. In addition, the metals should not be affected by lead deposits or other chemical reaction. A special steel was selected which the manufacturer guarantees will withstand up to 3,000°F for a minimum of 3,000 hours of operation."

(1) The ECU should either provide continuous spark pulses or provide for automatic restart after flameout. The safety implications of this are discussed in paragraph 3.3.2.6.

3.3.2.5 Maintainability

According to the developer, the only item which would normally require servicing is the special spark plug which is used to initially light off the exhaust gas. The developer estimated that the spark plug will retail for about $2.00. It is assumed it would be inspected at 12,000-mile intervals and replaced at 25,000 miles.

Three other maintenance requirements are assumed:

a. Maintenance of the air pump filter in accordance with the manufacturer's requirements (assumed to be every 12,000 miles).

b. Calibration inspection of the thermocouple temperature sensor at 25,000 miles. It is assumed that the afterburner could be designed to facilitate such maintenance.

c. Calibration inspection of the ECU at 25,000 miles.

3.3.2.6 Driveability and Safety

Device 425 was not tested as part of the retrofit study program; however, the developer reported that the number of hours the device has been tested exceeds 50,000 miles, and that there have been no troubles in operating a vehicle with the device installed under all weather and road conditions in which a vehicle might normally be operated. On several long road tests the test vehicle used 10-15 percent more fuel when equipped with the special 11.5:1 air-fuel ratio carburetor used with the device. This increase in fuel consumption would affect recurring costs as discussed in paragraph 3.3.2.8. No special type of fuel is required.

Although insufficient design information was available for a comprehensive safety review, three potential safety hazards appear to exist:

a. In the event of afterburner flameout and the absence of a continuous ignition spark or automatic restart capability, uncontrolled reignition could occur with explosive force.

b. In the event of afterburner internal failure or severe restriction of the exhaust gas flow, substantial or complete loss of power could occur.

c. Afterburner accidental puncture or burnthrough could result in a vehicle fire or venting of toxic fumes.

These are considered safety hazards for which preventive measures would have to be incorporated in the production design of the device, particularly through the ECU. The developer notes that a warning light could be installed on the vehicle instrument panel to indicate when the afterburner is malfunctioning.

As noted in Table 3-37, this increase in fuel consumption would be expected to increase recurring costs. To offset this cost, the developer proposes to include, as part of the retrofit kit, a special generator which would operate off of the afterburner heat. However, even if this were feasible, it would add to the device's complication and initial cost.

3.3.2.7 Installation Description

Device 425 installation consists in replacing the presently installed muffler and tailpipe with the afterburner unit, mounting an air pump in the engine compartment with power takeoff from the engine, mounting the ECU in the engine compartment and connecting a high voltage coil in the engine compartment, installing the malfunction warning system, and connecting the air hose, electrical wires, and drive belt. Adjustment of the engine consists in setting the air-fuel ratio at 11.5:1. (1)

Table 3-36 itemizes the installation procedure and the tools and special equipment required. Installation can be accomplished in a normally equipped automotive repair shop by the average mechanic.

3.3.2.8 Initial and Recurring Costs

Table 3-37 summarizes the estimated initial purchase and installation costs for this device. From the information available, it is estimated that the cost for installing this device, including material, would be $158.74. (1) Added to this would be recurring costs of $168.88 over 50,000 miles of operation. Approximately 80 percent of the recurring costs are attributable to increased fuel consumption.

3.3.2.9 Feasibility Summary

Device 425 indicates emission reduction effectiveness as tested by department store diagnostic center for the control of CO and HC exhaust emissions. Although NOx emissions with and without the device installed were not reported by the developer, the 131-ppm NOx average reported for four 7-mode test hot cycles (refer to paragraph 3.3.2.3) with the device installed is significant when compared to a 1967-vehicle fleet average of approximately 1,000-ppm NOx obtained in the EPA Short-Test-Cycle Effectiveness Study (Reference 17).

Though technically feasible, the device may be economically infeasible for retrofit applications to uncontrolled used cars, because of its high initial and recurring costs. If applied only to vehicles already equipped with air injection, the initial costs could be reduced by the amount of the air pump ($85). Since air injection systems may operate at air-fuel ratios of 12:1 (Reference 25), the carburetors associated with them may be compatible for use with the device. A key question, however, in converting an air injection system vehicle for use of Device 425 is whether the device is significantly more effective in reducing emissions than the air injection system.

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(1) For the installation described in this report, it is assumed that use of a replacement carburetor to provide 11.5:1 air-fuel ratio would not be required. This assumption influences initial costs of the device, as noted in Table 3-37 and paragraph 3.3.2.9.

Table 3-36. DEVICE 425 EXHAUST GAS AFTERBURNER INSTALLATION PROCEDURE

MINIMUM AVERAGE SKILL LEVEL: AUTOMOTIVE MECHANIC		
INSTALLATION AND ADJUSTMENT PROCEDURE	TOOLS, EQUIPMENT AND FACILITIES	TIME (MIN.)
1. Remove muffler and tail pipe	a. Hand tools b. Car lift	15
2. Install afterburner	a. Hand tools b. Afterburner unit c. Clamps	15
3. Attach bracket for air pump in the engine compartment	a. Hand tools b. Bracket	5
4. Mount air pump on bracket	a. Hand tools b. Air pump	5
5. Attach drive belt from engine crank-shaft pulley to air pump	Drive belt	5
6. Mount electronic control box in engine compartment	a. Hand tools b. Electronix control box	8
7. Connect air hose from air pump to control box to afterburner	a. Air hose b. Clamps	7
8. Mount high voltage coil in engine compartment	a. Hand tools b. High voltage coil	8
9. Connect wires from spark plug in afterburner to coil to control box	a. Hand tools b. Wire	7
10. Adjust air-fuel ratio to 11.5:1	Exhaust analyzer	15
	Total Time	1.50 hr

On post-1967 vehicles incorporating engine modifications for exhaust emission control, the existing carburetor would require modification or replacement to provide the rich fuel mixture desired for device operation. Carburetors on these vehicles typically operate in the 13.5:1 to 14.5:1 air-fuel ratio range (Reference 25). In addition to the carburetor modification or replacement associated with device use on these cars, an air pump would be required. Device initial costs for these cars might be in the range of $180-200.

Table 3-37. DEVICE 425 EXHAUST GAS AFTERBURNER INITIAL AND RECURRING COSTS

ITEM	DESCRIPTION	LABOR HOURS OR ITEM QUANTITY	COST (DOLLARS)
Initial Cost:			
Material			
1. Device	a. Air pump b. Afterburner unit c. Electronic control d. Malfunction warning system		125.00
2. Miscellaneous	a. High voltage coil b. Air hose and clamps c. Clamps for exhaust pipe d. Drive belt e. Wire		15.00
Labor			
1. Installation	Table 3-36	1.25 hr	15.62
2. Test and adjust	Table 3-36	0.25 hr	3.12
		Total Initial Cost	$158.74 (1)
50,000-Mile Recurring Cost:			
Material:			
1. Spark plug	Replace at 25,000 miles	2.00	2.00
2. Fuel	As specified by vehicle manufacturer	$0.35 per gallon x 10 percent fuel increase (400 gallons) for 50,000 miles	140.00
Labor:			
1. Spark plug	a. Inspect	0.1 hr/12,000 miles x 4 inspections	5.00
	b. One replacement	0.25 hr/25,000 miles	3.13
2. Air pump filter	Clean	0.25 hr/12,000 miles x 4 inspections	12.50
3. Thermocouple and ECU	Inspect and calibrate	0.5 hr/25,000 miles	6.25
		Total Recurring Cost	$ 168.88
		TOTAL COSTS	$ 327.62

(1) $20-$40 more if replacement carburetor is required.

On pre-1968 vehicles, the carburetor would generally be compatible for richer air-fuel mixture adjustment; however, these carburetors may not be compatible for an air-fuel ratio of 11.5:1. The developer of Device 425 found it necessary to install a special carburetor on his 1967 Chevrolet to obtain this air-fuel ratio.

The developer noted that the vehicle owner would be saved the cost of muffler replacement by use of Device 425. This assumption may be valid for single-muffler exhaust systems and, if so, could offset the cost of carburetor changes. For dual-muffler systems, however, the cost of exhaust pipe rerouting might offset any muffler savings.

In addition to these initial cost considerations, the device appears to have inherently higher recurring costs, due to an increase in fuel consumption.

Based on the cost considerations associated with Device 425, it would appear that its emission reduction capability as a retrofit device would be applied principally to those emission control situations (such as those associated with high vehicle population densities in metropolitan areas) in which cost considerations are of second order importance to the need for emission reduction.

3.4 EXHAUST GAS FILTER - RETROFIT SUBTYPE 1.1.4

The exhaust gas filter emission control device is designed to operate on the principle of trapping particulate matter in the exhaust gas to prevent such matter from being emitted into the atmosphere. The retrofit study indicated that the use of exhaust gas filters for emission control is a relatively uncommon approach to vehicle emission control. The Clean Air Act of 1970 set no specific limits on vehicle particulate emissions. Particulates in gasoline-fueled motor vehicles exhaust gas include iron, lead, and carbon compounds. Since average particle sizes may range from 0.1 to 1.0 micron (for some lead compounds), the removal of exhaust particles by filtering is difficult (Reference 20). As noted in Reference 20, there is little data available on the amount and nature of particulate emission from cars.

3.4.1 Device 164: Exhaust Gas Filter

This device, based on the information provided by the developer, appears to combine exhaust gas filtering with acoustical resonance to remove particulates from suspension in the exhaust gas. The device is in the prototype stage, with three units having been built to date. Only limited information about the device was obtainable from the developer, so a complete evaluation was not possible.

3.4.1.1 Physical Description

Device 164 appears to consist of a "muffler filter" and a "resonator filter" that may be combined in sequential and/or parallel hookups, in place of the conventional muffler system. The basic elements of the device are shown in Figure 3-30.

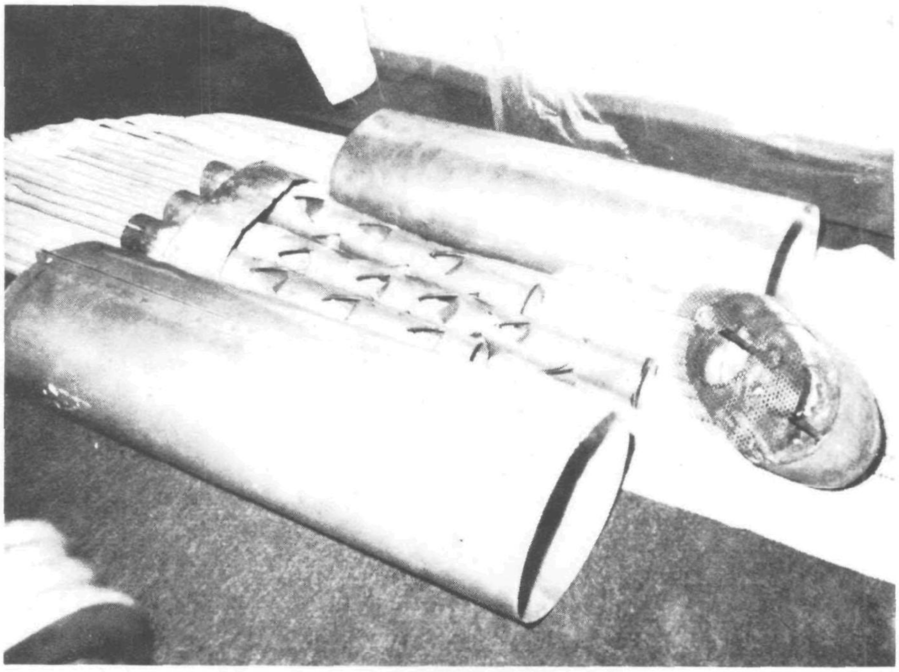


Figure 3-30. DEVICE 164 EXHAUST GAS FILTER COMPONENTS (DEVELOPER PHOTOGRAPH)

3.4.1.2 Functional Description

Device 164 is intended to replace the standard exhaust muffler with a combination muffler-filter unit and resonator.

Figure 3-31 shows a functional schematic of the device, in which two of the muffler filter units are connected in series and parallel to a downstream resonator. Under this arrangement, exhaust gas could flow through the No. 1 or the No. 2 muffler but all gas going through the No. 1 muffler eventually exits through the No. 2 muffler. The mechanics of the filtering and resonating functions are not known.

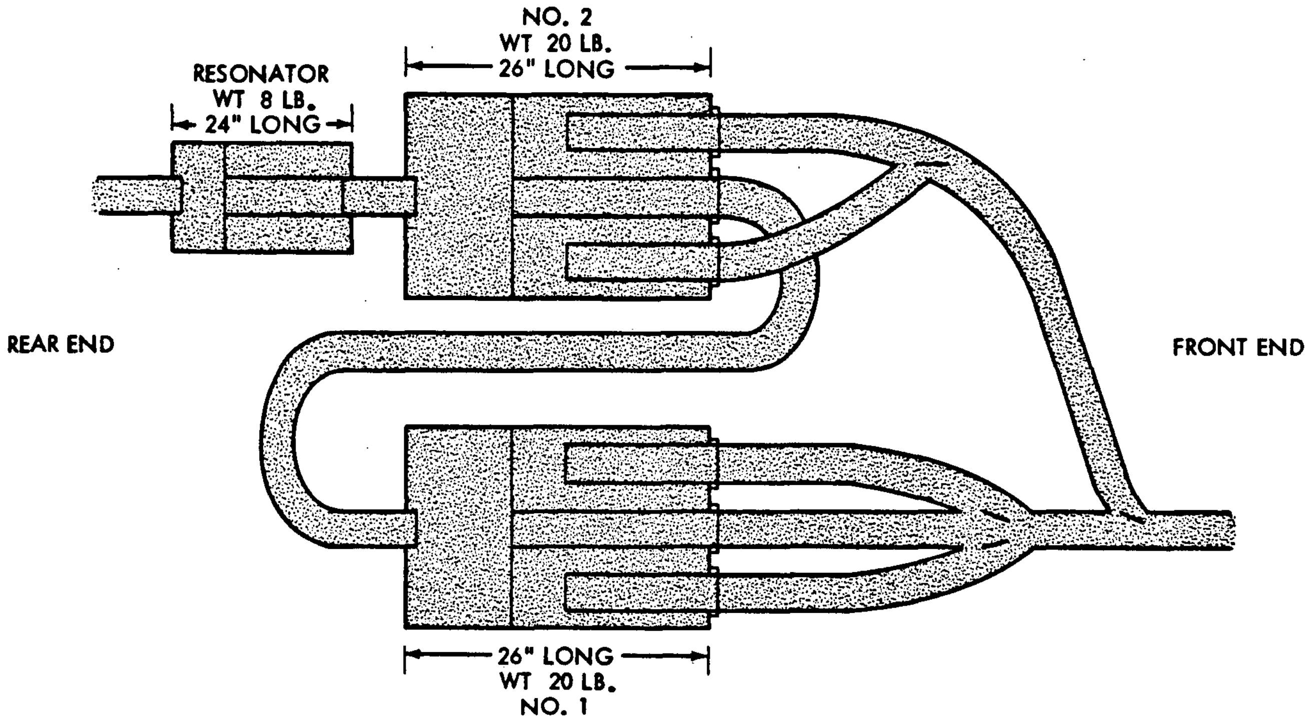


Figure 3-31. DEVICE 164 EXHAUST GAS FILTER FUNCTIONAL SCHEMATIC

According to test reports of the Ethyl Corporation (Reference 21), Device 164 was tested in three different configurations:

a. Two parallel exhaust pipes connected to one muffler filter unit and a second filter unit in series.

b. A single exhaust pipe with two muffler-filter units and a resonator in series, with two reverse bends in the piping arrangement.

c. Three branched exhaust pipes into one muffler-filter unit, a reverse bend pipe to a second muffler filter, and a pipe to a third muffler-filter.

The function of these configurations was not described.

3.4.1.3 Performance Characteristics

Table 3-38 shows the emission test results obtained by the developer with and without Device 164 installed on a test vehicle.

Table 3-38. DEVICE 164 EXHAUST GAS FILTER EMISSION TEST RESULTS REPORTED BY THE DEVELOPER (REFERENCE 21) (1)

TEST CONDITION (2)	POLLUTANT		
	HC (PPM)	CO (PERCENT)	NOx (PPM)
Without Device	148.5	1.31	983.5
With Device	133.5	1.28	982.5
Percent Reduction	10.0	2.0	0.1

(1) Average exhaust emissions measured during 7-mode, 7-cycle test of a 1970 Oldsmobile 88 with 455-cubic-inch displacement engine.

(2) One test for each condition.

It is not known what configuration of the device was tested to obtain the Table 3-38 results. In tests of the first two configurations listed in paragraph 3.4.1.2 suspended particulates were measured, using the Ethyl Black Bag Procedure, during four hot-start 7-mode cycles. With Configuration No. 1, total suspended particulates were 0.034 gm/mi. With Configuration 2, total suspended particulates were 0.028 gm/mi (Reference 21).

3.4.1.4 Reliability

Device 164 appears to have no moving parts, but to be of rigid structural construction. The developer reported that 28,000 miles have been accumulated on a vehicle with the device installed. It would appear that the device, in a production configuration, should have a service life equal to that of a standard muffler.

3.4.1.5 Maintainability

If the device traps particulate matter, some form of maintenance would be anticipated so as to remove the material accumulated over a period of time. It is assumed that at least once every 25,000 miles, the muffler-filter units would be inspected and cleaned. Assuming an average of two units per installation, about 0.5 hour would be required to accomplish this maintenance if suitable filter access provisions are designed into the device.

3.4.1.6 Driveability and Safety

The developer reported that the driveability characteristics of the device are normal. Backpressure tests reported by the Ethyl Corporation on Configuration No. 2 of the device indicated backpressure of 26 inches mercury at the inlet of the first muffler-filter unit, with the car accelerating at approximately 4-inch-mercury intake manifold vacuum in high gear at 70 mph (Reference 21). Higher exhaust backpressure could lower the volumetric efficiency of the engine and cause a decrease in horsepower, with consequent increase in fuel consumption (Reference 24, Chapter 14).

3.4.1.7 Installation Description

The installation of the device consists in replacing the presently installed exhaust system with the muffler-filter system. No adjustments to the device or engine are required after installation is complete. Installation of this device should take about one hour. Table 3-39 itemizes the installation procedure and the tools and special equipment required. Installation could be performed in a normally equipped automotive repair or muffler shop by the average mechanic or muffler installer.

Table 3-39. DEVICE 164 EXHAUST GAS FILTER INSTALLATION PROCEDURE

MINIMUM AVERAGE SKILL LEVEL: AUTOMOTIVE MECHANIC		
INSTALLATION AND ADJUSTMENT PROCEDURE	TOOLS, EQUIPMENT AND FACILITIES	TIME (MIN.)
1. Disconnect the exhaust line from the exhaust manifold.	a. Hand Tools b. Car Lift Rack	10
2. Remove and discard the presently installed exhaust line.	Oxyacetylene Torch	20
3. Install the exhaust filtering system.	a. Hand Tools b. Tube Clamps c. Exhaust Filter System	20
4. Insure that the new system mechanically fits in place and does not cause any interference. 5. Check exhaust system for backpressure leaks.		10
	Total Time	1 hr

3.4.1.8 Initial and Recurring Cost

Table 3-40 summarizes the costs for this device. From the information available, the cost of purchasing and installing this device, including material was estimated to be $102.50. The cost of cleaning the muffler-filters at 25,000 miles is the assumed recurring cost.

3.4.1.9 Feasibility Summary

This device is considered infeasible for use as a retrofit method for the control of light-duty vehicle exhaust emissions of CO, HC, or NO_x. For the low level of emission reduction effectiveness indicated by the device test data, the initial cost and the implied recurring cost would not provide a sufficient return for the investment.

The effectiveness of the device for controlling particulate matter could not be evaluated as part of this study, because of the lack of particulate emission data for the vehicle without the device installed.

Table 3-40. DEVICE 164 EXHAUST GAS FILTER INITIAL AND RECURRING COSTS

ITEM	DESCRIPTION	LABOR HOURS OR ITEM QUANTITY	COST (DOLLARS)
Initial Cost:			
Material			
1. Device	Exhaust Filtering System		85.00
2. Miscellaneous	Welding Rod and Muffler Brackets		5.00
Labor			
1. Installation	Table 3-39	1 hr	12.50
		Total Initial Cost	102.50
50,000-Mile Recurring Cost:			
Material			
1. Fuel	Possible increase in fuel consumption due to high exhaust backpressure	Fuel consumption data not available	Unknown
Labor			
1. Inspection	Inspect and Clean muffler-filter unit	0.5 hr/25,000 miles	6.25
		Total Recurring Cost	6.25
		TOTAL COSTS	108.75

3.5 EXHAUST GAS BACKPRESSURE CONTROL - RETROFIT SUBTYPE 1.1.5

This retrofit method category was established to cover one device which approaches the reduction of exhaust emissions by control of the backpressure of gas in the exhaust system. Several studies have been performed on the backpressure associated with thermal reactors and catalytic converters and the consequent horsepower required in an air pump to inject secondary air (Reference 2). Testing of Device 322 was performed by EPA to evaluate the relationship between exhaust backpressure and emissions; and to evaluate Device 322 as a retrofit emission control for used vehicles (Reference 22).

3.5.1 Device 322: Exhaust Gas Backpressure Valve

The developer of this device did not respond to the retrofit data survey; however, some information was obtained from an EPA test report (Reference 22).

3.5.1.1 Physical Description

This device consists of a spring-controlled flapper valve that attaches to the end of the exhaust pipe with the flapper hinge side up.

3.5.1.2 Functional Description

The flapper valve is normally held shut against the end of the tail pipe by pressure of the hinge spring. When the engine is operating, the exhaust gas pressure pushes the flapper valve open. The spring controlling the valve can be adjusted to vary the amount of pressure the exhaust tail pipe gas has to apply to open the valve.

3.5.1.3 Performance Characteristics

Table 3-41 shows the emission test results obtained by EPA in tests of the device installed on the exhaust pipe of a 1963 Ford Galaxie.

Table 3-41. DEVICE 322 EXHAUST GAS BACKPRESSURE VALVE EMISSION TEST RESULTS (REFERENCE 22) (1)

TEST CONDITION (2)	POLLUTANT (GM/MI)		
	HC	CO	NOx
Without Device	4.01	53.85	1.62
With Device	6.87	50.16	1.83
Percent Reduction	-71.3	6.9	-13.0

(1) Results obtained by EPA with device installed on a 1963 Ford Galaxie with 289-cubic-inch-displacement engine and automatic transmission, using the 1970 Federal Test Procedure (Reference 15).

(2) One test for each condition.

3.5.1.4 Feasibility Summary

Data were insufficient for a complete evaluation of Device 322 for driveability and safety, reliability, maintainability, installation procedure, and costs. Evaluation of these device characteristics is not considered to be justified for the present configuration, because of its questionable emission reduction effectiveness. The following conclusions are quoted from the Reference 22 EPA report:

> "Because of the increase of unburned hydrocarbons during the cold cycle and the lack of any meaningful reduction in both CO and NO, it appears that Device 322 has no beneficial effect on emissions."

The emission results obtained for Device 322 may not conclusively demonstrate that exhaust backpressure cannot be used to decrease exhaust emissions. Correlation of a range of backpressures with corresponding exhaust emissions should be accomplished to establish a more complete understanding of the interaction between exhaust backpressure and emissions.

SECTION 4

GROUP 1 RETROFIT METHOD DESCRIPTIONS: TYPE 1.2 - INDUCTION CONTROL SYSTEMS

This group of retrofit methods approaches the problem of vehicle exhaust emission control from the mixture induction side of the engine. Whereas the exhaust gas control devices described previously attempt to control the pollutant byproducts of combustion, the induction controls try to prevent the formation of exhaust pollutants. This is done in several ways: by promoting more complete fuel combustion, by inhibiting pollutant formation, or by oxidizing the pollutants as they form in the combustion chamber.

The oxidation process operates basically on the same principle as that for thermal reaction downstream in the exhaust system. CO and HC are oxidized in the presence of excess air under oxidation temperatures. The excess air for this reaction is obtained by operating the engine on a high air-fuel ratio. The high air-fuel ratio in effect can maintain a post-combustion reaction in the cylinder and exhaust ports like that described previously for the thermal reactors. In some cases, exhaust reaction temperature is augmented by retarding the ignition spark. The combination of high air-fuel ratio and spark retard, in reducing peak combustion flame temperature, also can inhibit NOx formation, as discussed in the next section on ignition control devices.

The inhibition of pollutant formation by induction control is directed mainly at NOx. Exhaust gas recirculation, water injection, and valve overlap are basic induction modifications that can reduce NOx. All these methods inhibit NOx formation by reducing the peak flame temperature of combustion.

The third approach to exhaust emission control reflected by the induction modification retrofit group is to provide more complete vaporization and mixing of the air-fuel mixture. The techniques used in this approach vary from carburetor redesign to use of mixing devices and superchargers. The basic objective is to reduce the pollutant byproducts of combustion by improving combustion efficiency.

Table 4-1 lists the 21 induction modification type devices studied. Of these, the first 12, comprising Subtype 1.2.1, operate on the principle of high air-fuel ratio, primarily to oxidize CO and HC. Subtype 1.2.2 operates on the principle of exhaust gas recirculation, inhibiting NOx formation. The remaining subtypes approach improved air-fuel vaporization and mixing through the various means indicated by the device nomenclature.

As with the exhaust gas control group described previously, some of the induction control systems are used in combination with vacuum advance disconnect (of the ignition control group) to provide reduction of all three pollutants. Two combination systems use exhaust gas recirculation with vacuum advance disconnect as a twofold approach to NOx reduction.

Table 4-1. TYPE 1.2 INDUCTION CONTROL SYSTEM RETROFIT DEVICES

DEVICE NO.	NOMENCLATURE
AIR BLEED TO INTAKE MANIFOLD - SUBTYPE 1.2.1	
1(1)(2)	Air Bleed to Intake Manifold
42(2)	Air Bleed to Intake Manifold
57	Air Bleed with Exhaust Gas Recirculation and Vacuum Advance
325	Air-Vapor Bleed to Intake Manifold
401	Air-Vapor Bleed to Intake Manifold
418(1)	Air Bleed to Intake Manifold
433	Air-Vapor Bleed to Intake Manifold
458(1)	Air Bleed to Intake Manifold
462(1)	Air Bleed to Intake and Exhaust Manifolds
EXHAUST GAS RECIRCULATION - SUBTYPE 1.2.2	
10(2)	Throttle-Controlled Exhaust Gas Recirculation with Vacuum Advance Disconnect
245(1)(2)	Variable Camshaft Timing
246(1)(2)	Speed-Controlled Exhaust Gas Recirculation with Vacuum Advance Disconnect
294(1)	Exhaust Gas Recirculation with Carburetor Modification
INTAKE MANIFOLD MODIFICATION - SUBTYPE 1.2.3	
172(1)	Intake Manifold Modification
384	Air-Fuel Mixture Diffuser
430	Induction Modification
440	Air-Fuel Mixture Deflection Plate
CARBURETOR MODIFICATION - SUBTYPE 1.2.4	
33	Carburetor Modification, Main Jet Differential Pressure
56	Crankcase Blowby and Idle Air Bleed Modification
288(2)	Carburetor Main Discharge Nozzle Modification
295(2)	Carburetor with Variable Venturi
317	Carburetor Modification with Vacuum Advance Disconnect
TURBOCHARGED ENGINE - SUBTYPE 1.2.5	
100(1)	Turbocharger
FUEL INJECTION - SUBTYPE 1.2.6	
22(1)	Electronic Fuel Injection

(1) Previously tested by EPA.
(2) Tested in retrofit program.

4.1 AIR BLEED TO INTAKE MANIFOLD (RETROFIT SUBTYPE 1.2.1)

Within the induction control systems group of retrofit devices, there were nine devices which operate on the principle of bleeding air into the intake manifold to lean the air-fuel mixture. As shown in Figure 2-1a (Section 2), with increasing air-to-fuel ratio, CO decreases to a very low level. HC also decreases, though not so significantly, and beyond some air-fuel ratio, increases again. Beyond an air-fuel ratio slightly higher than stoichiometric, NOx begins to decrease. However, by referring to Figure 2-1b, it can be seen that this reduction of NOx has an adverse effect on engine power. With light duty gasoline-fueled engines, the high air-fuel ratios at which NOx could be decreased are not achievable without degradating engine performance to the point where the vehicle is practically undriveable. Thus air bleed devices are mainly effective in decreasing CO, with moderate decrease of HC.

Leaning of the air-fuel mixture is used widely on new model-year vehicles. This is accomplished by lean idle adjustment and leaning the carburetor main circuit. An air bleed device can provide leaning of the mixture through a variable orifice or fixed orifice valve which is operated by intake manifold vacuum. This approach is common to the air bleed devices evaluated in the retrofit program.

4.1.1 Device 1: Air Bleed to Intake Manifold

Device 1 was one of two representative air bleed devices tested in the retrofit study program (also see Device 42). This device is basically an air valve that enables the air-fuel ratio to be increased by metering air to the intake manifold in accordance with intake manifold vacuum. The device is continuously operative at moderate through high intake manifold vacuums. The device is currently marketed in production quantities.

4.1.1.1 Physical Description

Device 1 consists of a 3- by 8-inch cylinder incorporating an oil-damped air valve, an intake adapter plate, and an air bleed hose. The adapter plate configuration varies according to the carburetor and intake manifold interface requirements. The air-valve cylinder mounts in the engine compartment, and the adapter plate installs between the existing carburetor and the intake manifold. The hose connects the air valve to the intake adapter plate.

Figure 4-1 shows the air valve cylinder and two adapter plate models. The cylinder contains a valve which is adjustable by means of a threaded collar. The adjustment collar, spring and valve shaft are housed in a reservoir of oil to dampen valve oscillation under rapid changes in intake manifold vacuum. The cylinder is mounted on a surface away from the motor, and because of the oil reservoir, must be mounted in a vertical position.

An air filter, which must be cleaned or replaced at specified intervals, is integral with the air-valve cylinder.

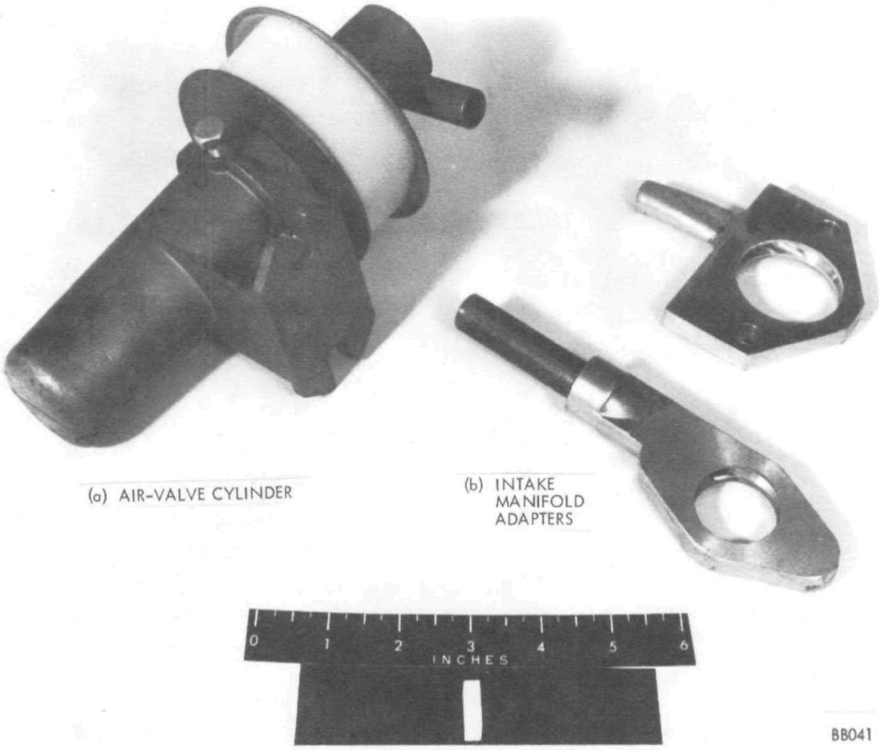


Figure 4-1. DEVICE 1 AIR BLEED COMPONENTS

4.1.1.2 Functional Description

Device 1 operates on the principle of bleeding air into the intake manifold in proportion to the manifold vacuum to increase air-fuel ratio. The additional air oxidizes CO and HC more completely during the combustion process. When manifold vacuum is high, such as at idle and on deceleration, CO and HC pollutants are high and device air bleed is maximum. The device provides additional air supply during these drive modes, so that the CO and (to a lesser extent) the HC can be oxidized to carbon dioxide and water.

Figure 4-2 shows a schematic diagram of the device. The engine vacuum sensed through the air hose opens a valve in the cylinder and allows controlled amounts of filtered air into the intake manifold. This air mixes with the air-fuel mixture from the carburetor to increase the ratio of air to fuel. The adapter plate has a circular channel to promote a vortex for mixing the new air with the existing air-fuel mixture. The air valve is adjusted by the threaded collar. Adjustment is maintained by the collar locknut. Vibration and rapid movement of the valve is dampened by the oil in the reservoir surrounding the adjustment collar.

To offset the effect of the air bleed at idle, the idle air-fuel mixture and speed may have to be readjusted to achieve a smooth idle.

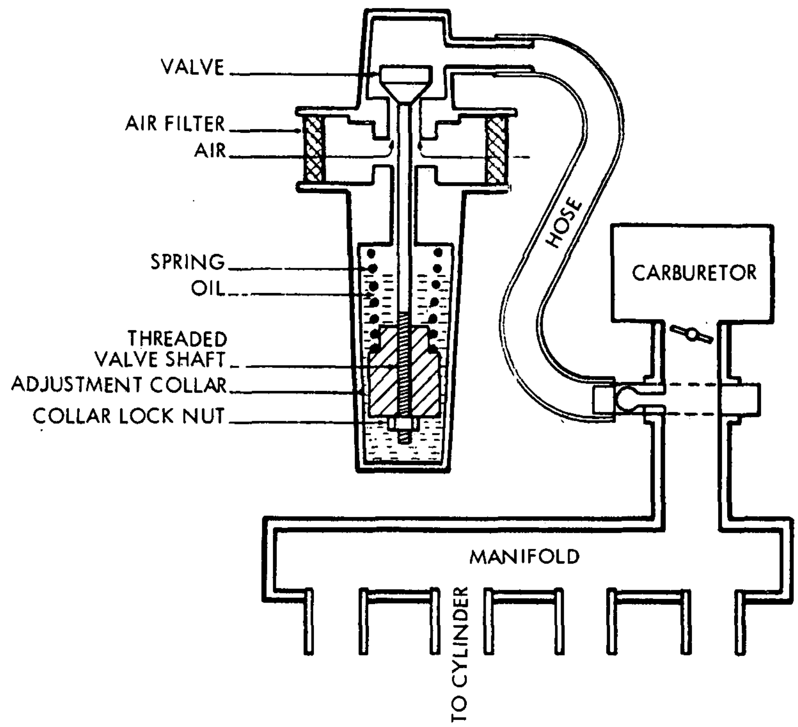


Figure 4-2. DEVICE 1 - FUNCTIONAL SCHEMATIC DIAGRAM

4.1.1.3 Performance Characteristics

Emission test results supplied by the developer in five cars are summarized in Table 4-2. These tests were performed using the 1970 Federal Test Procedure. During the retrofit study, the device was tested 18 times using the 1972 Federal Test Procedure. The results are summarized in Table 4-3.

The developer's data (Table 4-2) indicates the expected high CO reduction (74 percent), with considerably smaller overall reductions of HC and NOx. The results obtained in the retrofit program tests are more representative of the emission reduction effectiveness of this device, because of the greater number of tests. The pooled mean emission reductions shown by these tests are 58 percent for CO and 21 percent for HC. NOx increased by 5 percent.

Device 1 was tested by EPA with similar results. Table 4-4 summarizes the results of these tests.

The EPA test report (Reference 76) concluded that the device is an effective control system for CO, with relatively lesser effect on HC. The increase in NOx was an expected characteristic. This may be attributable to the additional oxygen availability of the leaner fuel mixture. The EPA report noted that this increase in NOx is minimized by the fact that the device cuts off the extra air under high load operation (at which time the intake vacuum drops and the air valve spring seats the valve).

The device was retested by EPA after 2,000 miles were driven on the 1970 Valiant. This test indicated that CO and HC had decreased further.

Table 4-2. DEVICE 1 AIR BLEED TO INTAKE MANIFOLD EMISSION RESULTS REPORTED BY DEVELOPER (1)

VEHICLE YEAR/MAKE/CID	HC (PPM)	CO (%)	NOx (PPM)
1969 Ford 8			
Without Device	173	1.84	995
With Device	183	0.08	920
Percent Reduction	-6	95	7.6
1968 Ford 8			
Without Device	285	0.74	2,172
With Device	329	0.15	1,927
Percent Reduction	-15	80	11
1968 Ford 6			
Without Device	175	0.67	2,080
With Device	167	0.28	1,936
Percent Reduction	4	60	6.9
1970 Chev 8			
Without Device	97	0.66	542
With Device	79	0.16	573
Percent Reduction	19	75	-6
1966 Fiat 4			
Without Device	392	4.78	750
With Device	216	1.81	367
Percent Reduction	45	62	50

(1) Tests performed for developer by Olson Laboratories as reported in Project 231-1, 20 May 1971, using 1970 Federal Test Procedure (Reference 15).

4.1.1.4 Reliability

The device manufacturer estimated a reliability exceeding 100,000 mean-miles-before-total-failure (MMBTF). Physical examination of the device indicates that 75,000 miles is a realistic minimum MMBTF, based on the construction and small number of moving parts. The oil damping should eliminate most conditions that would subject the parts to stress and wear.

4.1.1.5 Maintainability

The only routine maintenance indicated is changing the air filter and checking the air-fuel ratio. These maintenance actions could be performed at the same time the engine air filter is changed every 12,000 miles. Filter cost is estimated at $2.50.

It is estimated that total maintenance time would take less than 0.3 hour, including inspection and, if necessary, replacement of the O-ring gasket which seals the oil reservoir.

Table 4-3. DEVICE 1 AIR BLEED TO INTAKE MANIFOLD EMISSION REDUCTION AND FUEL CONSUMPTION PERFORMANCE (1)

VEHICLE YEAR/MAKE/CID	ANAHEIM TEST RESULTS				TAYLOR TEST RESULTS			
	POLLUTANT GRAMS/MILE			FUEL MILES/ GALLON	POLLUTANT GRAMS/MILE			FUEL MILES/ GALLON
	HC	CO	NOx		HC	CO	NOx	
1965 Chev 194								
Without Device	15.10	135.37	0.84	14.8				
With Device	12.44	143.93	1.27	11.4				
Percent Reduction	17.7	-6.3	-50.5	23.0				
1965 Ford 289								
Without Device	6.53	73.65	4.45	13.7	5.36 4.15	55.78 57.96	4.53 3.84	11.6 12.6
With Device	4.54	50.53	4.92	13.7	3.16 4.02	5.95 12.80	3.40 4.51	13.7 (2)
Percent Reduction	30.5	31.4	-10.6	0	41.0 3.1	89.3 77.9	24.9 -17.4	-18.1 (2)
1965 Ply 318								
Without Device	6.12	83.70	5.74	10.3	4.94 4.63	69.81 39.88	5.77 5.48	13.0 13.5
With Device	6.62	33.00	4.79	(2)	3.63 4.31	14.44 26.06	4.97 4.13	(2) 16.1
Percent Reduction	-8.2	60.6	16.6	(2)	26.5 6.9	79.3 34.7	13.9 24.8	(2) 19.3
1965 Chev 327								
Without Device	7.06	61.86	3.35	15.4	7.68 5.98	74.87 42.04	6.88 5.10	12.3 14.2
With Device	6.72	33.15	2.86	13.2	9.91 5.81	5.15 11.31	6.90 6.06	15.4 14.2
Percent Reduction	4.8	46.4	14.6	14.3	-29.0 2.8	93.1 73.1	-0.3 -18.8	-25.2 0
1965 Ford 390								
Without Device	8.35	109.86	2.32	11.0	7.36 8.66	99.55 109.96	3.48 3.20	13.0 10.7
With Device	6.61	64.37	2.32	13.2	5.62 4.24	25.86 40.51	4.47 5.04	14.5 13.7
Percent Reduction	20.8	41.4	0	-20.0	23.6 51.0	74.0 63.2	-28.4 -57.5	-12.0 28.0
1961 Chev 283								
Without Device	(2)	72.39	2.92	12.5	8.07 6.45	72.94 56.03	3.34 2.75	15.4 17.3
With Device	5.83	46.29	2.55	14.8	4.36 6.33	36.18 26.55	3.22 3.66	15.7 13.0
Percent Reduction	(2)	36.1	12.7	-18.4	46.0 1.9	50.4 52.6	3.6 -33.1	-2.0 24.4
1965 VW 92								
Without Device	10.81	76.12	1.69	20.0	6.12	37.50	2.18	21.2
With Device	5.79	32.81	1.48	(2)	1.76	5.44	2.03	15.1
Percent Reduction	46.4	56.9	12.4	(2)	71.2	85.5	6.9	29.0

Pooler Mean Percent Reduction (3)	HC 21.0	CO 57.8	NOx -4.8	Fuel -4

(1) Emission results obtained by Olson Laboratories in tests performed under Contract 68-04-0038 using 1972 Federal Test Procedure (Reference 3) Fuel consumption was measured during these tests.

(2) Test data invalid.

(3) Anaheim and Taylor results combined.

Table 4-4. DEVICE 1 EPA EMISSION TEST RESULTS (REFERENCE 76)

VEHICLE CONFIGURATION (1)	POLLUTANT (GM/MI)		
	HC	CO	NOx
Without Device (2)	5.55	80.90	3.9
With Device (3)	4.45	44.95	4.5
Percent Reduction	20	44	-15

(1) 1963 Chevrolet Impala with 283-CID engine and standard transmission and a 1970 Plymouth Valiant with 225-CID engine and automatic transmission

(2) Average of one 1972 Federal Test Procedure (Reference 3) on each vehicle.

(3) Average of seven tests performed in accordance with the 1972 Federal Test Procedure. Four tests were on the 1963 Chevrolet, and three were on the 1970 Plymouth.

No requirement for repair of the device is anticipated; however, the hose connecting the device to the carburetor adapter plate might require replacement prior to 50,000 miles because of environmental conditions (such as ozone) and the amount of calendar time to accumulate the mileage. Hose inspection would be a part of routine maintenance.

4.1.1.6 Driveability and Safety

This device was tested on six cars at both the Olson Laboratories' Anaheim and Taylor test facilities. Table 4-5 summarizes the driveability results of these tests.

As the data indicates, both acceleration and deceleration times increased, and general driveability indicated longer starting time. Fuel consumption decreased by an overall average of 4 percent, based on pooled fuel consumption data.

The EPA emission test report (Reference 76) pointed out that no adverse driveability effects occurred during 2,000 miles of driving with the 1970 Valiant that was tested. The report concluded that the vehicle was "...operating rich enough to tolerate the enleanment effect."

There were no apparent safety hazards.

4.1.1.7 Installation Description

Table 4-6 lists the steps necessary for installation of this device. Figure 4-3 is a sketch of a typical installation.

Table 4-5. DEVICE 1 AIR BLEED TO INTAKE MANIFOLD DRIVEABILITY TEST RESULTS

DRIVEABILITY CHARACTERISTICS	1965 CHEV. 194 CID	1965 FORD 289 CID	1965 PLY. 318 CID	1965 CHEV. 327 CID	1965 FORD 390 CID	1961 CHEV. 283 CID
	ANAHEIM, CALIF., DRIVEABILITY TEST RESULTS					
	CAR NO. 1	CAR NO. 2	CAR NO. 3	CAR NO. 4	CAR NO. 5	CAR NO. 6
CRITICAL DRIVEABILITY	No effect	No effect	Reduced the tendency to stall during cold start test	Reduced the tendency to stall during cold start test	No effect	No effect
GENERAL DRIVEABILITY	Reduced starting time and number of attempts during hot start test	No effect	No effect	Reduced starting time in cold start test	Reduced starting time during hot start test	Increased stumble during cold start acceleration
0 - 60 MPH ACCELERATION TIME (SECONDS)	Increased from 17.8 to 20.4	Increased from 12.0 to 12.6	Increased from 12.8 to 14.3	Increased from 11.5 to 12.5	Increased from 9.5 to 10.4	Increased from 15.9 to 17.1
60 - 40 MPH DECELERATION TIME (SECONDS)	Increased from 18.5 to 21.2	Increased from 15.5 to 23.0	Increased from 23.5 to 25	Increased from 22 to 23	Decreased from 28.9 to 22	Increased from 20.5 to 26.2
GAS MILEAGE PER GALLON (1)	Average increase of 0.5 percent (reference Table 4-3)					
	TAYLOR, MICH., DRIVEABILITY TEST RESULTS					
	CAR NO. 20	CAR NO. 8	CAR NO. 9	CAR NO. 10	CAR NO. 11	CAR NO. 12
CRITICAL DRIVEABILITY	No effect	No effect	Showed increase in rough idle and stalls on 1st test but not on replicate test	No effect	Rough idle improved with device installed increased on stall with 1st test	No effect
GENERAL DRIVEABILITY	Hot starting time increased slightly	Increase in cranking time and number attempts to start	Replicate test showed increase in hesitation and stumble	Increase in hesitation and stumble	No change in driveability	Cranking time increased for both hot and cold starts.
0 - 60 MPH ACCELERATION TIME (SECONDS)	Increased from 32.4 to 34.2	Increased from 11.5 to 12.8	Increased from 13.4 to 13.6	Increased from 10.3 to 11.0	Increased from 10.3 to 12.0	Increased from 12.5 to 12.9
60 - 40 MPH DECELERATION TIME (SECONDS)	Information not available	Increased from 20.9 to 21.2	Increased from 22.0 to 24.9	Decreased from 24.3 to 23.6	Increased from 22.1 to 23.2	Increased from 24.3 to 27.2
GAS MILEAGE PER GALLON (1)	Average increase of 6.4 percent (reference Table 4-3)					

(1) Pooled mean increase in miles per gallon equals 4 percent.

Table 4-6. DEVICE 1 AIR BLEED TO INTAKE MANIFOLD INSTALLATION PROCEDURE

MINIMUM AVERAGE SKILL LEVEL: AUTOMOTIVE MECHANIC		
INSTALLATION AND ADJUSTMENT PROCEDURE	TOOLS, EQUIPMENT AND FACILITIES	TIME (MIN.)
1. Start up engine; after reaching normal operating temperature, hookup vacuum gauge, tachometer, and exhaust analyzer	a. Vacuum gauge b. Tachometer c. Exhaust analyzer	15
2. With engine running, record vacuum, idle rpm, percent CO, and percent combustion		2
3. Stop engine		
4. Remove carburetor from engine intake manifold. Remove studs	Hand tools	14
5. Screw studs supplied with kit into intake manifold	a. Hand tools b. Studs	4
6. Assemble supplied adapter plate over manifold studs with new gaskets, also supplied in kit	a. Hand tools b. Gaskets c. Adapter plate	2
7. Replace carburetor on manifold, check all linkages and adjust as necessary	Hand tools	10
8. Mount reservoir bracket to vertical surface in engine compartment with screws supplied in kit. Mount as near to adapter plate as possible and as near to vertical as possible	a. Hand tools b. Electric drill c. Sheet metal screws d. Bracket	3
9. Assemble and clamp one end of the hose supplied in the kit to the outlet snout of reservoir and the other end to the inlet of the adapter plate	a. Hand tools b. Hose c. Clamps	1
10. Screw large counterweight nut at the bottom all the way in, compressing the spring	Hand tools	1
11. Start engine, adjust idle mixture and balance idle mixture screws to get the smoothest idle at the recommended idle speed. Combustion efficiency should be approximately 75-80 percent. (1)	a. Hand tools	5

Table 4-6. DEVICE 1 AIR BLEED TO INTAKE MANIFOLD INSTALLATION PROCEDURE (CONCL)

MINIMUM AVERAGE SKILL LEVEL: AUTOMOTIVE MECHANIC		
INSTALLATION AND ADJUSTMENT PROCEDURE	TOOLS, EQUIPMENT AND FACILITIES	TIME (MIN.)
12. With engine running at normal operating temperature, unscrew large counterweight nut at bottom until the vacuum gauge level reads about 1 to 3 inches Hg below the previously recorded vacuum at the same rpm (smaller engines 1 to 2 inches Hg, larger engines 3 inches Hg)	a. Hand tools b. Vacuum gauge	3
13. Tighten stop nut against counterweight and set into reservoir bracket	Hand tools	2
14. Fine adjust counterweight to bring combustion efficiency above 85 percent (1)	a. Hand tools b. Exhaust analyzer	10
15. Fill reservoir with 1-1/2 inches of automatic transmission fluid and tighten lock screw on outside	a. Hand tools b. Transmission fluid c. Reservoir	1
16. Remove all test equipment		2
(1) The expression "combustion efficiency" refers to the calibration used on some engine analyzers for adjusting the air-fuel ratio for lowest emissions commensurate with satisfactory engine performance. Other analyzers use percent carbon monoxide. The expression used in this table is that used by the developer.		

The developer stated that, as a prerequisite to device installation, the automotive engine should be in good operating condition if the expected performance is to be achieved. Any malfunction should be repaired and the engine tuned up before device installation. The exhaust system should also be checked and any leaks repaired.

Installation of this device consists in placing the adapter plate between the carburetor and intake manifold, mounting the air valve on a vertical surface in the engine compartment, and connecting the two with a hose. The adjustment required after installation consists in setting the counterweight in the device to obtain a vacuum reading of 1 to 3 inches below that obtained without the device installed, and adjusting the carburetor settings to get a combustion efficiency above 85 percent.(1) The developer estimated that one hour of labor would be required for installation. Installation could be accomplished in a normally equipped garage by the average mechanic. The carburetor adjustment requirement would preclude installation by the average vehicle owner.

(1) Refer to footnote, Table 4-6.

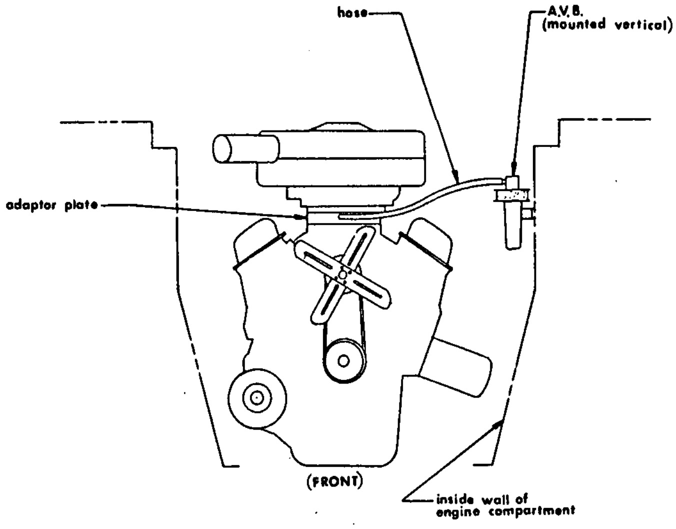


Figure 4-3. DEVICE 1 AIR BLEED TO INTAKE MANIFOLD
TYPICAL INSTALLATION (DEVELOPER SKETCH)

4.1.1.8 Initial and Recurring Costs

The developer stated that for most cars kits and parts cost $40, but that the special adapter plates might increase the kit cost to $48 for some four-barrel carburetors. Table 4-7 is a summary of the initial and recurring costs involved.

4.1.1.9 Feasibility Summary

Results of data developed during the retrofit study test program showed that the device did not affect driveability unsatisfactorily and on the average decreased CO significantly with some decrease in HC. NOx increased slightly. The device appears to be reliable, relatively low in cost, and simple and inexpensive to install and maintain; and offers a return on investment through fuel savings.

Since the device indicates cost-effective reduction of CO and HC, and is presently available on the market, it appears to be a reasonable candidate for retrofit use. Applicability of the device would appear to be more effective for those vehicle model years not already incorporating lean air-fuel mixture. This would include most vehicles prior to 1968. As noted in the EPA emission test report (Reference 76), any further leaning of the later model vehicles might cause misfire or the adverse driveability characteristics associated with excessively lean air-fuel mixtures.

Table 4-7. DEVICE 1 AIR BLEED TO INTAKE MANIFOLD INITIAL AND RECURRING COSTS

ITEM	DESCRIPTION	LABOR HOURS OR ITEM QUANTITY	COST (DOLLARS)
Initial Cost:			
Material			
1. Device	a. Adapter plate b. Reservoir		40.00-48.00
2. Miscellaneous	a. Intake manifold studs b. Gaskets c. Sheet metal screws d. Hose e. Hose clamps f. Transmission fluid		(Included in above)
Labor			
1. Installation	Table 4-6	1 hr	12.50
2. Test and adjust		0.25 hr	3.12
		Total Initial Cost	$55.62-63.62
50,000-Mile Recurring Cost:			
Material			
1. Fuel	Average fuel savings of 4 percent	Savings of 160 gal. x $0.35/gal. (1)	-56.00
2. Filter	Air valve	$2.50 each at four replacements during service life	10.00
Labor			
1. Inspection	Filter, carburetor mixture adjustment, and hose inspection	0.3 hr at $12.50/hr	3.75
		Total Recurring Cost	-42.25
		TOTAL COSTS	$21.37

(1) Based on an assumed national average of 10,000 miles per year at 12.5 mpg, fuel savings equals 4 percent of 4,000 gallons.

4.1.2 Device 42: Air Bleed to Intake Manifold

This device operates on the same principle as the other air bleed devices studied. The main differences between this and the other devices in this category are in the periods when the air bleed is operative and in the method of controlling the amount of additional air that is allowed to enter the intake manifold. Device 42 operates as an air bleed to intake manifold at low to moderate vacuums. During high intake manifold vacuum, the airflow through the device is restricted.

This device was included as a test specimen in the initial phase of the retrofit study.

4.1.2.1 Physical Description

Device 42 is shown in Figure 4-4. The device consists of an air valve which meters air from the carburetor air cleaner to the intake manifold in two places through dual air hoses. The air valve is T-shaped. Each leg is about 3 inches long and 1 inch in diameter. The outlet of the stem of the T accepts a hose which attaches to the air cleaner. The other two outlets at each end of the bar of the T accept hoses which connect to two locations on the intake manifold.

Inside the valve are three plastic balls which control the amount of air bleed between the air filter and manifold. The case of the valve is made of plastic, and the hoses are rubber. Push connector nipples are used to connect the hoses to the manifold and air cleaner.

Figure 4-4. DEVICE 42: AIR BLEED TO INTAKE MANIFOLD

4.1.2.2 Functional Description

Figure 4-5 shows a functional diagram of the device. Under low and medium vacuum, air bleeds from the air cleaner to the intake manifold. Under high vacuum, such as at idle or deceleration, the plastic balls deform and restrict the flow of air. The air inlet leg can be adjusted to vary the length of the chamber containing the plastic balls. Adjustment of air bleed is accomplished by varying the chamber length.

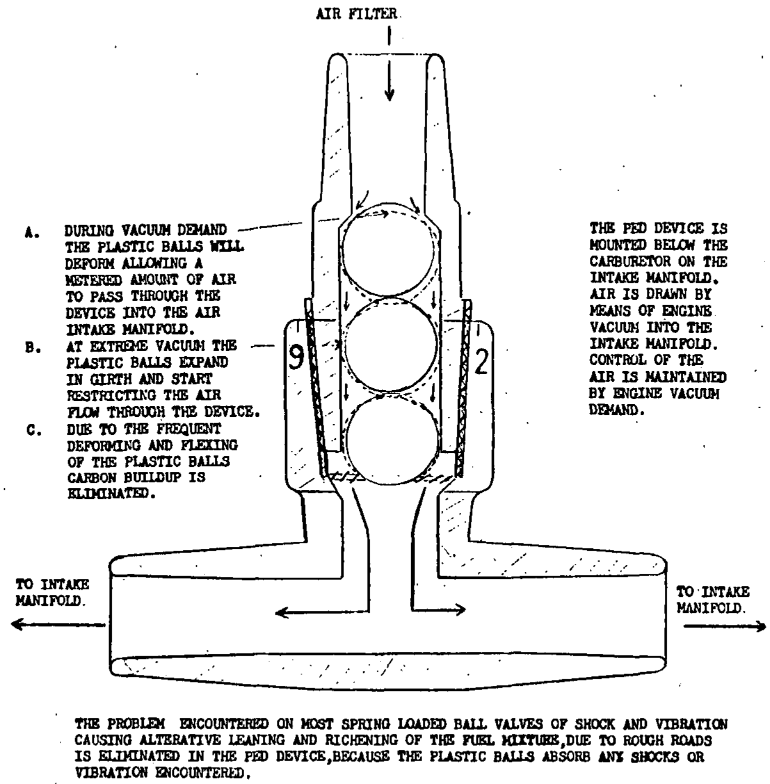


Figure 4-5. DEVICE 42 AIR BLEED TO INTAKE MANIFOLD FUNCTIONAL SCHEMATIC (DEVELOPER DIAGRAM)

The effect of the air bleed is to increase the air-fuel ratio during normal operation, but not during idle or deceleration when intake vacuum is highest. When the plastic balls deform under these high vacuum conditions, the air bleed is minimum and air-fuel mixture ratio is not changed from that normally supplied by the carburetor. Shutting off the air bleed at idle in this manner prevents a rough idling engine.

Adjustment of the valve is done at medium rpm to minimize HC and CO. Leaning and richening of the mixture from vibration and shock is avoided by the shock absorption capability of the plastic balls. The overall effectiveness of this device would appear to be influenced primarily by the material composition of the plastic balls utilized.

4.1.2.3 Performance Characteristics

The developer of the device provided emission data on four automobiles and during the retrofit study the device was tested on two automobiles. The results of these tests are summarized in Tables 4-8 and 4-9. The average percentage emission reductions for the two tests performed in the retrofit program were 45.3 for CO, 23.2 for HC, and 2.6 for NOx. These test results indicate that Device 42 is effective in decreasing CO and, to a lesser extent, HC.

4.1.2.4 Reliability

The device may be subject to aging of the plastic material used in its construction and cyclic fatigue loading of the balls used as a valve. Provided optimum plastic compositions have been selected, reliability would be estimated to exceed 75,000 MMBTF.

The selection of optimum plastics should include consideration of:

1. Complete operating temperature profile
2. Compatibility with fuel and other organics present in the engine compartment
3. Geographical climate extremes of temperature for cold engine starts and very hot running
4. Resistance to deterioration from ozone
5. Fatigue life of the ball material.

The entire valve assembly, being a low cost item, might be considered for replacement during routine maintenance, if required to meet the system reliability requirement.

4.1.2.5 Maintainability

The only periodic maintenance of the device would be to clean the air filter every 12,000 miles. Replacement would be recommended for visually deteriorated components such as hoses or the valve housing. It is estimated that filter cleaning or any replacement could be accomplished in less than 15 minutes. No routine adjustment of the air valve would appear to be necessary.

4.1.2.6 Driveability and Safety

This device was tested for driveability as part of the retrofit study with results shown in Table 4-10.

During the period of this test, Car No. 4 was continuously on the verge of poor performance when cold. The comments shown in Table 4-10 for this car may possibly be attributed to a shift in performance of the vehicle more than the fault of the device.

As is characteristic of air bleed devices, fuel economy appeared to improve. One

Table 4-8. DEVICE 42 AIR BLEED TO INTAKE MANIFOLD EMISSION REDUCTION AND FUEL CONSUMPTION PERFORMANCE (1)

VEHICLE YEAR/MAKE/CID	ANAHEIM TEST RESULTS			
	POLLUTANT GRAMS/MILE			FUEL MILES/ GALLON
	HC	CO	NOx	
1965 Chev 327				
Without Device	6.15	66.49	3.25	13.70
With Device	6.62	33.34	3.35	13.70
Percent Reduction	-7.6	50.0	-3.1	0
1965 Ford 390				
Without Device	14.14	150.50	3.72	10.42
With Device	6.50	88.94	3.41	11.93
Percent Reduction	54.0	40.9	8.3	-14.5
Average Reduction %	23.2	45.3	2.6	- 7.2

(1) Emission results obtained by Olson Laboratories in tests performed under Contract 68-04-0038 using 1972 Federal Test Procedure (Reference 3). Fuel consumption was measured during these tests.

Table 4-9. DEVICE 42 MEAN EMISSION TEST RESULTS BASED ON TESTS REPORTED BY DEVELOPER (1)

VEHICLE CONFIGURATION	POLLUTANT		
	HC (PPM)	CO (%)	NOx (PPM)
Without Device	453	4.44	892
With Device	311	1.39	919
Percent Reduction	26	45	-3

(1) HC and CO are averages of three 7-cycle, 7-mode tests on 1967 Ford, 1967 Pontiac, and 1970 Renault with and without device installed; NOx is based on one test of the Renault.

test showed no change in fuel consumption, while the other test showed an improvement of 14% in gasoline mileage.

Table 4-10. DEVICE 42 AIR BLEED TO INTAKE MANIFOLD DRIVEABILITY TEST RESULTS

DRIVEABILITY CHARACTERISTICS	1965 CHEV. 194 CID	1965 FORD 289 CID	1965 PLY. 318 CID	1965 CHEV. 327 CID	1965 FORD 390 CID	1961 CHEV. 283 CID
	ANAHEIM, CALIF., DRIVEABILITY TEST RESULTS					
	CAR NO. 1	CAR NO. 2	CAR NO. 3	CAR NO. 4	CAR NO. 5	CAR NO. 6
CRITICAL DRIVEABILITY	(1)	(1)	(1)	Increased stall on deceleration during cold start test	No effect	(1)
GENERAL DRIVEABILITY				Rough idle during cold start test; reduced hesitation during cold start test	Decreased detonation during hot start acceleration	
0 - 60 MPH ACCELERATION TIME (SECONDS)				Increased from 11.7 to 12.2	Increased from 10.0 to 10.2	
60 - 40 MPH DECELERATION TIME (SECONDS)				Increased from 23.7 to 24.2	Increased from 23.7 to 26.7	
GAS MILEAGE PER GALLON	Average increase of 7.3 percent (reference Table 4-8)					

(1) Device No. 42 was not tested on these vehicles.

No safety hazards were identified. If one of the air restriction balls were ingested into the intake manifold, it is not likely that engine failure would be catastrophic.

4.1.2.7 Installation Description

The installation of this device consists in drilling two holes in the intake manifold and one in the air filter, and connecting these points with rubber tubing in which the device is installed. The air valve may be installed on the fire wall, fender well, or directly on the carburetor air cleaner housing. Figure 4-6 shows the latter installation.

Adjustment of the device after installation is accomplished by reading the value of CO on an engine exhaust analyzer, and adjusting the air inlet leg to give the desired reading. Engine rpm at idle may require adjustment.

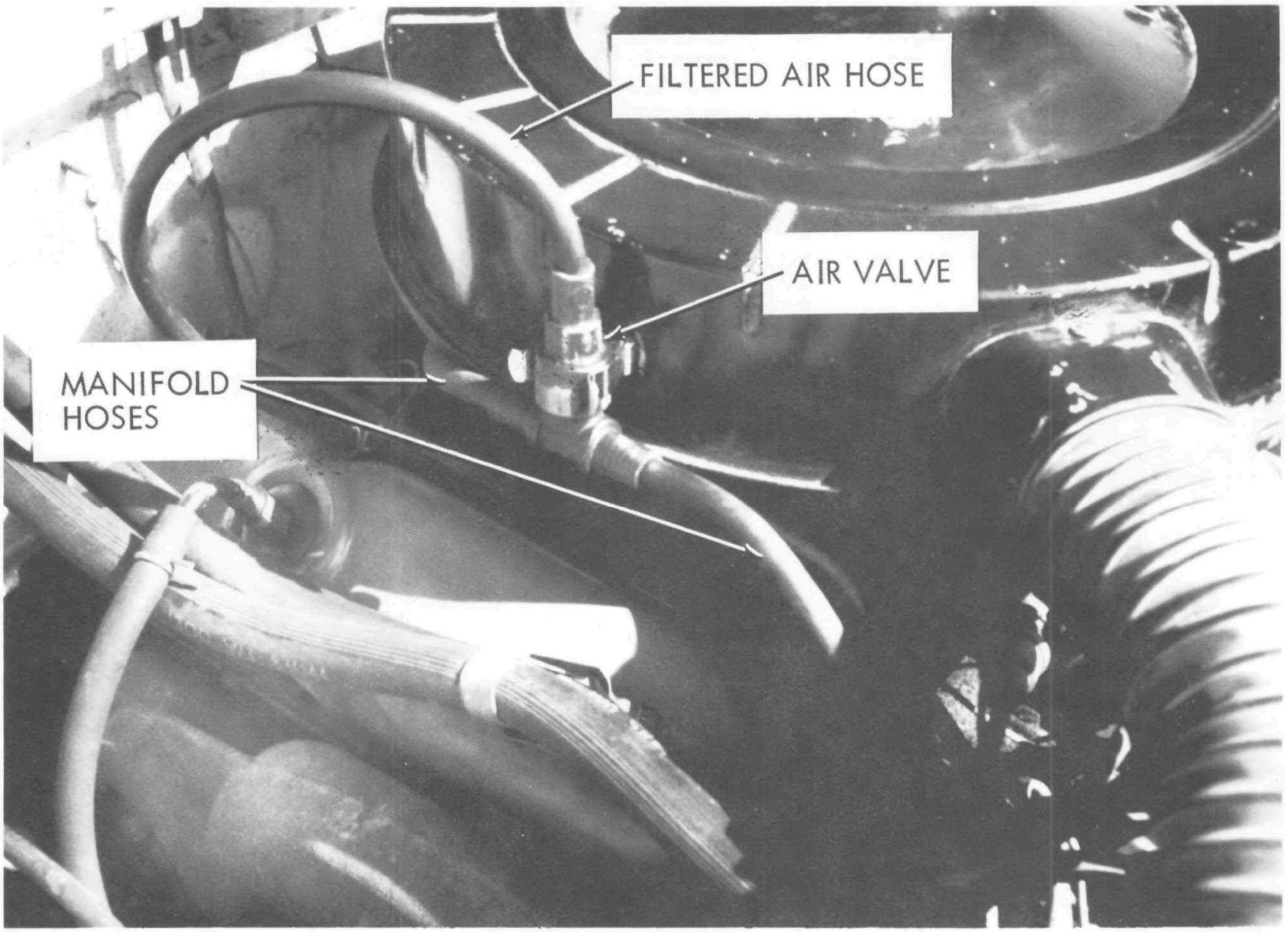


Figure 4-6. DEVICE 42 AIR BLEED TO INTAKE MANIFOLD: TYPICAL INSTALLATION OF AIR VALVE ON CARBURETOR AIR CLEANER (DEVELOPER PHOTO)

Table 4-11 itemizes the installation procedure. Installation can be accomplished in a normally equipped repair shop by the average mechanic. From the information available, it is estimated that installation of this device, including material, would be $22.50.

4.1.2.8 Initial and Recurring Costs

Table 4-12 summarizes the initial and recurring costs for the device. The developer estimated an initial cost of less than $10 for the device. As with most devices of this type, the fuel saving (if any) eventually would pay off the initial cost. Device 42 could provide a return on investment after about one year of use.

4.1.2.9 Feasibility Summary

This device appears to be practical for retrofit on some older cars if careful tune-ups are performed to adjust for low emissions. Tests of this device showed that driveability and acceleration times were affected very little by installation of this device, while exhaust emissions showed a significant reduction of CO. No safety hazards appear to exist, and the device is relatively inexpensive to purchase, install, and maintain, with even some cost return through a fuel economy saving.

Table 4-11. DEVICE 42 AIR BLEED TO INTAKE MANIFOLD INSTALLATION PROCEDURE

MINIMUM AVERAGE SKILL LEVEL: AUTOMOTIVE MECHANIC		
INSTALLATION AND ADJUSTMENT PROCEDURE	TOOLS, EQUIPMENT AND FACILITIES	TIME (MIN.)
1. Make sure the air filter is clean.		3
2. Clean or replace PCV valve.	Hand tools	10
3. Examine intake manifold to find the best location to install 1/4-inch push connector nipples.		3
4. Drill two 15/64-inch holes. (Use strong magnet to collect drill chips)	a. Electric drill b. Magnet	10
5. Tap nipples gently into the holes. Leave the machine screws in the nipples for this operation.	a. Hand tools b. Nipples	5
6. Remove the machine screws from the nipples and connect the rubber tubes to nipples and device.	a. Hand tools b. Rubber tubes	2
7. Drill one 9/16-inch hole in lower half of the air filter casing to receive air hose plastic securing bushing. In an oil bath filter drill into upper section.	Electric drill	3
8. Push air hose and plastic bushing into the 9/16-inch hole	a. Air hose b. Plastic bushing	2
9. Adjust by CO reading on exhuast analyzer. If CO is too low, close device about half a turn. If CO is too high, unscrew the device about a half a turn.	Exhaust analyzer	17
10. Adjust rpm with carburetor idle screw	Tachometer	5
	Total Time	1 hr

Table 4-12. DEVICE 42 AIR BLEED TO INTAKE MANIFOLD INITIAL AND RECURRING COSTS

ITEM	DESCRIPTION	LABOR HOURS OR ITEM QUANTITY	COST (DOLLARS)
Initial Cost:			
Material			
1. Device			10.00
2. Miscellaneous	a. Nipples b. Rubber tubing		(Included in above)
Labor			
1. Installation	Table 4-11	0.75 hr	9.38
2. Test and adjust		0.25 hr	3.12
		Total Initial Cost	$ 22.50
50,000-Mile Recurring Cost:			
Material			
1. Fuel	Average fuel savings of 7 percent	280-gal. fuel reduction x $0.35 per gallon over 50,000 miles (1)	-98.00
Labor			
1. Filter	Clean Air Filter	Once every 12,000 miles @ 0.25 hr each = 1 hr for 50,000 miles, or $12.50	12.50
		Total Recurring Cost	-$85.50
		TOTAL COSTS	-$63.00

(1) Based on an assumed national average of 10,000 miles per year at 12.5 mpg, fuel savings equals 7 percent of 4,000 gallons.

4.1.3 Device 57: Air Bleed with Exhaust Gas Recirculation and Vacuum Advance Disconnect

This device shows the effects of combining exhaust gas recirculation and distributor vacuum advance disconnect with air bleed into the intake manifold. The air bleed and exhaust gas recirculation is operational at moderate through high intake manifold vacuums, and vacuum disconnect is continuous unless the engine overheats. This approach should provide an increased amount of air for reduction of HC and CO emissions during combustion, along with reduction of combustion temperatures to inhibit NOx emissions. The increased exhaust gas temperature should promote further oxidation of CO and HC in the exhaust ports and manifold.

4.1.3.1 Physical Description

As shown in Figure 4-7, Device 57 consists of an adapter plate that installs between the carburetor and the intake manifold, a dashpot to mount on the plate, and a temperature sensitive switch to disconnect vacuum to the distributor vacuum advance mechanism. The adapter plate is approximately 1 inch thick and is made of aluminum. It contains a butterfly valve type of flow sensor with lips on the edge to meter air and exhaust flow into the manifold from jets which protrude into the throat.

The dashpot mounts on the adapter plate to dampen oscillation of the flow sensor. The temperature sensitive switch, which is designed to be mounted in the radiator, is about 3/4 inch in diameter and 2 inches long. Two hoses connect it to the distributor and vacuum source.

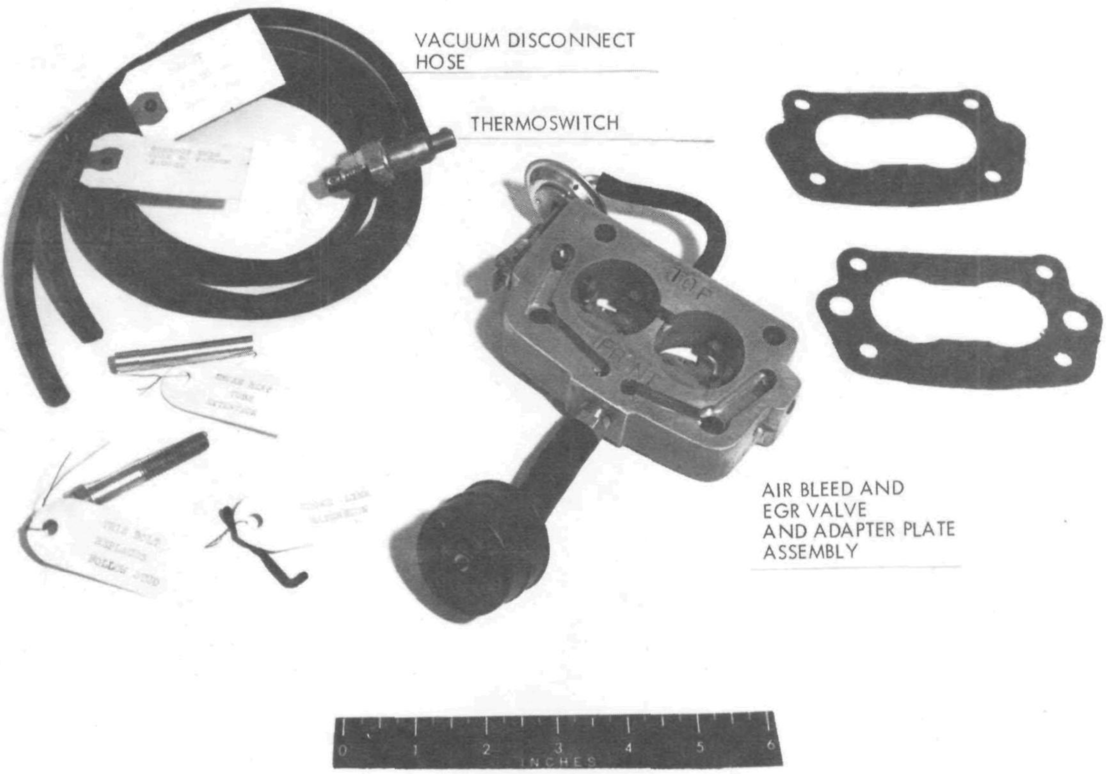


Figure 4-7. DEVICE 57 AIR BLEED WITH EGR AND VACUUM ADVANCE DISCONNECT SYSTEM COMPONENTS

4.1.3.2 Functional Description

The system operates on the principle of metering exhaust gas and filtered air into the intake manifold as a function of air-fuel mixture flow through the carburetor. The vacuum advance to the distributor is normally disconnected, but is reconnected if the engine overheats. The distributor vacuum advance is disconnected through a standard temperature-sensitive vacuum switch.

The adapter plate contains an exhaust gas circuit and a filtered air circuit. Both circuits are controlled by identical valves with no moving parts. The developer reported that "the flow through both valves is regulated by a single sensor having one moving part. The sensor responds to airflow through the engine. Attached externally to one side of the plate is a dashpot to dampen the 'hunting' action of the sensor."

The following principles of operation are quoted from the developer's data for the exhaust gas recirculation circuit and for the filtered air circuit:

"EGR Circuit:

"Exhaust gases are recirculated into the intake manifold in varying amounts in proportion to the cubic feet of air being consumed by the engine. The total volume of recirculation can be preset for a given engine model before installation. Since the exhaust gases do not contact any of the metering mechanism, corrosion or scale buildup does not occur to alter metering action with mileage accumulation.

"Filtered Air Circuit:

"Identical in operation to the EGR circuit, but with the inclusion of an adjustable needle to regulate, or block, filtered air flow. This circuit is used to lean out the carburetor above idle without having to make internal changes inside the carburetor.

"This system will reduce HC, CO and NO_x to acceptable levels on used cars.

"The function of the system can be roughly divided into three sections:

1. Recycling a metered amount of exhaust gases through the engine.

2. Adjusting the air-fuel ratio of the carburetor without internal alterations of the carburetor.

3. Disconnecting the vacuum spark advance through the conventional thermostatic protection switch.

"Items 1 and 2 are accomplished through the use of a shutoff-metering valve combination which is sensitive to airflow through the intake manifold, and will introduce the predetermined amount of exhaust gases (or filtered air) required for any mode of engine operation.

"Since there are no moving parts in the valve and only one moving part (in the overall assembly), the complete assembly can be incorporated into a plate to be installed between the existing carburetor and the intake manifold."

"Once installed, the operational adjustments consist of regulating the amount of filtered air found to be necessary on each engine, using a garage type exhaust gas analyzer at idle speed and at 2,500 rpm no load. No adjustment of exhaust gas recycling is necessary as the orifice restricting total flow has been predetermined on each engine type for maximum emission reduction compatible with acceptable driveability. Less than total flow is, of course, metered by the valve in proportion to air flow through the engine. (The valve sensor responds to air volume moving through the intake manifold.)"

4.1.3.3 Performance Characteristics

This device was tested on a 1957 Chevrolet by the developer. The test procedure and test results are described in the following excerpts from information supplied by the developer:

"The vehicle selected was a suspected high emitter for the purpose of demonstrating the device's ability to perform reductions in HC-CO due to carburetor conditions which ordinarily would require internal carburetor service.

"After completion of all testing, the carburetor was torn down and inspected. It was found to have float level at 3/4 inch (factory specification), main jets were 7002656 (factory specified Sea Level jet) but jets were scarred and battered. Vent valve distorted as to be continuously open.

"The owner's repair bill of a month previous lists new spark plugs, points, condenser, carburetor repair kit, and PCV valve.

"It can be argued that the greater part of the HC-CO reduction achieved could have also been gained by correct adjustments and/or repair to the carburetor. But, using the device, such conditions were improved without internal carburetor service. However, the relation of CO to NO_x before and after, suggests that the percent reduction of NO_x by the device is accurate. The 'with device' test was run after the device had been installed and adjusted by the 'emergency method'." (1)

Table 4-13 shows the results of the test. These results indicate that the device may be effective in reducing all three exhaust pollutants. Further testing would be required to verify that these results can be obtained consistently for a variety of used cars.

(1) Refer to Table 4-14, Item 9c, for definition of the emergency method of Device 57 adjustment.

Table 4-13. DEVICE 57 AIR BLEED WITH EGR AND VACUUM ADVANCE DISCONNECT EMISSION TEST RESULTS REPORTED BY DEVELOPER

VEHICLE CONFIGURATION (1)	POLLUTANT (GM/MI)		
	HC	CO	NO_x
Without Device	10.81	85.62	2.23
With Device	4.78	40.85	1.19
Percent Reduction	55.8	52.3	46.6

(1) 1957 Chevrolet with 283-CID engine with dwell at 30 degrees, timing advance line disconnected and plugged at 8 degrees, 500-rpm idle without device and 550 rpm with the device (both with transmission in drive, and idle mixture set to best idle for highest rpm). One 7-cycle, 7-mode test with and without device installed.

4.1.3.4 Reliability

The carburetor adapter plate subsystem concept appears capable of demonstrating a reliability in excess of 50,000 MMBTF with satisfactory maintenance. Additionally, the thermostatic override control for the distributor vacuum advance appears capable of demonstrating an acceptable reliability. Essential to this successful demonstration is proper installation.

4.1.3.5 Maintainability

It is anticipated that the use of a detergent bearing gasoline, or the periodic use of carburetor detergent gasoline additives, would maintain the exhaust gas valve areas sufficiently clean to preclude the need to remove the carburetor for periodic maintenance every 12,000 miles. Tests of this concept should be carried out to verify its validity. Periodic maintenance every 12,000 miles would include:

1. Inspection and cleaning of the air bleed filter

2. Manual actuation of the valve shaft to assure that it is free to fully rotate and that the vacuum diaphragm is intact

3. Inspection of the thermostatic override control for the vacuum advance.

It is estimated that normal maintenance could be accomplished in approximately 25 minutes (0.4 hour).

No repair is anticipated prior to 50,000 miles; however, replacement of the thermostatic control might be required. The method of installation indicated by the developer would preclude removal of an installed control, requiring installation of a replacement control in an adjacent location. It is estimated that this repair could be performed in 60 minutes.

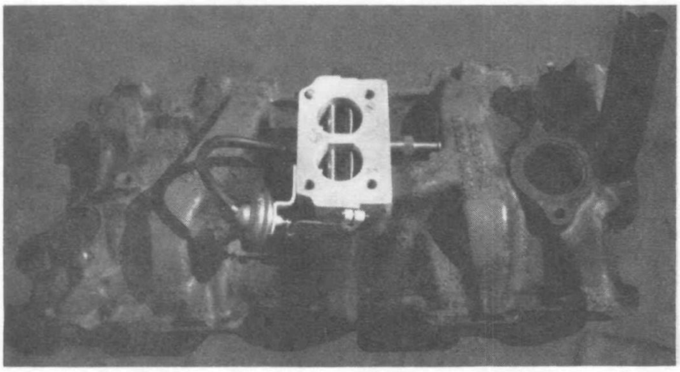
4.1.3.6 Driveability and Safety

Driveability data provided by the developer indicated no major adverse effect on the vehicle's performance as a result of device installation. General driveability was characterized by increased rough idle during cold start and increased stretchiness during cold start acceleration. These are typical characteristics of air bleed systems.

In the event the thermostatic control fails such that the distributor vacuum advance is continuously inoperative, engine overheating could occur. Also, the probability of having a carburetor backfire is increased by the method of exhaust gas recirculation used. This would constitute a fire hazard if the carburetor used with the device is not capable of suppressing a backfire.

4.1.3.7 Installation Description

The installation of this device consists in mounting the combination adapter plate and valve between the carburetor and intake manifold, installing a vacuum disconnect switch, and connecting vacuum hoses to carburetor and distributor through the vacuum disconnect switch. Figure 4-8 shows the adapter plate and valve installed on a V-8 intake manifold with the carburetor.



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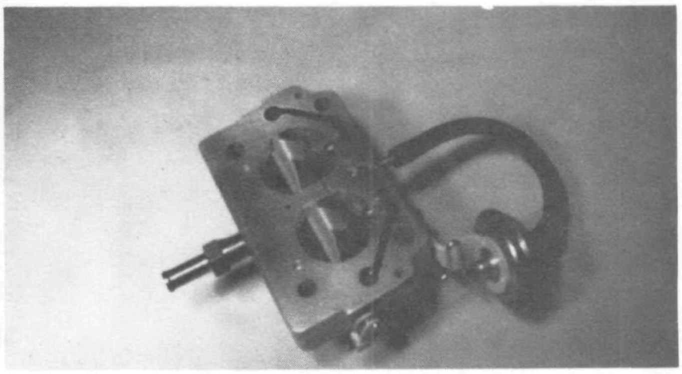

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Figure 4-8. DEVICE 57 AIR BLEED WITH EGR AND VACUUM ADVANCE DISCONNECT INSTALLED ON V-8 INTAKE MANIFOLD (DEVELOPER PHOTO)

Adjustment of the engine consists in setting the carburetor and ignition to automobile manufacturer's specifications with the following exceptions. Idle speed for cars with automatic transmission should be adjusted to 50 rpm over factory specifications while cars with standard or overdrive transmissions should be adjusted to 75 rpm over factory specifications. Idle mixture should be adjusted to obtain 86 percent efficiency using a combustion analyzer.(1) Adjustment of the device adapter plate air adjustment consists in running a dynamometer test and adjusting the screw on the adapter plate to obtain 0.8 to 1.0 percent CO. Alternate procedures are specified by the developer if a dynamometer is not available (refer to Table 4-14, Item 9).

The developer stated that installation would have to be in thoroughly controlled facilities where equipment and personnel can be relied upon to adjust and service the unit properly. He stated that this device is not recommended for over-the-counter sales with no guarantee on how it will be installed or adjusted. The developer estimated that it would take 1.8 hours of labor to install and adjust this device.

Table 4-14 contains a detailed description of the installation procedure and identified tools and special equipment required as well as time. Installation can be accomplished in a normally equipped repair shop by the average mechanic.

Table 4-14. DEVICE 57 AIR BLEED WITH EGR AND VACUUM ADVANCE DISCONNECT INSTALLATION PROCEDURE

MINIMUM AVERAGE SKILL LEVEL: AUTOMOTIVE MECHANIC		
INSTALLATION AND ADJUSTMENT PROCEDURE	TOOLS, EQUIPMENT AND FACILITIES	TIME (MIN.)
1. Remove carburetor and mounting studs.	Hand tools	15
2. Clean manifold surfaces and install longer studs.	a. Hand tools b. Longer studs	5
3. Using new gaskets, slip device plate over studs and reinstall carburetor. (Large majority of engines have existing exhaust holes which will automatically feed exhaust gases into device plate. Those that do not, slip drill template over studs and drill with 3/8-inch electric drill.)	a. Hand tools b. Drill template c. 3/8-inch electric drill	20
4. Inspect and readjust if needed; linkages, shift rods, kickdown switches, etc.	Hand tools	5
5. If cross-over type choke is used, a choke rod extrusion is furnished to be snapped onto existing choke rod.	a. Hand tools b. Choke rod extrusion	3
6. Install vacuum disconnect switch kit in radiator and route vacuum hoses to carburetor and distributor.	a. Hand tools b. Switch kit	12

(1) Refer to footnote, Table 4-6, on Page 4-11.

Table 4-14. DEVICE 57 AIR BLEED WITH EGR AND VACUUM ADVANCE DISCONNECT INSTALLATION PROCEDURE (CONCL)

MINIMUM AVERAGE SKILL LEVEL: AUTOMOTIVE MECHANIC		
INSTALLATION AND ADJUSTMENT PROCEDURE	TOOLS, EQUIPMENT AND FACILITIES	TIME (MIN.)
Adjustments - Factory carburetor and ignition specifications apply with these exceptions:		
7. Idle speed (automatic transmission) a. In drive, factory specifications plus 50 rpm or b. Idle speed (standard and over-drives), factory specifications plus 75 rpm.	Tachometer	3
8. Idle Mixture a. 0.9 to 1.2 percent CO or b. 86 percent (1) or c. Best lean idle.	Infrared analyzer or combustion analyzer.	18
9. Device Plate air adjustment a. Follow Clayton Key Mode procedure for "high cruise" while adjusting screw to read CO 0.8 to 1.0 percent or	a. Dynamometer and analyzer	24
b. 2,200 rpm in neutral, adjust to 1.2 percent +0.1 CO or 87 percent +1 combustion (1) or	b. Analyzer and tachometer	
c. Emergency method only: 2,200 rpm in neutral, slowly turn air screw out from its seat until lean roughness is detected then turn screw in one full turn. (Note: Device plate air screw does not operate at curb idle.)	c. Tachometer	
	TOTAL TIME	1.75 hr

(1) The expression "combustion efficiency" refers to the calibration used on some engine analyzers for adjusting the air-fuel ratio for lowest emissions commensurate with satisfactory engine performance. Other analyzers use percent carbon monoxide. The expression used in this table is that used by the developer.

4.1.3.8 Initial and Recurring Costs

The developer estimated that the cost of the device installed would be $55. Table 4-15 summarizes the installation costs. From the information available, it was estimated in the retrofit study that the total cost for installing this device, including material, would be $62.88.

4.1.3.9 Feasibility Summary

Device 57 test results provided by the developer for one automobile indicate effective reduction in all three exhaust emissions. If further testing shows similar emission reduction for other cars, the device would appear to be technically feasible as a retrofit device for older cars.

Table 4-15. DEVICE 57 AIR BLEED WITH EGR AND VACUUM ADVANCE DISCONNECT INITIAL AND RECURRING COSTS

ITEM	DESCRIPTION	LABOR HOURS OR ITEM QUANTITY	COST (DOLLARS)
Initial Cost:			
Material			
1. Device	One piece plate with two valves and sensor controlling air and exhaust gas		41.00
2. Miscellaneous	a. Studs for intake manifold b. Template for drilling c. Switch kit d. Vacuum hose e. Choke rod extension		(Included in above)
Labor			
1. Installation	Table 4-14	1 hr	12.50
2. Test and adjust		0.75	9.38
		Total Initial Cost	$62.88
50,000-Mile Recurring Cost:			
Labor			
1. Inspection	Refer to paragraph 4.1.3.5	0.4 hour every 12,000 miles at $12.50 per hour	20.00
		Total Recurring Cost	$20.00
		TOTAL COSTS	$82.88

4.1.4 Device 325/433: Air Vapor Bleed to Intake Manifold

Devices 325 and 433 are identical alcohol-water vapor injection systems being marketed by different companies. Though these devices are generally referred to as vapor injectors, their basic effect appears to be that of an air bleed to the intake manifold. Direct air bleed is provided at idle and alcohol-water-air vapor bleed is provided at all other engine speeds and loads.

Alcohol-water injection has been used for many years in aircraft and race cars as a means of obtaining maximum power. The objective in these applications has been to operate at higher air-fuel ratios than would be possible without injection. The alcohol-water injection provides detonation control for the higher engine performance ranges and also cools the various combustion parts. Exhaust emission research in recent years has indicated that use of alcohol-water injection may provide the cooler combustion flame temperatures that inhibit NOx formation without power loss (Reference 77). This research also has indicated that under some engine modes the reduction of HC is also enhanced.

4.1.4.1 Physical Description

The Device 325/433 injection system consists of four basic components and interconnecting hoses. The basic system components, as shown in Figures 4-9 and 4-10, are:

1. A plastic fluid storage bottle measuring 7-1/2 by 7-1/2 by 10 inches and weighing about 2 pounds empty.

2. A plastic metering valve to control injection of alcohol-water vapor mixture.

3. A fiber adapter plate to fit between the carburetor and intake manifold.

4. Idle adjustment air needles to replace those normally supplied for the carburetor.

The fluid storage bottle is mounted in the engine compartment away from exhaust heat. It is connected through hoses and the valve to the carburetor adapter plate and to the PCV valve. The idle air needles are screwed into the carburetor to replace the normal idle adjustment screws. These screws have an air passageway drilled their entire length.

4.1.4.2 Functional Description

The vapor injection system operates on the principle of injecting an alcohol-water-air vapor into the intake manifold, to improve mixture thermal capacity, increase power, and reduce emissions.

Figure 4-11 illustrates a typical system functioning on a V-8 engine. Air is bled into the carburetor air-fuel mixture directly through the special idle needles, leaning the air-fuel mixture at idle. The alcohol-water-air vapor mixture is drawn into the intake manifold through the PCV inlet downstream of the PCV valve. The metering valve operates on a low vacuum and supplements the flow of crankcase blow-by from the PCV valve to the manifold with the alcohol-water-air vapor from the fluid storage bottle. A metering orifice downstream of the valve, limits the total flow of vapor.

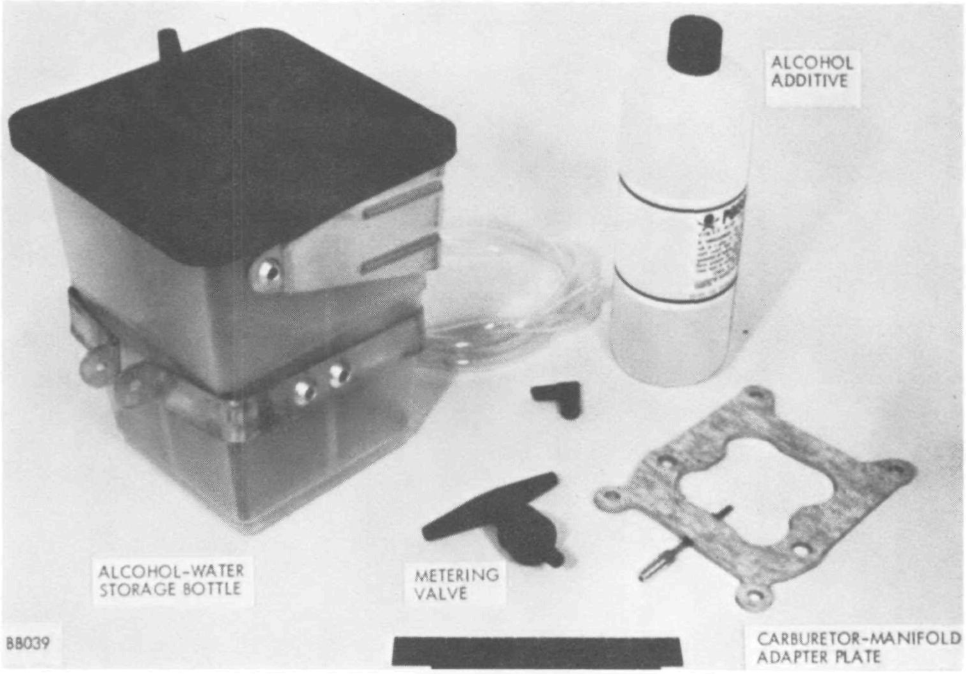


Figure 4-9. DEVICE 325/433 AIR-VAPOR BLEED TO INTAKE MANIFOLD SYSTEM COMPONENTS (REFER TO FIGURE 4-10 FOR AIR NEEDLES)

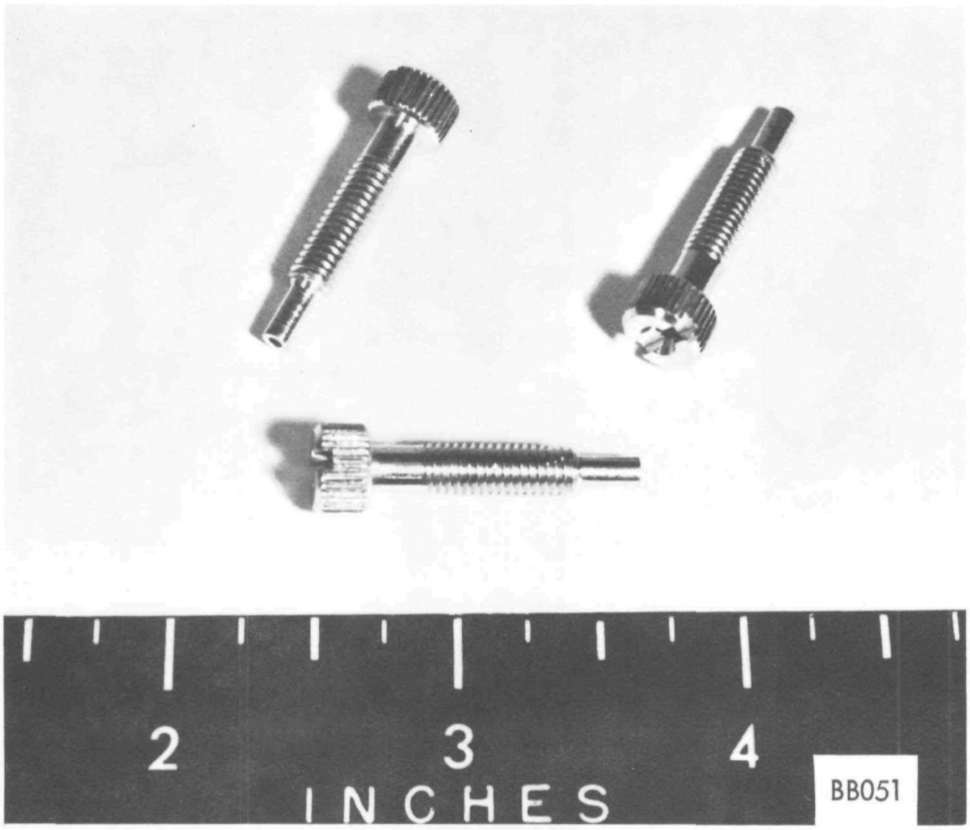


Figure 4-10. DEVICE 325/433 AIR INJECTION NEEDLES

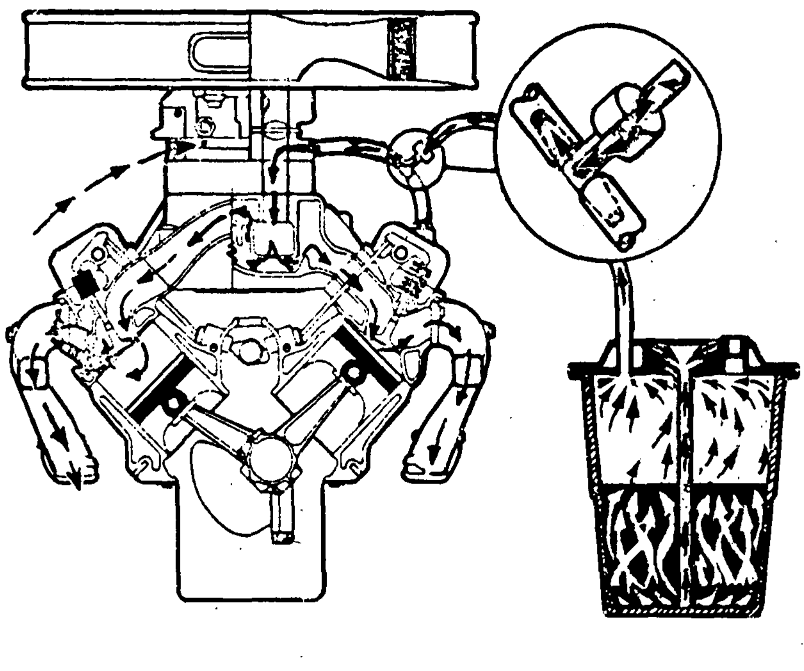


Figure 4-11. DEVICE 325/433 AIR-VAPOR BLEED TO INTAKE MANIFOLD FUNCTIONAL SCHEMATIC (DEVELOPER DIAGRAM)

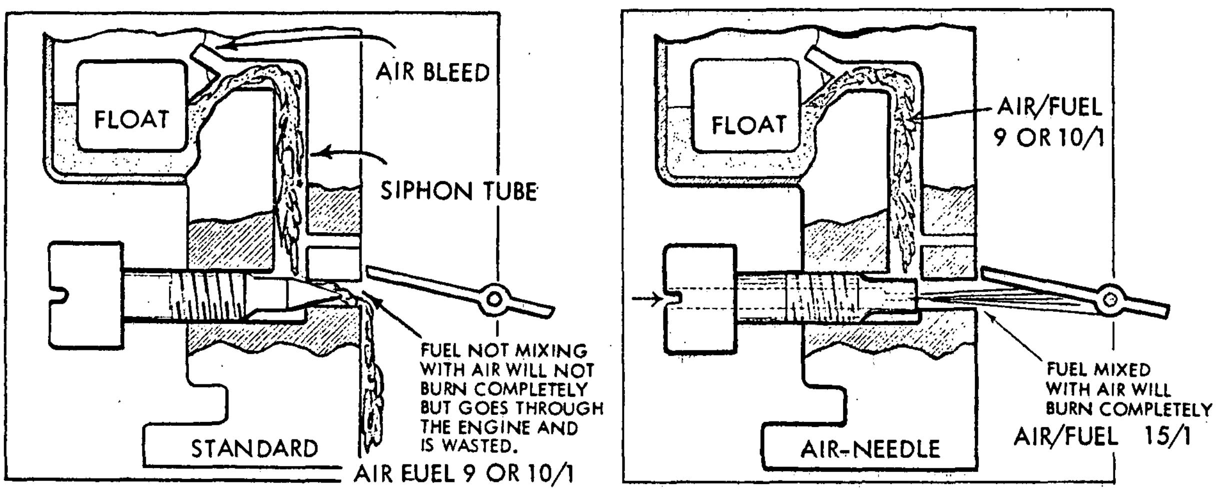
Vapor is achieved in the fluid storage bottle by venting the bottom of the fluid to atmosphere and drawing a vacuum on the bottle above the fluid level, causing the air to pass through the liquid. The developer provides the following information in his sales brochures to describe operation and theory of the device:

> "The Vapor Injector is connected to the carburetor by means of a vacuum line or an adapter plate, and the suction created by normal engine operation draws fresh air into the top of the liquid container. This air goes down through the polycarbonate tube and emerges from the aerator in the form of thousands of micro bubbles. These bubbles flow to the top of the fuel where they burst forming a vapor cloud composed of alcohol, water, and four other oxygen bearing chemicals. The same suction that introduced air into the container now draws the vapor into the carburetor by a means where it combines with the regular mixture of air and fuel. Under the terrific heat of combustion, the elements in the fuel release pure oxygen and steam. These elements slow the combustion process and causes an increase in volumetric efficiency or burning of the fuel. Unlike other systems, this auto emission control system has a valve which increases the volume of vapor as engine vacuum decreases. This is just the opposite of other systems which cease to function when they are needed most, such as when it is necessary to accelerate to pass a car or climb a hill."

"The addition of the air-needles makes the system unique. The air-needles replace the stock air idle adjustment screws. The engineered orifice allows a jet stream of air to blast the air-fuel mixture in the carburetor venturi. This air blast further atomizes the fuel in the mixture and results in increased combustion efficiency and the lowering of the hydrocarbon and carbon monoxide emissions from the exhaust .... ."

"Conventional Needles allow quantities of fuel to spill through the idle aperture like running water (Figure 4-12a). This excess gasoline accumulates in the cylinders and burns as fire on the piston. There is far too much fuel to burn completely and most of the gasoline goes out through the exhaust or is left behind as dirty carbon deposits..."

"Air Needles force a stream of air to carry the incoming fuel (Figure 4-12b). This blast of air agitates, and aerates the over rich gasoline mixtures. This 'oxidized' mist is carried on into the cylinders to be ignited. The more complete atomization of fuel results in greater combustion efficiency which means less fuel comsumption, reduced carbon deposits, fewer polluting emissions."



(a) Standard Needle (b) Air Injection Needle

Figure 4-12. DEVICE 325/433 AIR NEEDLE SYSTEM COMPARED TO STANDARD NEEDLE (DEVELOPER DIAGRAM)

In considering this information supplied by the developer, there are two points that should be clarified:

1. It is not clear how the valve increases the air-vapor flow as engine vacuum decreases as claimed by the developer. The metering valve provided with the unit opens at low vacuum, providing an increasing flow with increasing vacuum to some point in the mid-vacuum range where it reaches

a maximum flow as determined by the size of the orifice. Higher vacuums, then, such as on deceleration, allow the maximum flow rate.

2. A properly adjusted carburetor will provide an air-fuel mixture at idle in the range at 12 to 1 or 13 to 1 rather than the 9 to 1 or 10 to 1 stated by the manufacturer.

4.1.4.3 Performance Characteristics

Tests on Device 325/433 were performed for the developer on this device by Automotive Testing Laboratories. A summary of the results for seven cars is presented in Table 4-16 from information supplied by the developer.

Table 4-16. DEVICE 325/433 AIR-VAPOR BLEED TO INTAKE MANIFOLD EMISSION TEST RESULTS PROVIDED BY DEVELOPER (1)

VEHICLE			HOT CYCLE EMISSIONS			
MODEL	CID	CONTROL SYSTEM	TEST	CO (%)	HC (PPM)	NOx (PPM)
1960 Valiant	170	Without device	A-288	6.43	608	342
1960 Valiant	170	With device	A-289	5.95	444	324
1965 Nova	194	Without device	A-239	3.22	404	665
1965 Nova	194	With device	A-252	1.35	244	796
1964 Valiant	225	Without device	A-240	1.74	387	1117
1964 Valiant	225	With device	A-243	0.97	390	1109
1964 Dart	273	Without device	A-216	1.88	517	1208
1964 Dart	273	With device	A-245	1.19	385	975
1965 Mustang	289	Without device	A-289	4.36	804	702
1965 Mustang	289	With device	A-281	2.51	525	563
1965 Ford	352	Without device	A-228	1.61	308	931
1965 Ford	352	With device	A-247	1.38	206	569
1965 Ford	390	Without device	A-249	2.73	431	1166
1965 Ford	390	With device	A-250	0.89	240	1107

(1) Emission results obtained by California 7-cycle, 7-mode test procedure (Reference 115), hot cycles only.

For these seven vehicles, average reductions of exhaust emissions after installation and adjustment of the system are shown in Table 4-17.

Table 4-17. DEVICE 325/433 AIR-VAPOR BLEED TO INTAKE MANIFOLD AVERAGE PERCENTAGE EMISSION REDUCTION (1)

VEHICLE CONFIGURATION	POLLUTANT		
	HC (PPM)	CO (%)	NOx (PPM)
Without Device	494	3.14	876
With Device	347	2.03	791
Percent Reduction	29.7	32.1	10.0

(1) Average of seven hot-cycle tests reported in Table 4-16.

These results indicate that the device may be effective in controlling HC and CO. Further testing for cold and hot start conditions would be required to verify the overall effectiveness of the device.

4.1.4.4 Reliability

The developer reported that approximately 10,000 production units of Device 325/433 have been installed and have accumulated 5 million vehicle miles, with no failure reported. Based on an examination of the device, it should exceed 50,000 MMBTF, if installed and maintained according to specification.

4.1.4.5 Maintainability

The developer specified maintenance requirements as follows:

1. The vapor injector must be checked and serviced regularly for maximum efficiency.

2. The device should receive the maintenance attention as given other vehicle components.

3. The fluid level should be checked regularly and serviced every 90 days or 2,500 miles, whichever occurs first. The unit should be cleaned and filled with new fluid, and the air filter checked and changed when dirty.

Additional maintenance would include checking the air needle bleed hole by using a wire-type feeler gauge or other appropriate probe, and a visual inspection of the vapor injection system to assure that the unit is aerating and that all connections are secure. It is estimated that the maintenance required can be performed in less than 30 minutes.

4.1.4.6 Driveability and Safety

The developer reported that there are no adverse effects from the device on vehicle driveability. There appear to be no safety hazards. The device has indicated no problems over 5 million vehicle miles.

4.1.4.7 Installation Description

The installation of Device 325/433 consists in mounting the alcohol-water reservoir in the engine compartment in a near vertical position, installing an adapter plate between the carburetor and intake manifold, replacing the idle adjustment screws with special screws, installing the metering valve in the PCV line, connecting the hoses, and filling the reservoir with the special fluid.

Adjustment consists in setting the engine idle to factory specifications, and retarding the spark by 2 or 3 degrees if necessary. The developer states that to obtain the best results from the vapor injector, installation should be accomplished by a "certified service man or engine mechanic."

Table 4-18 summarizes the installation requirements. The developer estimated that the installation of the system would take about one hour. Installation can be accomplished in a normally equipped repair shop by the average mechanic.

4.1.4.8 Initial and Recurring Costs

According to the developer, the cost of the device installation is $40. Table 4-19 summarizes the estimated total installation costs for this device. From the information available, it is estimated that the initial cost of this device, including material, would be $55.62.

4.1.4.9 Feasibility Summary

This device represents a twofold approach to achieving reduced emissions of CO and HC by air and vapor dilution of the air-fuel mixture. Further testing would appear to be required to determine the relative contribution of each approach to emission control over a range of vehicles and test conditions, as well as to determine the overall cost effectiveness of these related approaches.

Table 4-18. DEVICE 325/433 AIR-VAPOR BLEED TO INTAKE MANIFOLD INSTALLATION PROCEDURE

MINIMUM AVERAGE SKILL LEVEL: AUTOMOTIVE MECHANIC		
INSTALLATION AND ADJUSTMENT PROCEDURE	TOOLS, EQUIPMENT AND FACILITIES	TIME (MIN.)
1. Drill or punch holes for reservoir mounting bracket, using sheet metal screws provided in kit. Reservoir is to be mounted in the engine compartment in a near vertical position, preferably away from exhaust manifold.	a. Electric drill b. Sheet metal screws c. Mounting bracket	25
2. Remove plug from top of reservoir and fill with special fluid, replace plug.	Special fluid	5
3. Install reservoir in mounting bracket.	Special fluid	3
4. Attach hose to outlet in reservoir.	a. Hose b. Clamp	2
5. Install metering valve in vacuum line between PCV valve and intake manifold.	a. Metering valve b. Knife c. Clamps or hand tools d. Adapter plate	2
6. Attach hose from reservoir to metering valve.	Clamps	2
7. Remove stock air-idle adjustment screw and screw in special replacement screw.	Special idle adjustment screw	5
8. Start vehicle engine and allow it to warm up to normal operating temperature.		10
9. Place the transmission in neutral until chemical has a smooth boil of bubbles. Race engine so that during the short thrusts of power, the solution will not boil up and be drawn into the outlet tube as a liquid.		6
10. Attach a tachometer and set the idle to factory specifications.	Tachometer	10
11. Most vehicles can be changed to regular fuel without further adjustment. It may be necessary to retard spark by 2 or 3 degrees.	Engine analyzer	5
	Total Time	1.25 hr

Table 4-19. DEVICE 325/433 AIR-VAPOR BLEED TO INTAKE MANIFOLD INITIAL AND RECURRING COSTS

ITEM	DESCRIPTION	LABOR HOURS OR ITEM QUANTITY	COST (DOLLARS)
Initial Cost:			
Material			
1. Device	a. Fluid reservoir b. Metering valve or adapter plate c. Special idle adjustment screw		40.00
2. Miscellaneous	a. Mounting bracket b. Sheet metal screws c. Special fluid d. Hose and clamps		(Included in above)
Labor			
1. Installation	Table 4-18	1 hr.	12.50
2. Test and adjust	Table 4-18	0.25 hr	3.12
		Total Initial Cost	$55.62
50,000-Mile Recurring Cost:			
Material			
1. Alcohol-water mix	Alcohol additive	$2.30/refill at 2,500-mile intervals	46.00
Labor			
1. Inspect and service		0.5 hr every 2,500 miles: 10 x $12.50	125.00
		Total Recurring Cost	$171.00
		TOTAL COSTS	$226.62

4.1.5 Device 401: Air-Vapor Bleed to Intake Manifold

This device operates on the same air-vapor bleed principle as Device 325/433. Device 401, however, utilizes only the intake manifold as the air-vapor bleed intake point.

4.1.5.1 Physical Description

Device 401 is called a vapor injector, and consists of an alcohol-water fluid storage bottle with hose connections to the intake manifold. Figure 4-13 shows a typical system installation. The fluid storage bottle (B) is of 2-quart capacity and is mounted in the engine compartment away from exhaust heat. It is connected through hoses (D) to one of the primary vacuum lines. If connected to the PCV line (E) as shown, the unit must be teed in downstream of the PCV valve. The vapor injector metering valve (A) is located on the bottle.

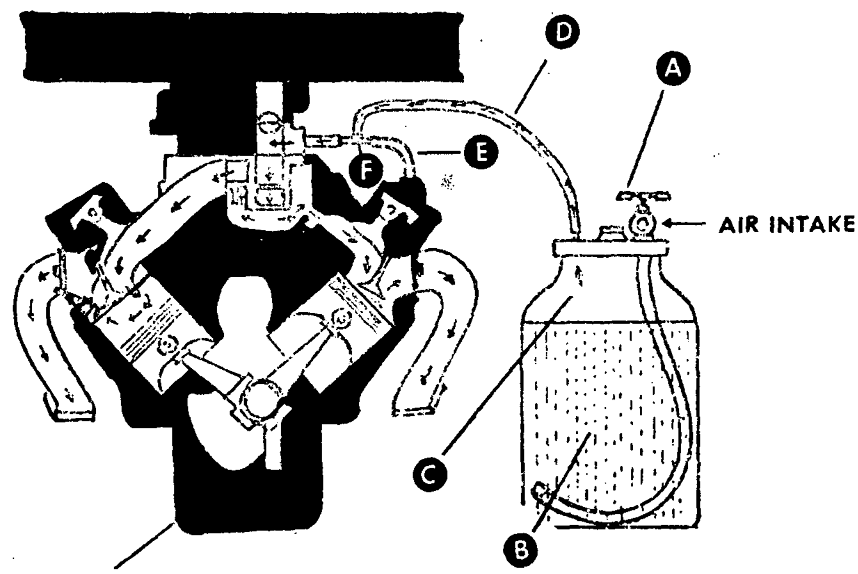


Figure 4-13. DEVICE 401 AIR-VAPOR BLEED TO INTAKE MANIFOLD SYSTEM CONFIGURATION (DEVELOPER DIAGRAM)

4.1.5.2 Functional Description

The vapor injection system operates on the principle of injecting an alcohol-water-air vapor mixture into the combustion process of the engine to enhance combustion and the formation of fewer pollutant byproducts. The vapor is typically drawn into the intake manifold through the PCV inlet downstream of the PCV valve. The metering valve operates on a low vacuum and supplements the flow or crankcase blowby from the PCV valve to the manifold with the alcohol-water-air vapor from the fluid storage bottle. A metering orifice in the valve limits the total flow of vapor.

Flow is achieved in the fluid storage bottle by venting the bottom of the fluid to atmosphere and drawing a vacuum on the bottle above the fluid level causing the air to pass through the liquid. The resulting air-vapor mixture is drawn into the PCV line to the intake manifold, under intake manifold vacuum.

4.1.5.3 Performance Characteristics

The developer provided results of emission tests performed on a 1970 Chevrolet prior to the retrofit program. These results are summarized in Table 4-20. The device indicates emission control characteristics similar to the air bleed class. CO reduction is average for an air bleed, whereas HC is typical. The increase in NOx further classifies the device as basically an air bleed type. This increase in NOx would indicate that not enough fluid enters the intake manifold to have any cooling effect on combustion temperature.

Table 4-20. DEVICE 401 AIR-VAPOR BLEED TO INTAKE MANIFOLD EMISSION TEST RESULTS REPORTED BY DEVELOPER

VEHICLE CONFIGURATION (1)	POLLUTANT (GM/MI)		
	HC	CO	NOx
Without Device	1.76	23.73	5.64
With Device	1.33	15.63	7.39
Percent Reduction	25.0	34.1	-31.0

(1) Results of one set of 7-cycle, 7-mode, cold-start tests performed on a 1970 Chevrolet with 350-CID engine, with and without the device installed.

4.1.5.4 Reliability

This device is sufficiently similar to Devices 325 and 433 to estimate that its reliability exceeds 50,000 MMBTF.

4.1.5.5 Maintainability

The developer indicates that the 2-quart fluid supply must be replenished at about two-month intervals, the equivalent of about 2,000 miles. It is estimated that addition of the fluid and any necessary readjustment of the flow rate valve can be accomplished in less than 10 minutes. Two quarts of the fluid costs $2.50.

4.1.5.6 Driveability and Safety

Although driveability data were not provided by the developer, it would appear that the device would have about the same driveability characteristics as the other air bleed devices. The device is a production system and thus is apparently in use. No safety hazards are apparent.

4.1.5.7 Installation Description

Installation of Device 401 consists in mounting a fluid reservoir in the engine compartment, and connecting a hose from the reservoir to the intake manifold. Adjustment of the device consists in adjusting the flow of air through the air intake valve on the fuel reservoir with the engine running, until the bubbles breaking the surface are too numerous to count. Adjustment of the engine consists in setting the ignition timing and ignition point dwell to factory specifications, and adjusting the engine idle rpm.

Table 4-21 presents the details of the installation requirements. Installation can be accomplished in a normally equipped repair shop with an average mechanic skill level.

Table 4-21. DEVICE 401 AIR-VAPOR BLEED TO INTAKE MANIFOLD INSTALLATION PROCEDURE

MINIMUM AVERAGE SKILL LEVEL: AUTOMOTIVE MECHANIC		
INSTALLATION AND ADJUSTMENT PROCEDURE	TOOLS, EQUIPMENT AND FACILITIES	TIME (MIN.)
1. Make sure car is in sound mechanical condition; rings, valves, carburetor, vacuum lines tight, clean air filter, PCV valve working.	Hand tools	15
2. Find vertical place in engine compartment away from excessive heat and install mounting bracket for reservoir.	a. Hand tools b. Mounting bracket	10
3. Mount reservoir in bracket and fill with fluid mixture.	a. Fuel reservoir b. Fluid	5
4. Cut line between PCV valve and intake manifold. Insert T-fitting into this line.	a. Hand tools b. T-fitting	5
5. Connect hose from T-fitting to reservoir.	Hose	5
6. Start engine and adjust the flow of air through the air intake valve on the reservoir until the bubbles breaking the surface are too numerous to count.		5
7. Set the dwell on the ignition points at this time to factory specifications.	Engine analyzer	5
8. Adjust engine idle speed.	Engine Analyzer	2
9. Set ignition timing to factory specifications	Engine analyzer	8
	Total Time	1 hr

4.1.5.8 Initial and Recurring Costs

The developer estimated that the cost of the device would be $30 and the fluid $2.50. Table 4-22 summarizes the overall costs for this device. From the information available, it is estimated that the cost for installing this device, including material, would be $45.50.

4.1.5.9 Feasibility Summary

Device 401 is basically an air bleed device. The test data provided by the developer indicates some effectiveness for HC and CO reduction. There appear to be no safety hazards or reliability problems. The filling of the fluid reservoir with an alcohol-water mixture every two months or so is the principal recurring cost.

The device appears to be technically feasible as a candidate retrofit device to reduce HC and CO, and is available on the automotive accessory market. Whether the device is as cost effective for a variety of used cars as other less expensive air bleed devices should be evaluated in further tests of these devices.

Table 4-22. DEVICE 401 AIR-VAPOR BLEED TO INTAKE MANIFOLD INITIAL AND RECURRING COSTS

ITEM	DESCRIPTION	LABOR HOURS OR ITEM QUANTITY	COST (DOLLARS)
Initial Cost:			
Material			
1. Device	a. Fuel reservoir b. Mounting bracket c. T-fitting		30.00
2. Miscellaneous	a. Fluid b. Hose		3.00
Labor			
1. Installation	Table 4-21	0.75 hr	9.38
2. Test and adjust	Table 4-21	0.25 hr	3.12
		Total Initial Cost	45.50
50,000-Mile Recurring Cost:			
Material			
1. Refill fluid reservoir	Refer to paragraph 4.1.5.5	2 quarts every 2,000 miles x $2.50 for 50,000 miles	62.50
		Total Recurring Cost	62.50
		TOTAL COSTS	108.00

4.1.6 Device 418: Air Bleed to Intake Manifold

This device uses the crankcase blowby return line as the means of introducing additional air to the intake manifold. This is the same approach to air bleed intake as used by Device 401, described in the preceding paragraphs. If the vehicle is originally equipped with a PCV system, it is designed to provide some air ventilation through the crankcase which tends to lean the carburetor mixture. On the other hand, the blowby gases which leak past the piston rings are mostly air-fuel mixture, and when recirculated to the intake manifold, does not change the carburetor air-fuel ratio appreciably. Only limited evaluation of this approach was possible in the retrofit study, as the developer did not respond to the data survey questionnaire. Data presented below are based on emission tests performed on the device by EPA (Reference 88).

4.1.6.1 Physical Description

Device 418 is small, tubular in shape, and is installed in the PCV line according to the manufacturer's instructions. The standard PCV valve is left in place.

4.1.6.2 Functional Description

Under high vacuum conditions use of Device 418 results in the bleeding-in of additional air. In the EPA tests, the flow through the PCV line under high intake manifold vacuum (12 inches mercury and higher) increased from about 2 cubic feet per minute without the device, to 4.5 cfm with the device. This was an increase of 125 percent under idle type conditions. At low vacuum (6 to 30 inches of water) PCV flow with the device installed was restricted up to 45 percent of normal flow.

4.1.6.3 Performance Characteristics

The device was tested by EPA installed in the PCV line of a 1970 Chevrolet Impala, a 1970 Plymouth Valiant, and a 1963 Ford. The Impala was equipped with an automatic transmission and a 350-CID engine. The Valiant was equipped with an automatic transmission and a 225-CID engine. The 1963 Ford had a 269-CID engine with automatic transmission. Indolene 30 was used for testing of the Impala and the Ford while Indolene Clear was utilized for the Valiant.

Table 4-23 summarizes the results of tests to the 1972 Federal Test Procedure. For the 1970 Impala, use of the 1972 Federal Test Procedure showed that HC and CO were reduced, but NOx increased 4 percent. The 1963 Ford showed a decrease of HC and CO, and a 35 percent increase in NOx. The Valiant showed a reduction of 20% for HC, 48% CO, and 10% for NOx.

In addition to the emission tests described in the previous section, two other tests were employed to further evaluate the device. Fuel consumption was measured during each emission test. The Valiant equipped with the device showed a 9 percent reduction in fuel consumption during the 1972 Federal Test Procedure evaluations. On the other hand, the Impala used 7 percent more fuel during 1972 Federal Test Procedure tests when equipped with this device. The Ford used 4 percent less fuel when equipped with the device.

Table 4-23. DEVICE 418 AIR BLEED TO INTAKE MANIFOLD
MEAN EMISSION TEST RESULTS (REFERENCE 88) (1)

VEHICLE CONFIGURATION	POLLUTANT (GM/MI)			NUMBER OF TESTS
	HC	CO	NOx	
1970 Valiant:				
Without Device	2.78	48.02	6.27	6
With Device	2.00	25.40	5.62	4
Percent Reduction	28	48	10	
1970 Impala:				
Without Device	4.83	48.60	5.2	8
With Device	3.79	25.26	5.4	3
Percent Reduction	22	48	-4	
1963 Ford:				
Without Device	6.56	98.19	3.65	2
With Device	5.96	46.70	4.94	4
Percent Reduction	10	52	-35	
(1) Average of results obtained with 1972 Federal Test Procedure (Reference 3)				

4.1.6.4 Feasibility Summary

It was not possible to evaluate this device for reliability, maintainability, driveability, and safety, or costs because the necessary data were not available.

Carbon monoxide emissions were substantially reduced by the installation of the device. Because the device caused additional leaning of the air-fuel mixture, very lean running vehicles might develop adverse driveability effects with installation of the device. A sizeable portion of new vehicles currently operate close to the lean limit of combustion. Although the NOx did not react consistently to the installation of the device, the increasing NOx emissions from two of the vehicles (Impala and Ford) appear to be the only adverse effects of the leaning.

Fuel consumption effects ranged from a 9 percent savings to a 7 percent penalty on the Impala. No conclusion as to the effect of this device on fuel consumption can be made. Based on the performance of other air bleed devices, Device 418 could be expected to provide some fuel economy.

Considering the overall test results, Device 418 indicates satisfactory effectiveness for the control of CO exhaust pollutant, but less significance for control of HC and none for NOx.

4.1.7 Device 458: Air Bleed to Intake Manifold

The sole source of information on this device was an EPA test report (Reference 89). This device operates on the air-bleed principle by adding a mixture of air and vaporized chemical to the piston blowby gas returning to the intake manifold from the crankcase. The device connects into the positive-crankcase-ventilation return line. This type of system hookup is similar to that of Device 401 (paragraph 4.1.5). The amount of air-vapor mixture added to the piston blowby gas is controlled by amount of intake manifold vacuum.

The device was tested by EPA as part of its continuing evaluation of retrofit devices for used cars. The results of these tests are summarized in Table 4-24.

Table 4-24. DEVICE 458 AIR BLEED TO INTAKE MANIFOLD
EMISSION TEST RESULTS (REFERENCE 89) (1)

VEHICLE CONFIGURATION (2)	POLLUTANT (GM/MI)			NUMBER OF TESTS
	HC	CO	NOx	
Without Device	2.7	28	3.7	1
With Device	2.8	26	4.0	2
Percent Reduction	-3.7	7	-8.1	
No Fluid (3)	2.3	24	2.7	
Percent Reduction	14.8	14	27.0	

(1) Average of results using 1970 Federal Test Procedure (Reference 15).

(2) 1968 Ford Falcon with 200-CID, six-cylinder engine and normal transmission; equipped with original air injection pump.

(3) Device hardware hooked up, but no fluid in container.

The EPA report concluded that:

> "The effectiveness of the vapor injector device for reducing emissions is apparently a function of the air bled into the manifold. This results in a leaner air-fuel mixture."

Based on this test program, it would appear that Device 458 has marginal effectiveness for exhaust emission control even when used only as an air-bleed system. As concluded in the EPA report, "equivalent results could be obtained by using a very lean idle setting."

4.1.8 Device 462: Air Bleed to Intake and Exhaust Manifolds

This device appears to operate on the air-bleed principle by allowing filtered air to be drawn into the piston blowby return line to the intake manifold. The device also appears to incorporate a rudimentary form of thermal reaction in that it also allows air to enter the exhaust manifold. These two principles combined constitute a twofold approach to the control of CO and HC. The intake air bleed decreases the amount of CO and HC generated during combustion, and the exhaust air bleed may continue the oxidation process in the exhaust manifold.

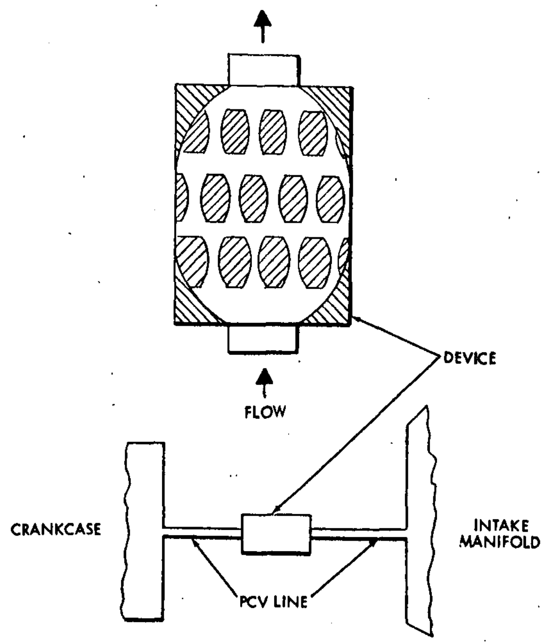
The only information obtained on this device was in an EPA exhaust emission test report (Reference 90). The following description of the device was provided in that document:

> "The (device) is a two part system containing an 'exhaust scavenger' and a 'crankcase scavenger.' The exhaust scavenger is a pipe with a one-way valve that is connected to the exhaust through holes that must be drilled and tapped into the exhaust manifold. Under any condition of low pressure in the manifold, air will be drawn through a valve and filter from the engine compartment into the manifold. The crankcase scavenger is a large diameter tube containing plates with drilled holes to allow air passage and a filter. This unit is installed in the positive crankcase ventilation (PCV) line with the interior working parts of the PCV removed. This allows an increase in air flow at idle as there is no idle restriction in the crankcase scavenger as is normally found in the PCV system. The total effect of this device is to admit additional air to the manifold, thus providing a leaner fuel-air mixture to the engine. . . .
>
> "In the Government installation of the (device) the only portion of the emission control system disconnected was the PCV valve as required in the instructions. On the vehicle converted. . . the PCV valve was disconnected and the heat stove that supplies warm air to the carburetor was cut into to provide clearance for the device. The effect of this system is unknown but considered minimal."

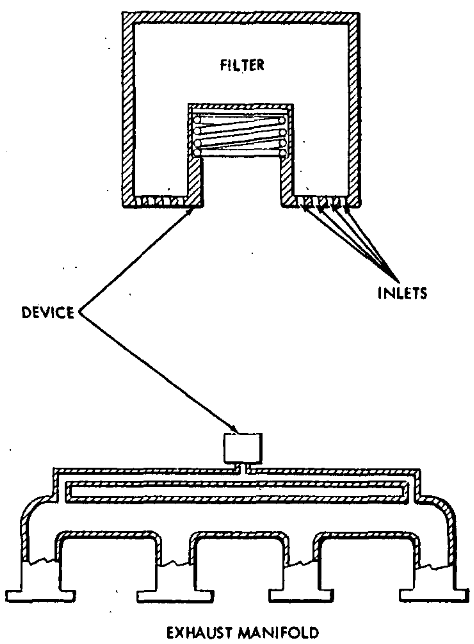
Figure 4-14 shows a sketch of the two parts of the overall system, as provided in an attachment to the EPA report.

The results of emission tests performed by EPA are summarized in Table 4-25. The EPA report concluded that the emission reduction effectiveness of the device was minimal, and that equivalent results could be obtained by using a lean idle setting. The report also said that there were no fuel economy improvements shown for the device based on the tests performed.

This limited evaluation indicates that Device 462 would be a marginal candidate for retrofit on used cars to control their exhaust emissions. Further study using detailed device data would be required to evaluate the overall cost effectiveness of this device as a retrofit emission control.



(a) Intake Air Bleed



(b) Exhaust Air Bleed

Figure 4-14. DEVICE 462 AIR BLEED TO INTAKE AND EXHAUST MANIFOLDS FUNCTIONAL AND INSTALLATION SCHEMATICS (REFERENCE 90)

Table 4-25. DEVICE 462 AIR BLEED TO INTAKE AND EXHAUST MANIFOLDS
MEAN EMISSION TEST RESULTS (REFERENCE 90)

VEHICLE CONFIGURATION	POLLUTANT (GM/MI)			NUMBER OF TESTS	
	HC	CO	NOx		
1963 Chevrolet (1)				HC/CO	NOx
Without Device	8.8	90	1.8	8	4
With Device	7.2	89	1.4	6	3
Percent Reduction	18	1	22		
1968 Falcon (2)					
Without Device	3.5	35	5.5	2	
With Device	3.1	29	6.4	3	
Percent Reduction	11	17	-16		
Weighted Percent Reduction (1) and (2)	24.6	10.1	-30		
1968 Falcon (3)					
Without Device	3.0	29	3.9	2	
With Device	2.3	24	3.9	1	
Percent Reduction	23	17	0		

(1) 1963 Chevrolet V-8 with manual transmission, HC and CO average of eight tests without and six tests with the device installed, and NOx average of 4 tests without and 3 tests with device installed. All tests performed using the 1972 Federal Test Procedure (Reference 3).

(2) 1968 Ford Falcon with 200-CID six-cylinder engine and manual transmission, average of two tests without and three tests with the device installed, using 1972 procedure.

(3) Same vehicle as (2), average of two tests without and one test with the device installed, using 1970 Federal Test Procedure (Reference 15).

4.2 EXHAUST GAS RECIRCULATION - RETROFIT SUBTYPE 1.2.2

Exhaust gas recirculation (EGR) systems are intended to reduce nitrogen oxide emissions by recirculating a portion of the exhaust gases to the combustion chamber. Recirculated exhaust gas provides an essentially inert dilutant in the fuel-air mixture entering the combustion chamber. This increases the heat capacity of the gas mixture, decreasing combustion temperature with corresponding decrease in the formation of nitrogen oxides (Reference 116). The product of exhaust gas flow rate and specific heat have been found to correlate with NOx reduction (Reference 117).

Recirculated exhaust gas is typically ported through a line between a bleed tap in the exhaust system and an injection port in the intake manifold. The amount of exhaust gas recirculated to the induction system is a function of the line resistance and differential pressure between the exhaust bleed port and intake injection port. The amount of exhaust gas recirculated may be controlled by inserting a metering orifice in the connecting line. Since the amount of gas recirculated also depends on pressure differential between the exhaust system and intake port, the amount of recirculated gas may also vary with operating mode. For example, a decrease in manifold vacuum, as during an accelerating mode, could cause a corresponding decrease in the portion of recirculated exhaust gas.

Exhaust gas recirculation either as a single approach or combined with a control approach for HC and CO offers potential for NOx control. A problem of concern is the compatibility of the exhaust gas recirculation approach with companion control approaches for HC and CO emissions. The recirculation systems must be designed to operate in exhaust gas environment without performance degradation either in itself or other engine components as a result of exhaust gas deposits and contamination.

An example of an apparently compatible combination for EGR is that represented by Device 57, Air Bleed with EGR and Vacuum Advance Disconnect, described in paragraph 4.1.3. How much an air bleed may negate the NOx inhibition of EGR is a question not yet answered.

Among the four devices discussed in this section (refer to Table 4-1), Devices 10, 246, and 294 represent combination approaches in which EGR is the principal device cost factor. Devices 10 and 246 combine EGR with vacuum advance disconnect, and Device 294 combines EGR with an experimental carburetor. Device 245 was the only retrofit system found that used EGR as a single approach to emission control, and does so without external recirculation of the exhaust gas.

Devices 10 and 246 - though similar in approach in combining EGR with vacuum advance disconnect - operate differently. Device 10 uses vacuum advance disconnect at all speeds, whereas Device 246 uses it only at idle and below 26 mph, when the EGR system is not operative. Both of these devices were tested in the retrofit study program.

Insufficient data were available on Device 294 to determine its approach to EGR.

4.2.1 Device 10: Throttle-Controlled Exhaust Gas Recirculation with Vacuum Advance Disconnect

This device is a carburetor fuel vaporizer modification that incorporates throttle-controlled exhaust gas recirculation with vacuum advance disconnect. The device was tested for emission reduction effectiveness, fuel consumption, and driveability in the retrofit program. The device has been a candidate for accreditation as a used car retrofit device in California (Reference 80).

4.2.1.1 Physical Description

A system installation of Device 10 is shown in Figure 4-15. The device provides the following emission control techniques:

1. The carburetor inner venturi cluster is replaced with a "vaporizer" which consists of a tubular insert mounted in the venturi inlet. Fuel is metered downward through the insert to an injector head. The injector head contains an array of 20 injector holes through which fuel is injected laterally in the plane of the venturi throat.(1)

2. An exhaust recirculation line is added which recirculates a small fraction of exhaust gas from a point upstream of the muffler to a point downstream of the carburetor throttle plate into the intake manifold. The exhaust recirculation line is a 3/8-inch tubing. Exhaust gas enters the intake manifold through a port in an adapter plate mounted between the carburetor and intake manifold. The adapter plate also includes a control valve which permits increased exhaust gas recirculation as the throttle setting is increased. The recirculation valve operates by a ball chain attached to the throttle linkage. A preset amount of slack in the chain permits small throttle openings without recirculating exhaust gas. Thus, there is no recirculation at idle or low speeds. Flow of recirculated gas would be less at wide open throttle settings due to low manifold pressures, except that this is compensated for by the opening of the throttle-controlled butterfly control valve, which increases the flow of exhaust gas.

3. A thermostatic vacuum switch is installed on the radiator return hose and the distributor vacuum advance line is routed through this switch. Under normal water temperature conditions the thermostatic vacuum switch closes the vacuum line between the carburetor and distributor, rendering the vacuum advance inoperative.

4.2.1.2 Functional Description

Functional characteristics of the emission control system may be summarized as follows:

1. The varporizer replacing the main fuel discharger nozzle in the venturi throat provides for more complete and homogeneous mixing of fuel and air.

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(1) As noted in paragraph 4.2.1.6, this vaporizer was not included on one of the cars tested in the retrofit program.

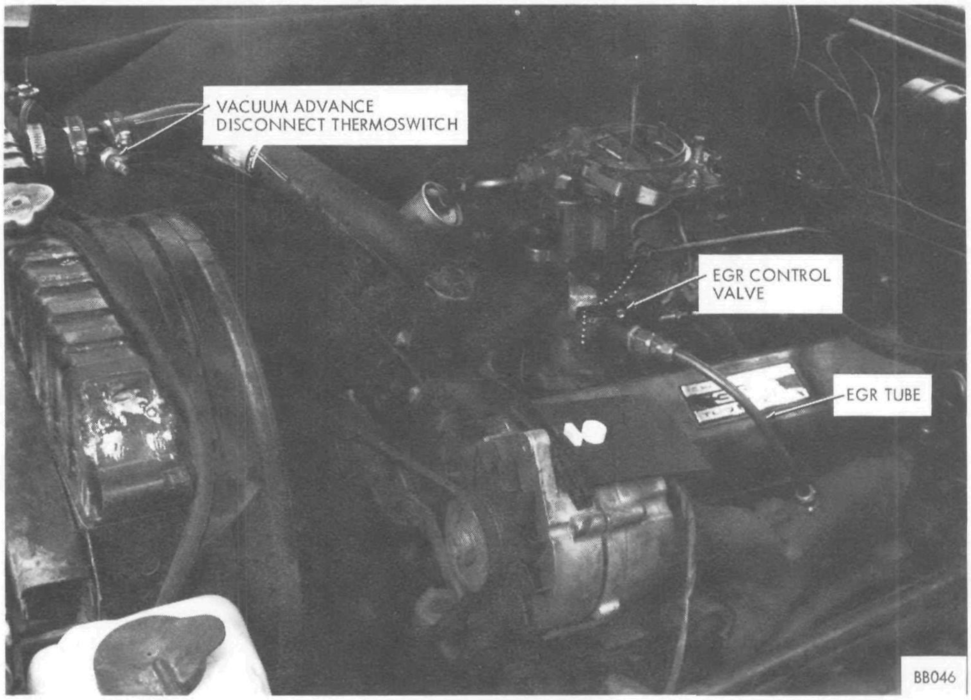


Figure 4-15. DEVICE 10 THROTTLE-CONTROLLED EGR WITH VACUUM ADVANCE DISCONNECT SYSTEM CONFIGURATION

2. The exhaust gas recirculation system between exhaust and intake manifolds lowers combustion temperatures and resulting NOx emission reduction at mid- to wide-open-throttle positions.

3. The distributor vacuum advance is normally disconnected to provide reduced combustion residence time. This is intended to provide reduced burning time in the cylinders and reduction in the formation of NOx emissions. This also promotes additional burning of hydrocarbons in the exhaust manifold. If the engine begins overheating as a result of the disconnected vacuum advance, the thermostatic switch located in the radiator return hose opens and restores the vacuum advance to normal operation.

4.2.1.3 Performance Characteristics

Table 4-26 presents emission reduction characteristics of Device 10 based on data measured in the retrofit test program. The device showed an average emission reduction of 37 percent for HC, 29 percent for CO, and 54 percent for NOx. Additional emission reduction data were reported in Reference 80. This report showed a 50-car average emission reduction of 36 percent for HC, -0.5 percent (increase) for CO, and 56 percent for NOx. Tests performed in the retrofit study were in accordance with the 1972 Federal Test Procedure CVS mass measurements (Reference 3) while the tests performed in the Reference 80 program were in accordance with 7-mode, 7-cycle concentration measurement procedures (Reference 115).

Table 4-26. DEVICE 10 THROTTLE-CONTROLLED EGR WITH VACUUM ADVANCE DISCONNECT EMISSION REDUCTION AND FUEL CONSUMPTION PERFORMANCE (1)

VEHICLE YEAR/MAKE/CID	ANAHEIM TEST RESULTS			
	POLLUTANT GRAMS/MILE			FUEL MILES/ GALLON
	HC	CO	NOx	
1965 Chev 327 Without Device With Device	 9.17 4.96	 66.67 40.69	 3.46 1.54	 13.22 13.70
Percent Reduction	45.9	39.0	55.5	-4.0
1961 Chev 283 Without Device With Device	 6.33 4.59	 89.96 73.50	 2.19 1.06	 12.54 12.15
Percent Reduction	27.5	18.3	51.6	3.1
Mean Percent Reduction	36.7	28.7	53.6	-0.5

(1) Emission results obtained by Olson Laboratories in tests performed under Contract 68-04-0038 using 1972 Federal Test Procedure (Reference 3). Fuel consumption was measured during these tests.

4.2.1.4 Reliability

Evaluation of the test results in the referenced Northrop report indicate that the system has a potential reliability in excess of 50,000 mean-miles-before-total-failure provided certain deficiencies are corrected. Of particular note were the failures of the exhaust gas recirculation valves which were prone to stick in the open position. This was attributed to the buildup of carbon deposits inside the valve.

The thermostatic override control for the vacuum advance is another reliability-critical component. Although no engine (or retrofit system) failures were attributed to this component, recommendations were made in the Northrop report to provide greater confidence in the reliability of the device (Reference 80).

4.2.1.5 Maintainability

Assuming that product improvements are made beyond the previously tested configuration, it is anticipated that routine maintenance could be performed within 30 minutes (MTTM) at 12,000-mile intervals (MMBM). This maintenance would consist of an inspection of lines and fittings and cleaning of the EGR valve. Also the thermostatic switch should be tested for correct functioning. A means of testing this switch should be incorporated integral to the switch.

4.2.1.6 Driveability and Safety

During the retrofit study, this device was tested on two cars at the Olson Laboratories' Anaheim facility. Tests were run on Retrofit Test Vehicle Cars 4 and 6. Table 4-27 summarizes the driveability results of these tests. The main effect of the device appeared to be an increase in 0-60-mph acceleration time.

Table 4-27. DEVICE 10 THROTTLE-CONTROLLED EGR WITH VACUUM ADVANCE DISCONNECT DRIVEABILITY TEST RESULTS

DRIVEABILITY CHARACTERISTICS	1965 CHEV. 194 CID	1965 FORD 289 CID	1965 PLY. 318 CID	1965 CHEV. 327 CID	1965 FORD 390 CID	1961 CHEV. 283 CID
	ANAHEIM, CALIF., DRIVEABILITY TEST RESULTS (1)					
	CAR NO. 1	CAR NO. 2	CAR NO. 3	CAR NO. 4	CAR NO. 5	CAR NO. 6
CRITICAL DRIVEABILITY	(1)	(1)	(1)	Decreased stall during cold start deceleration	(1)	No effect
GENERAL DRIVEABILITY				Reduced cranking time during cold start; reduced stall during cold start idle		Increased number of attempts to start during cold start; increased rough idle during cold start idle; increased stumble during cold start acceleration, increased number of attempts to start during hot start
0 - 60 MPH ACCELERATION TIME (SECONDS)				Increased from 11.2 to 11.35		Increased from 15.3 to 20.0
60 - 40 MPH DECELERATION TIME (SECONDS)				No data		Decreased from 24 to 22.5
GAS MILEAGE PER GALLON	Average increase of 0.5 percent (reference Table 4-26)					

(1) Device 10 was not tested on these vehicles.

The developer included a special carburetor cluster as part of the device installation on Car 6. It is suspected that this was the cause of the rough idle and carburetion problems during the test of Car 6 with the device installed. The carburetor cluster was experimental and apparently not perfected. This cluster was not installed as part of the test on Car 4.

No system hazards or safety problems were indicated for this device, provided that:

1. The exhaust gas recirculation valve does not jam the throttle open. It appears that the ball chain linkage could preclude this possibility if the system design and installation is correct for the specific engine/carburetor configuration.

2. The thermostatic switch does not fail in an unsafe vehicle driving mode; for example, failure of the switch may or may not result in activating the distributor vacuum advance mechanism. Inability to provide for the fail-safe mode could result in catastrophic engine overheating or unexpected reactivation of vacuum advance.

3. A leak does not occur in the tube from the exhaust manifold to the carburetor adapter plate (fatigue or corrosion). Although this mode of failure could ultimately result in burned valves, the failure should cause obvious performance changes prior to engine failure; however, under certain conditions of operation, the vehicle driver and passengers might be exposed to the possibility of exhaust gas inhalation.

4.2.1.7 Installation Description

The installation of this device consists in installing an adapter plate with EGR control valve between the carburetor and intake manifold, replacing the inner venturi in the carburetor with the vaporizer, connecting a recirculating tube from the exhaust pipe to the adapter plate on the carburetor, and installing a thermostatic vacuum advance disconnect switch in the radiator return line. The adjustments required after installation consist in setting the carburetor to new idle rpm values.

Table 4-28 presents the step-by-step installation procedure. Figure 4-15 shows a typical installation. Installation can be accomplished in a normally equipped automobile repair shop with normal skills.

4.2.1.8 Initial and Recurring Costs

The developer stated that the system can be installed by an average mechanic in about one hour, and should retail for under $65.00. It is estimated that the installation cost, including material, would be $70.62.

Table 4-29 summarizes costs for this device.

4.2.1.9 Feasibility Summary

The recent California evaluation of Device 10, involving installation and evaluation of this device on 50 uncontrolled cars, may be summarized as follows: (Reference 80).

1. <u>Emissions</u>: 50-vehicle average percentage reduction (7-cycle, 7-mode concentration measurement test procedure):

HC	CO	NOx
36%	-0.5% (increase)	56%

Table 4-28. DEVICE 10 THROTTLE-CONTROLLED EGR WITH VACUUM ADVANCE DISCONNECT INSTALLATION PROCEDURE

MINIMUM AVERAGE SKILL LEVEL: AUTOMOTIVE MECHANIC		
INSTALLATION AND ADJUSTMENT PROCEDURE	TOOLS, EQUIPMENT AND FACILITIES	TIME (MIN.)
1. Remove carburetor and studs from intake manifold	Hand tools	12
2. Install longer studs in intake manifold	a. Hand tools b. Studs	4
3. Install adapter plate over studs or intake manifold	Adapter plate	2
4. Disassemble carburetor and remove inner venturi	Hand tools	3
5. Install vaporizer in place of inner venturi and reassemble carburetor	a. Hand tools b. Vaporizer	3
6. Install carburetor with adapter plate between carburetor and intake manifold	Hand tools	6
7. Burn hole in exhaust pipe before muffler and weld in connection for recirculating tube	Oxyacetylene welder connection	15
8. Connect recirculating tube to recirculation control valve, which is connected to adapter plate	Recirculating tube	1
9. Connect linkage from recirculation control valve to throttle linkage	Hand tools	2
10. Install thermostatic vacuum switch in radiator hose	Hand tools	10
11. Connect thermostatic vacuum switch to intake manifold and to vacuum advance on distributor	Hand tools	2
12. Adjust throttle to give 600-rpm curb idle for automatic transmissions and 700-rpm idle in neutral for manual transmissions	a. Tachometer b. Hand tools	15
	Total Time	1.25 hr

Table 4-29. DEVICE 10 THROTTLE-CONTROLLED EGR WITH VACUUM ADVANCE DISCONNECT INITIAL AND RECURRING COSTS

ITEM	DESCRIPTION	LABOR HOURS OR ITEM QUANTITY	COST (DOLLARS)
Initial Cost:			
Material			
1. Device	a. Adapter plate b. APC vaporizer c. Recirculating tube d. Thermostatic vacuum switch		55.00
2. Miscellaneous	a. Studs for intake manifold b. Pipe connector		(Included in above)
Labor			
1. Installation	Table 4-28	1 hr	12.50
2. Test and adjust		0.25 hr	3.12
		Total Initial Cost	$70.62
50,000-Mile Recurring Cost:			
Material			
1. Fuel	Note: The 0.5 percent fuel savings indicated for this device is considered to be of marginal significance considering the possibility of experimental error.		
Labor			
1. Inspection	Paragraph 4.2.1.5	Four 0.5 hr. inspections @ 12,000-mile intervals x $12.50 per hr	25.00
		Total Recurring Cost	$25.00
		TOTAL COSTS	$95.62

2. Installation: Average cost of installation by California Class A garages, $21.32.

3. Driveability: 60 percent of car owners reported worse driving characteristics. 40 percent reported no change or improvement.

4. Reliability: Failure prone exhaust recirculation valve correctable by redesign.

Tests performed in the retrofit study indicated effective reduction of all three pollutants by use of the device under the rigorous 1972 Federal Test Procedure. In reviewing the information available on this device, it appears that all deficiencies to date have been diagnosed as correctable. The relatively insignificant reduction in CO emission in the California evaluation was attributed to lack of idle mixture adjustment procedures in the installation instructions. Most driveability complaints were believed correctable if road testing is made part of the installation procedure.

In summary, this device has undergone sufficient development and evaluation as a retrofit device to identify a majority of its potential shortcomings, all of which appear correctable. Its performance indicates it to be a technically feasible candidate for retrofit use.

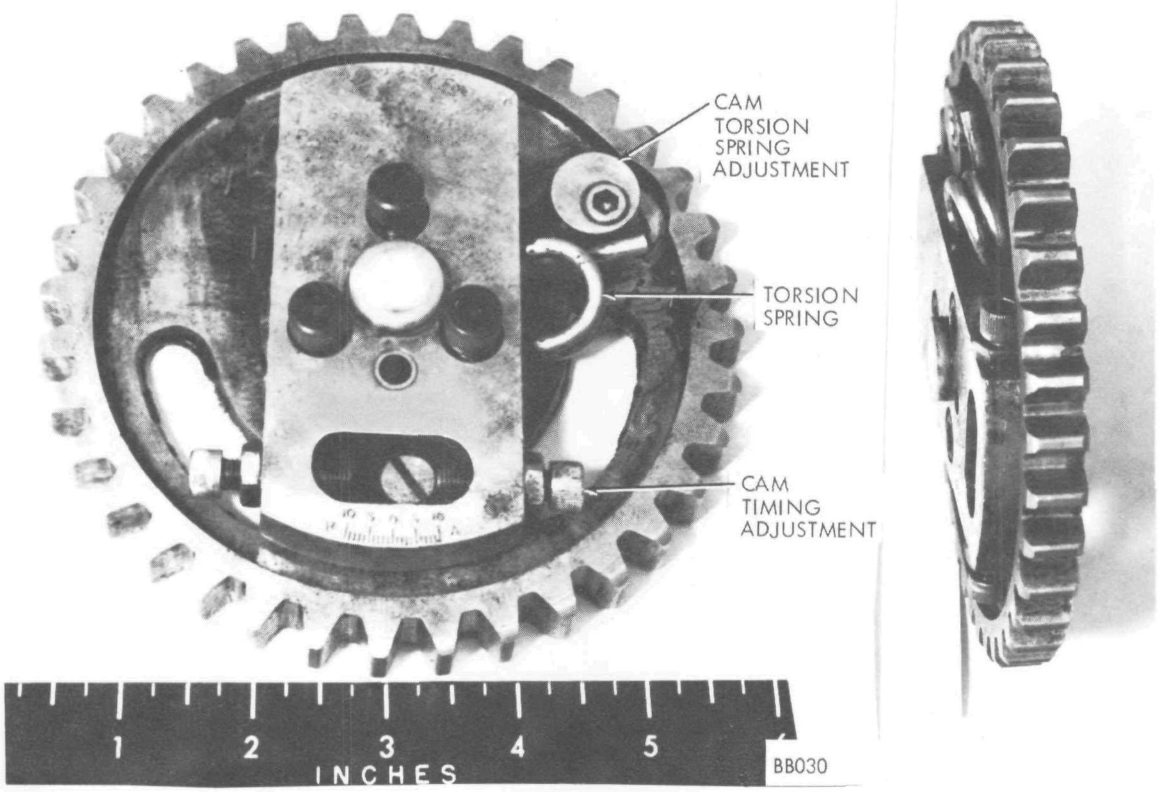
4.2.2 Device 245: Variable Camshaft Timing

Device 245 was one of 11 devices tested in the retrofit study program. This device varies camshaft timing from fully advanced at idle and low speeds, to a fully retarded condition at high engine speed. The original purpose of this device was to maximize engine torque over the engine operating range. However, variable camshaft timing is currently being studied as an alternative means of exhaust gas recirculation. The concept is to change the closing or opening time of the exhaust valve in relation to the piston top-dead-center time, so that some of the exhaust gas is trapped in the cylinder. This constitutes another form of exhaust gas recirculation (Reference 87).

4.2.2.1 Physical Description

Device 245, shown in Figure 4-16, is a three-piece cam timing gear. The cam is connected to the gear through an adjustment bar. The bar rotates within the sprocket gear, and the two are connected by means of a torsion spring. The variable cam action is provided through the torsion spring.

The device replaces the conventional timing gear through which the camshaft is driven. During installation, the camshaft is set at a full advance position with respect to the crankshaft by adjusting the right-hand or full advance set screw. This causes a slight preload in the torsional spring. The left-hand screw is then set to provide a stop at the desired full retard position.



(a) Front View (b) Side View

Figure 4-16. DEVICE 245 VARIABLE CAMSHAFT TIMING GEAR

4.2.2.2 Functional Description

The objective of the variable cam device is to provide full advance valve timing at low engine speed, and full retard timing at high speeds. The resulting change in exhaust valve closing traps some of the exhaust gas in the cylinder. The trapped gas lowers the temperature of the next combustion event and inhibits NOx formation.

Torque required to drive the camshaft is transmitted through the sprocket gear and torsional spring to the camshaft. Transmission of high torques through the torsion spring causes the spring to deflect such that the camshaft rotates to a retarded position with respect to the sprocket gear. One degree of rotation with respect to the camshaft sprocket represents two degrees of retardation with respect to crankshaft or piston position.

At low or idle speeds relatively low torque is required to drive the camshaft and little or no rotational deflection of the camshaft relative to the sprocket gear occurs. As engine speed increases, more torque is necessary to drive the camshaft. Cause of the increased torque requirement is increased frictional losses between cam lobes and lifters, rocker arms, spring surge, and exhaust valve opening against high cylinder pressures. Transmittal of increased torque at high speeds causes deflection of the torsion spring and rotation of the camshaft with respect to the driving sprocket gear, resulting in a retardation of the valve timing. The distributor shaft is gear driven off the camshaft, so that retardation of the ignition spark also occurs as engine speed increases.

The variable cam device permits the following valve timing control settings:

1. Degree of advancement at idle or low speed may be adjusted by crankshaft timing gear and variable cam sprocket at the time of installation.

2. Speed at which the cam begins to retard may be adjusted by the preload setting on the torsional spring during installation.

3. Rate of retardation with increased speed may be varied by varying the spring constant. This would probably require use of interchangeable springs if this parameter is found to be a significant design variable between engines.

4. Limit settings on degree of retardation may be adjusted with set screws at time of installation.

4.2.2.3 Performance Characteristics

Table 4-30 summarizes tests performed with Device 245 installed on one vehicle during the retrofit study test program. These data showed a decrease only in NOx emissions with a large accompanying increase in CO and HC emission levels.

Table 4-30. DEVICE 245 VARIABLE CAMSHAFT EMISSION REDUCTION AND FUEL CONSUMPTION PERFORMANCE

VEHICLE YEAR/MAKE/CID	ANAHEIM TEST RESULTS (1)			
	POLLUTANT GRAMS/MILE			FUEL MILES/ GALLON
	HC	CO	NOx	
1961 Chevrolet 283				
Without Device	4.54	70.78	2.39	16.8
With Device	6.17	89.83	1.89	15.1
Percent Reduction	-35.9	-26.9	20.9	10.1

(1) Emission results obtained by Olson Laboratories in one set of tests performed under Contract 68-04-0038 using 1972 Federal Test Procedure (Reference 3). Fuel consumption was measured during these tests.

For comparison with Device 245 emission control performance, Table 4-31 presents a summary of emission test data reported by HEW/NAPCA in Reference 91. The report presented results of several tests on a device which included ignition and carburetion modifications along with variable camshaft timing. In these tests, the 1962 Chevrolet Biscayne with 283 CID engine was run (1) with no variable cam, distributor vacuum advance connected, and stock carburetor; and (2) with variable cam, distributor advance disconnected, and a lean carburetor.

4.2.2.4 Reliability

The developer claimed "unlimited" reliability, based upon over 5,000 units having been distributed to dealers and information reported back from users. The developer also claimed approvals for the device from the American Hot Rod Association and the National Hot Rod Association. Additional tests of the device on high-performance vehicles have been reported in the automotive magazines "Car Craft," August 1968 issue, and "Popular Hot Rodding," January 1968 issue.

(2) Additional tests were performed by HEW/NAPCA on another variable camshaft system as reported in Reference 92. This device used a vacuum diaphragm and electrical circuits to control cam timing. The device is described in Reference 93. The tests showed effective reduction of NOx, and the report concluded that variable cam timing could have a beneficial effect on NOx without increasing CO or HC. Comparing 1970 Federal Test Procedure data for variable cam timing and conventional exhaust gas recirculation showed the former to be 50 percent more effective. Three engine camshaft approaches to NOx reduction were investigated as reported in Reference 118. NOx levels of 1.2-2.0 gm/mi were attained using the 1970 Federal Test Procedure.

Table 4-31. COMPARATIVE EMISSION TEST RESULTS FOR A DEVICE TESTED BY EPA WITH VARIABLE CAMSHAFT TIMING, VACUUM ADVANCE DISCONNECT AND LEAN CARBURETION (REFERENCE 91) (1)

VEHICLE CONFIGURATION (2)	POLLUTANT (GM/MI)		
	HC	CO	NOx
Without Device	12.9	123	3.2
With Device	5.5	61	1.7
Percent Reduction	57	50	47

(1) Emission results obtained using CVS measurements during nine repeat cycles of the 1970 Federal Test Procedure (Reference 16). One test with and without device.

(2) 1962 Chevrolet Biscayne with 283-CID engine.

The available data and examination of the substantial construction of the device indicate that its reliability should substantially exceed 50,000 miles, if it is installed in accordance with the developer's instructions. Accordingly, an MMBTF of 75,000 miles is estimated. This reliability estimate would not be applicable to vehicles which are used mostly for racing or similar activities.

No partial failure mode was identified other than a broken spring, which is discussed more fully in paragraph 4.2.2.6. Breakage of the spring is a remote possibility and was not considered to constitute a partial failure mode.

4.2.2.5 Maintainability

The additional vehicle maintenance required as a result of a Device 245 installation would possibly consist in checking the ignition timing and dwell at 25,000 miles (MMBM). Mean-time-to-maintain (MTTM) for this activity would be about 0.5 hour.

4.2.2.6 Driveability and Safety

During the retrofit study, tests were run on Car 6 both with and without the device installed. Table 4-32 summarizes the driveability results of these tests.

During the installation of the device, the developer retarded the ignition timing as part of his standard procedure. It is believed that the ignition timing may have been retarded too far and that the driveability problems encountered were caused by this factor rather than by the device. Improvement of the installation procedure for ignition timing might produce better driveability results.

An increase in fuel consumption was recorded during the emission tests. (Table 4-30).

The manufacturer claimed that the device has no failure modes, because breakage of the torsion spring would only result in full spark retard, even at low rpm. However, this could result in engine overheating.

Table 4-32. DEVICE 245 DRIVEABILITY TEST RESULTS

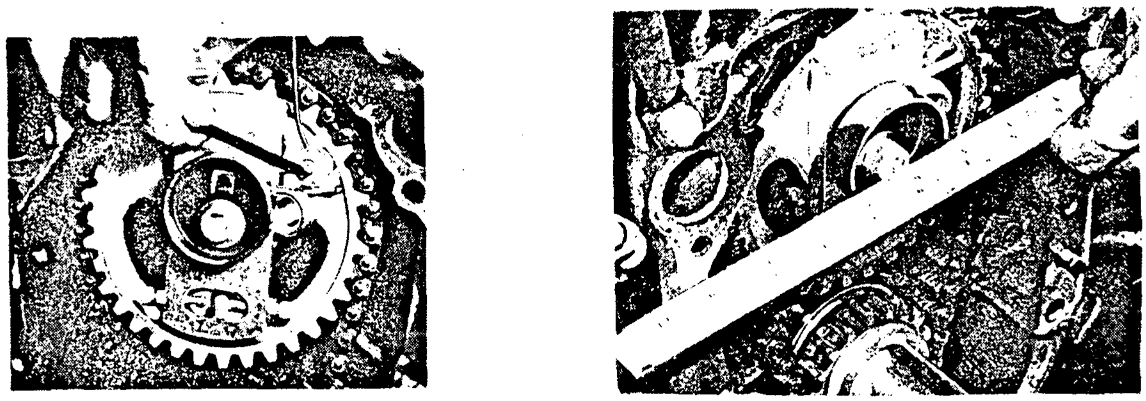
DRIVEABILITY CHARACTERISTICS	1965 CHEV. 194 CID	1965 FORD 289 CID	1965 PLY. 318 CID	1965 CHEV. 327 CID	1965 FORD 390 CID	1961 CHEV. 283 CID
	ANAHEIM, CALIF., DRIVEABILITY TEST RESULTS (1)					
	CAR NO. 1	CAR NO. 2	CAR NO. 3	CAR NO. 4	CAR NO. 5	CAR NO. 6
CRITICAL DRIVEABILITY	(1)	(1)	(1)	(1)	(1)	No effect
GENERAL DRIVEABILITY						Decreased stall during cold start idle; increased stretchiness and stumble during cold start acceleration; increased stretchiness during hot start acceleration
0 - 60 MPH ACCELERATION TIME (SECONDS)						Increased from 17.3 to 23.9
60 - 40 MPH DECELERATION TIME (SECONDS)						Decreased from 23.1 to 21.9
GAS MILEAGE PER GALLON	Average decrease of 10.1 percent (reference Table 4-30)					

(1) Device No. 245 was not tested on these vehicles.

Depending upon the internal configuration within the timing gear cover, a broken spring might become lodged between the timing gear and chain, resulting in catastrophic engine failure under hazardous circumstances. As a minimum, a broken spring could result in poor low speed performance; and, probably, in enough noise to provide adequate warning to the vehicle operator to avoid or minimize engine damage. No other potential hazards are indicated.

4.2.2.7 Installation Description

A typical installation of Device 245 is shown in Figure 4-17. The installation consists in replacing the conventional cam timing sprocket with a Device 245 sprocket. The device is adjusted by setting the proper spring preload on the sprocket. Adjustment of the engine consists in testing to verify that at least a 0.090-inch clearance exists between each piston and valve (fully open), and adjusting distributor ignition timing for maximum output at about 3,500 rpm.



(a) Torsion Spring Adjustment (b) General Installation

Figure 4-17. DEVICE 245 VARIABLE CAMSHAFT INSTALLATION

Table 4-33 itemizes the installation requirements. This table is derived from the installation instructions contained in a Device 245 kit for Oldsmobile V-8 engines (330, 350, 400, 425, and 455 CID).

The developer estimated one to two hours labor for installation and a retail cost of material of $40 to $50. Installation can be accomplished in normally equipped repair shop by the average mechanic. From the information available, it is estimated that the total cost of this installation, including material, would be from $68.12 to $78.12.

4.2.2.8 Initial and Recurring Costs

Table 4-34 itemizes the 50,000-mile service life costs for the device. Although there are minimal maintenance requirements, the indicated increase in fuel consumption could increase fuel costs about $28.00 per year.

4.2.2.9 Feasibility Summary

The evaluation of Device 245 as a retrofit method for used-car emission control should consider that the device is basically an NOx control. Thus any application of the device for emission control purposes would have to be limited to those air quality control requirements in which NOx is the principal pollutant. The alternative would be to combine Device 245 with other retrofit methods for control of two or all of the principal pollutants. The Reference 91 emission test data indicate the benefit of such combinations, although the variable cam timing approach tested by EPA was not identical to Device 245 (refer to Table 4-31). However, the cost of combining devices may be too high for the effectiveness gained in emission reduction.

Further testing of Device 245 would be required to establish its NOx control effectiveness for a variety of used cars, as well as its driveability and impact on fuel consumption.

Table 4-33. DEVICE 245 VARIABLE CAMSHAFT TIMING INSTALLATION PROCEDURE

MINIMUM AVERAGE SKILL LEVEL: AUTOMOTIVE MECHANIC		
INSTALLATION AND ADJUSTMENT PROCEDURE	TOOLS, EQUIPMENT AND FACILITIES	TIME (MIN.)
1. Before installation, note ignition timing with engine about 3,500 rpm using strobe timing light. Timing should be the same after installation.	a. Tachometer b. Strobe timing light	3
2. Remove fan, water pump, belts, crankshaft pulley and other interference as necessary to get at timing chain cover.	Hand tools	40
3. Remove timing chain cover and turn engine over so sprocket timing marks are aligned.	Hand tools	2
4. Remove center bolt, fuel pump eccentric, and present cam sprocket (fuel pump eccentric will be reused).	Hand tools	3
5. Remove spring adjusting eccentric from Varicam sprocket.	a. Hand tools b. Sprocket	1
6. Hold sprocket in place with timing mark aligned. (If it does not match the chain, get a new chain and crank sprocket to match the Varicam sprocket).	None	1
7. Push faceplate in place	None	1
8. Hold fuel pump eccentric in place with tab in dowel pinhole.	None	1
9. Insert special locking center bolt and tighten to a little less than normal.	a. Hand tools b. Special locking center bolt	3
10. Hand rotate engine a little in both directions. Loosen center bolt just enough to allow faceplate to move in relation to sprocket.	Hand tools	3

Table 4-33. DEVICE 245 VARIABLE CAMSHAFT TIMING INSTALLATION PROCEDURE (CONCL)

MINIMUM AVERAGE SKILL LEVEL: AUTOMOTIVE MECHANIC		
INSTALLATION AND ADJUSTMENT PROCEDURE	TOOLS, EQUIPMENT AND FACILITIES	TIME (MIN.)
11. Check each cylinder for clearance between piston and each valve of at least 0.090 inch.	Hand tools	6
12. Adjust spring preload on sprocket.	Hand tools	1
13. Insert thrust button into center of bolt.	Thrust button	1
14. Check clearance between chain cover and thrust button, and chain cover and fuel pump eccentric.	a. Metal straightedge b. Feeler gauges	3
15. Install chain cover. Check installation for any interference by turning over engine by hand.	Hand tools	6
16. Reassemble engine	Hand tools	45
17. Adjust distributor for maximum output at about 3,500 rpm by tachometer or dynamometer	Tachometer	15
	Total Time	2.25 hr

Table 4-34. DEVICE 245 VARIABLE CAMSHAFT TIMING INITIAL AND RECURRING COSTS

ITEM	DESCRIPTION	LABOR HOURS OR ITEM QUANTITY	COST (DOLLARS)
Initial Cost:			
Material			
1. Device	Sprocket		40.00-50.00
2. Miscellaneous	Special locking center bolt thrust button		(Included in above)
Labor			
1. Installation	Table 4-33	2 hr	25.00
2. Test and adjust	Table 4-33	0.25 hr	3.12
		Total Initial Cost	68.12-$78.12
50,000-Mile Recurring Cost:			
Material			
1. Fuel	Average fuel increase of 10.1 percent (Table 4-32)	404-gal fuel increase x $0.35 per gallon over 50,000 miles (1)	141.40
Labor			
1. Inspection	Paragraph 4.2.2.5	0.5 hr/25,000 miles @ $12.50 per hr	12.50
		Total Recurring Cost	153.90
		TOTAL COSTS	232.02

(1) Based on an assumed national average of 10,000 miles per year at 12.5 mpg.

4.2.3 Device 246: Speed-Controlled Exhaust Gas Recirculation with Vacuum Advance Disconnect

This device approaches the control of NOx by means of a speed-controlled exhaust gas recirculation (EGR) system. This is combined with disconnect of the distributor vacuum advance for further control of NOx and control of HC. The speed control allows about 15 percent of the exhaust gas to be recirculated to the intake manifold whenever the vehicle speed exceeds 26 mph. The speed control shuts off recirculation whenever the speed drops below approximately 12 mph. A deceleration switch is also provided to stop recirculation whenever the accelerator pedal is completely released. The deceleration switch also disconnects the distributor vacuum advance when the accelerator pedal is released..

The distributor vacuum advance unit is connected to the recirculation system such that the vacuum advance operates during exhaust gas recirculation at speeds above 26 mph. The vacuum advance is disconnected when exhaust gas recirculation is terminated at low speed by the speed or acceleration pedal controls. Thus the device apparently is designed to control NOx by EGR at speeds above idle and by vacuum advance disconnect at idle.

Approximately 9 prototype units have been made by the developer and 90 are scheduled for completion by mid-April 1972. The device was one of four retrofit devices subjected to extensive emissions and driveability tests during the retrofit study, and also was subjected to a 25,000-mile durability test. The device also has been tested by EPA, as reported in Reference 94.

4.2.3.1 Physical Characteristics

Principal components of the exhaust gas recirculation system are shown in Figure 4-18. The exhaust pipe bleed adapter connects to the vehicle exhaust header as close to the exhaust manifold as possible. The EGR valve connects to the exhaust adapter and the EGR tube is connected between the valve and the intake adapter between the carburetor and the intake manifold.

The solenoid valve is interconnected in the vacuum advance tube between the distributor and the intake manifold, and to the EGR valve. The speed switch and cable are connected to the speedometer tap on the transmission and to the EGR valve. The solenoid valve is connected to the speed switch electrically.

4.2.3.2 Functional Characteristics

The vehicle speed is sensed by the speed switch attached to the transmission through a speedometer cable. When the vehicle speed reaches 26 mph, the speed switch opens, deenergizing the solenoid actuated valve. Below 26 mph and at idle, the solenoid valve is energized and held closed preventing both recirculation and vacuum advance.

Figure 4-19 shows a functional schematic of the system. When the solenoid valve opens at 26 mph, it ports vacuum to the EGR valve and to the distributor vacuum advance. Only a small amount of vacuum, approximately 1.5 inches of mercury, is required to activate the EGR valve. Opening of the EGR valve permits exhaust to recirculate to the intake manifold. Exhaust gas recirculation is controlled to approximately 15 percent of total exhaust by a metering restrictor located directly downstream of the poppet seat of the EGR valve.

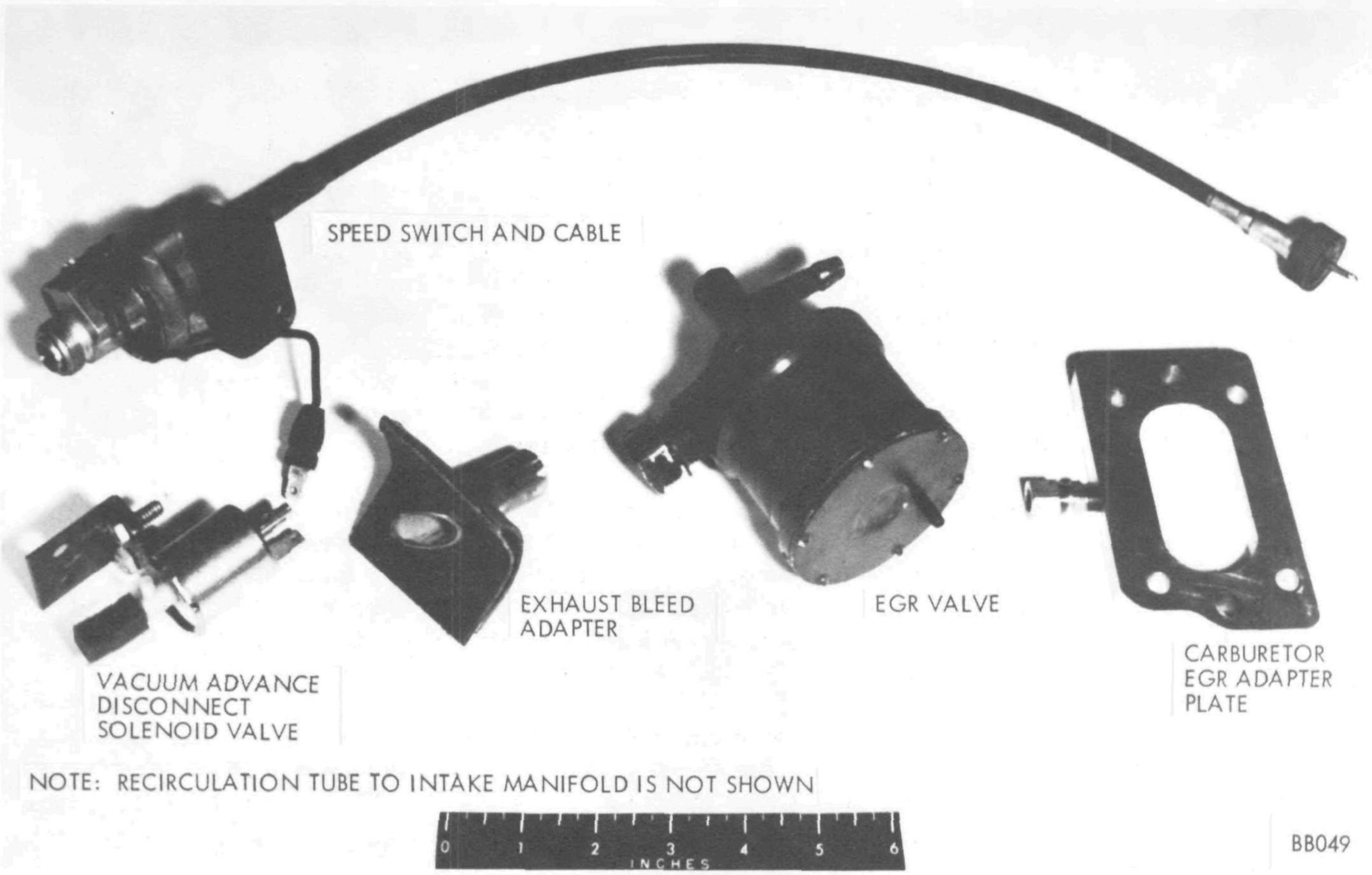


Figure 4-18. DEVICE 246 SPEED-CONTROLLED EGR WITH VACUUM ADVANCE DISCONNECT SYSTEM COMPONENTS

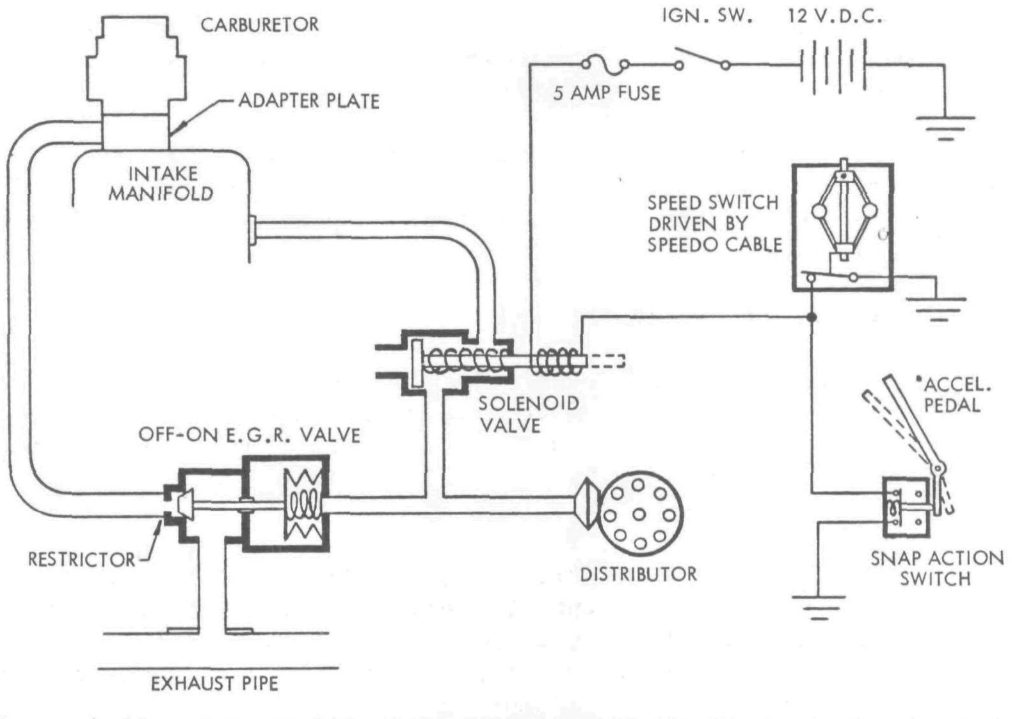


Figure 4-19. DEVICE 246 SPEED-CONTROLLED EGR WITH VACUUM ADVANCE DISCONNECT FUNCTIONAL SCHEMATIC (DEVELOPER'S DIAGRAM)

The vacuum advance is operating only during periods of exhaust gas recirculation, and is effectively disconnected when exhaust gas is not recirculated at low speed and upon deceleration from high speed. Below 26 mph, EGR is shut off by a snap action switch actuated by the closed throttle pedal. This switch energizes the solenoid to terminate EGR and vacuum advance whenever the accelerator pedal is released, regardless of speed.

4.2.3.3 Performance Characteristics

Emission reductions measured in tests of Device 246 during the retrofit study are summarized in Table 4-35. These test results indicate that the device is mainly an NOx control system, though some CO reduction was also indicated. Data supplied by the developer in Table 4-36 indicate that the device was effective in reducing HC and NOx emissions.

Tests were performed on this device by EPA as summarized in Table 4-37. The vehicles were tested in single- and double-solenoid configurations. In the latter, the vacuum advance disconnect and the EGR functions were divided between two solenoids. This was to enable separate control of the two methods for test purposes. The EPA report noted that the tests of the 1963 Chevrolet without the device installed were made without the carburetor base plate in position, and that this may account for the substantial reduction in CO.

Based on the overall results summarized in these tables, the device appears to reduce NOx consistently. Some control of CO also is indicated. HC control appears to be relatively less significant.

4.2.3.4 Reliability

The basic exhaust gas recirculation (EGR) valve concept appears capable of demonstrating a reliability in excess of 50,000 mean-miles-before-total-failure with proper maintenance. Maintenance for this type of valve might be required, including replacement of the valve prior to failure from any fatigue failures that might result from cycle loading. Longevity testing and analysis would be required to determine the need for such replacement.

There could be some concern for this type of EGR hookup with regard to the possibility of fatigue failures in the exhaust gas circuit, between the exhaust pipe and the carburetor adapter plate, resulting from engine induced vibration. Testing would be required to determine the adequacy of the design for the vibration environment. The possible problem of vibration-induced fatigue is peculiar to this EGR device because of the tie-in to the exhaust pipe. The differences in vibration response characteristics between the exhaust pipe and the engine could possibly induce fatigue failure in the EGR tubing and in the exhaust-pipe-to-tubing connection.

The remaining functional components of the device are high-production items of established acceptable reliability. It was indicated by the developer that the speed switch and speedometer cable assembly are installed as standard items in one line of 1971 vehicles.

Table 4-35. DEVICE 246 SPEED-CONTROLLED EGR WITH VACUUM ADVANCE DISCONNECT EMISSION REDUCTION AND FUEL CONSUMPTION PERFORMANCE (1)

VEHICLE YEAR/MAKE/CID	ANAHEIM TEST RESULTS				TAYLOR TEST RESULTS			
	POLLUTANT GRAMS/MILE			FUEL MILES/ GALLON	POLLUTANT GRAMS/MILE			FUEL MILES/ GALLON
	HC	CO	NOx		HC	CO	NOx	
1965 Chev 194								
Without Device	(2)	202.99	0.65	(2)				
With Device	(2)	177.78	0.263	11.6				
Percent Reduction	(2)	12.4	60.0	(2)				
1965 Ford 289								
Without Device	8.81	106.46	4.60	14.2	3.06 3.69	83.54 38.40	6.12 3.24	(2) 12.8
With Device	6.38	70.61	2.88	11.4	(2) 4.10	(2) 40.00	(2) 1.37	(2) 14.5
Percent Reduction	27.6	33.7	37.4	20.0	(2) -11.1	(2) -4.2	(2) 57.7	(2) -13.3
1965 Ply 318								
Without Device	6.12	94.73	5.93	10.0	6.02 3.38	97.62 43.38	4.29 3.87	12.7 13.5
With Device	6.96	63.59	2.70	12.8	5.52 3.55	40.64 17.00	2.25 1.62	14.0 (2)
Percent Reduction	-13.7	32.9	54.5	-28.0	8.3 -5.0	58.4 60.8	47.6 58.1	-10.2 (2)
1965 Chev 327								
Without Device	8.66	59.29	4.45	12.8	3.95 4.70	(2) 45.56	(2) 3.42	(2) (2)
With Device	8.42	45.40	2.81	11.9	9.80 3.84	(2) 24.86	(2) 1.51	(2) (2)
Percent Reduction	2.8	23.4	36.9	7.0	(2) 18.3	(2) 45.4	(2) 55.8	(2) (2)
1965 Ford 390								
Without Device	10.88	163.37	3.16	9.4	7.61 5.33	125.34 89.38	4.12 2.86	12.3 11.6
With Device	10.78	146.60	1.31	10.6	6.24 2.88	85.97 24.29	2.28 1.45	13.0 15.8
Percent Reduction	0.9	10.3	58.5	-13.0	18.0 46.0	31.4 72.8	44.7 49.3	-6.0 -36.2
1961 Chev 283								
Without Device	(2)	85.86	1.46	10.5	8.17 5.27	72.41 55.71	3.42 2.56	14.8 16.5
With Device	8.68	92.98	0.81	11.6	7.36 3.15	50.62 25.95	2.02 1.50	14.2 14.5
Percent Reduction	(2)	-8.3	44.5	-11.0	9.9 40.2	30.1 53.4	40.9 41.4	4.1 12.0
1965 VW 92								
Without Device	7.79	51.78	1.57	(2)	5.32	34.11	1.75	(2)
With Device	6.59	45.79	1.16	(2)	4.82	43.18	(2)	(2)
Percent Reduction	15.4	11.6	26.1	(2)	9.4	-26.6	(2)	(2)
Pooled Mean Percentage Reduction (3)	HC 12.1		CO 30.9		NOx 47.6		Fuel -7	

(1) Emission results obtained by Olson Laboratories in tests performed under Contract 68-04-0038 using 1972 Federal Test Procedure (Reference 3). Fuel consumption was measured during these tests.

(2) Test data invalid

(3) Anaheim and Taylor results combined.

Table 4-36. DEVICE 246 SPEED-CONTROLLED EGR WITH VACUUM ADVANCE DISCONNECT EMISSION TEST RESULTS REPORTED BY DEVELOPER (1)

VEHICLE CONFIGURATION (2)	POLLUTANT (GM/MI)			NUMBER OF TESTS
	HC	CO	NOx	
Without Device	5.09	12.51	9.85	2
With Device	3.30	11.37	3.06	3
Percent Reduction	35.2	9.1	68.9	

(1) Results obtained using 1972 Federal Test Procedure (Reference 3) hot-start tests.

(2) 1969 Ford Station Wagon with 429-CID engine, 10.5:1 compression ratio, 2-barrel carburetor, and automatic transmission. Indolene 30 test fuel was used. Dynamometer inertia was 4,500 pounds.

Subject to the qualifications stated above, the exhaust gas recirculation system reliability is estimated to be on the order of 75,000 MMBTF.

4.2.3.5 Maintainability

The developer recommended cleaning the EGR valve every 6 months. The requirement for 6-month/6,000-mile (MMBM) cleaning of the EGR valve orifice is considered a general estimate, as insufficient data were available to specifically establish this requirement. At that time it is also recommended that the solenoid vacuum valve filter be inspected and cleaned or replaced if necessary. If the production configuration EGR valve provides ease of accessibility to clean the orifice, it is estimated the maintenance task could be done within 30 minutes (MTTM).

Specific repair times to remove and replace any failed components would be dependent upon the specific configuration of the vehicle in which the system is installed.

4.2.3.6 Driveability and Safety

Table 4-38 summarizes the driveability results of tests performed on Device 246 during the retrofit program. Car 3 exhibited a tendency toward hesitation possibly caused by carburetor settings. This problem may or may not be due to the installation of the device. Car 4 had a tendency toward detonation at all times when the hot start tests were run. The problem encountered may or may not be due to the installation of the device.

Gas mileage increased an average 7 percent with the device operating. The developer in his tests reported inconsistencies in fuel consumption between the 1969 Ford station wagon, which had increased fuel consumption in all types of driving, and the

Table 4-37. DEVICE 246 SPEED-CONTROLLED EGR WITH VACUUM ADVANCE DISCONNECT EMISSION TEST RESULTS REPORTED BY EPA (REFERENCE 94) (1)

VEHICLE CONFIGURATION	POLLUTANT (GM/MI)			NUMBER OF TESTS
	HC	CO	NOx	
1971 Chevrolet (2)				
Without Device	3.7	64.3	3.5	2
With One Switch	3.0	57.7	2.4	1
Percent Reduction	19	10	31	
With Two Switches	3.2	51.9	1.9	1
Percent Reduction	14	19	46	
1964 Plymouth (3)				
Without Device	7.5	116.4	3.7	1
With One Switch	6.8	109.9	1.3	1
Percent Reduction	10	6	65	
With Two Switches	8.5	103.4	1.1	1
Percent Reduction	-13	11	70	
1963 Chevrolet (4)				
Without Device	8.3	113.8	1.4	1
With One Switch	5.6	49.1	0.45	2
Percent Reduction	32	57	68	

(1) Average of results using 1972 Federal Test Procedure (Reference 3).

(2) 1971 Chevrolet Impala with 400-CID engine, 2-barrel carburetor, and automatic transmission.

(3) 1964 Plymouth Fury with 318-CID engine, 2-barrel carburetor, and automatic transmission.

(4) 1963 Chevrolet Impala with 283-CID engine, 2-barrel carburetor, and manual 3-speed transmission.

1964 Plymouth, which had decreased fuel consumption in composite and country driving.(1) This variation was attributed by the developer to a possibly lean setting on the Plymouth vehicle.

(1) Same vehicles as identified in Tables 4-36 and 4-37.

Table 4-38. DEVICE 246 SPEED-CONTROLLED EGR WITH VACUUM ADVANCE DISCONNECT DRIVEABILITY TEST RESULTS

DRIVEABILITY CHARACTERISTICS	1965 CHEV. 194 CID	1965 FORD 289 CID	1965 PLY. 318 CID	1965 CHEV. 327 CID	1965 FORD 390 CID	1961 CHEV. 283 CID
	ANAHEIM, CALIF., DRIVEABILITY TEST RESULTS (1)					
	CAR NO. 1	CAR NO. 2	CAR NO. 3	CAR NO. 4	CAR NO. 5	CAR NO. 6
CRITICAL DRIVEABILITY	No effect	No effect	Decreased stall during cold start deceleration	No effect	No effect	(1)
GENERAL DRIVEABILITY	Increased time to start during hot start	Increased stall during cold start idle; reduced hesitation during cold start acceleration; reduced singing during hot start cruise.	Increased stumble during cold start acceleration.	Increased stumble during cold start acceleration; increased detonation during hot start acceleration.	No effect	(1)
0 - 60 MPH ACCELERATION TIME (SECONDS)	Increased from 19.0 to 19.3	Increased from 12.2 to 13.7	Decreased from 14.2 to 13.3	Increased from 11.6 to 12.5	Increased from 12.1 to 12.7	(1)
60 - 40 MPH DECELERATION TIME (SECONDS)	Increased from 20.5 to 21.5	Increased from 20.2 to 21.7	Increased from 24.0 to 25.5	Increased from 20.8 to 23.0	Increased from 19.8 to 25.0	(1)
GAS MILEAGE PER GALLON	Average increase of 5 percent (reference Table 4-35)					
	TAYLOR, MICH., DRIVEABILITY TEST RESULTS					
	CAR NO. 20	CAR NO. 8	CAR NO. 9	CAR NO. 10	CAR NO. 11	CAR NO. 12
CRITICAL DRIVEABILITY	No effect	Showed rough idle on hot start during replicate test	No effect	No effect	Rough idle on 1st test	No effect
GENERAL DRIVEABILITY	Increase in hesitation on both cold and hot starts, and trace of stumble on cold start	Increase in hesitation for hot and cold start tests.	1st device test showed increase in hesitation and stumble on cold start. Hot start increase in hesitation and surge. Replicate test no problems.	Increase in hesitation and stumble during cold start	Driveability improved	Increase in stumble on cold start (1st test)
0 - 60 MPH ACCELERATION TIME (SECONDS)	Increased from 35.2 to 35.3	Increased from 11.7 to 13.4	Increased from 13.4 to 13.8	Increased from 10.8 to 11.7	Decreased from 10.1 to 9.8	Decreased from 15.4 to 14.7
60 - 40 MPH DECELERATION TIME (SECONDS)	Information not available	Decreased from 24.4 to 22.5	Increased from 22.9 to 24.3	Increased from 23.4 to 25.5	Decreased from 25.4 to 23.1	Increased from 24.7 to 28.8
GAS MILEAGE PER GALLON	Average increase of 8.2 percent (reference Table 4-35)					

(1) Device No. 246 was not tested on this vehicle.

Two potential hazard areas involving CO leakage were identified in the study of the particular EGR approach represented by this device. Both can be visually inspected to avoid the occurrence of an unsafe condition. The two areas are:

1. A leak in the tube from the exhaust pipe to the EGR valve due to vibration fatigue or corrosion.

2. A leak in the tube from the EGR valve to the carburetor adapter plate (fatigue or corrosion). (Although this mode of leak could ultimately result in burned valves, the failure should cause obvious performance changes prior to engine failure.)

These safety considerations were discussed in terms of system reliability in paragraph 4.2.3.4.

4.2.3.7 Installation Description

The installation of this device consists in installing the adapter plate between the carburetor and intake manifold, drilling a hole in the exhaust line between the exhaust manifold and muffler to install the EGR inlet adapter, connecting a tubing assembly from exhaust inlet adapter to the vacuum-operated shutoff valve and thence to the carburetor adapter plate, installing the solenoid vacuum valve, connecting tubing and wiring, and replacing the speedometer cable with a new speedometer cable having a speed switch included. The developer estimated 2 hours labor for installation and $61 as the retail price of material.

Table 4-39 describes the installation requirements. Figures 4-20 and 4-21 show a typical installation. Installation can be accomplished in a normally equipped repair shop with average mechanic skills.

4.2.3.8 Initial and Recurring Cost

Table 4-40 itemizes the overall costs for Device 246 installation, operation, and maintenance. Initial cost of installation was estimated to be $89.12. If the device provides the fuel economy indicated, half of the initial investment would be repaid over a 50,000-mile service life.

4.2.3.9 Feasibility Summary

This device is considered technically feasible with respect to emission reduction, reliability, driveability, and operating costs, for applications requiring NOx control. Fleet vehicle testing of the device in the retrofit program indicated that some control of CO also may be provided by the device. Further fleet testing may be required to resolve the effectiveness of the device for any application other than NOx control.

Satisfactory driveability was indicated for 4 of the 6 vehicles equipped with this device. A majority of the components used in this device (speed switch, acceleration switch, solenoid valve) are off-the-shelf components with demonstrated reliability.

Table 4-39. DEVICE 246 SPEED-CONTROLLED EGR WITH VACUUM ADVANCE DISCONNECT INSTALLATION PROCEDURE

MINIMUM AVERAGE SKILL LEVEL: AUTOMOTIVE MECHANIC		
INSTALLATION AND ADJUSTMENT PROCEDURE	TOOLS, EQUIPMENT AND FACILITIES	TIME (MIN.)
1. Remove carburetor and studs from intake manifold.	Hand tools	24
2. Install new longer studs in intake manifold.	a. Hand tools b. Studs	4
3. Install carburetor adapter plate over new studs on intake manifold.	a. Hand tools b. Adapter plate c. Gaskets	2
4. Reinstall carburetor with adapter plate between carburetor and intake manifold.	Hand tools	12
5. Drill hole in exhaust pipe between exhaust manifold and muffler.	Oxyacetyline torch	21
6. Install inlet adapter in hole in exhaust pipe.	a. Hand tools b. Inlet adapter c. Clamps	8
7. Attach tubing assembly from exhaust inlet adapter to vacuum operated shut off valve to carburetor adapter plate.	a. Tubing clamps b. Vacuum operated shutoff valve	16
8. Mount solenoid vacuum valve on fire-wall in engine component.	a. Electric drill b. Screws c. Solenoid vacuum valve	6
9. Disconnect hose from vacuum spark advance and connect to solenoid vacuum valve.	Hose clamps	2
10. Connect hose from solenoid vacuum valve to vacuum operated shutoff valve with T-connection in this line.	a. Hose b. Clamps c. T-connection	2
11. Connect hose from the connection to vacuum spark advance.	a. Hose b. Clamps	2
12. Remove speedometer cable and install new speedometer cable with speed switch included.	a. Hand tools b. Speedometer cable with speed switch	15

Table 4-39. DEVICE 246 SPEED-CONTROLLED EGR WITH VACUUM ADVANCE DISCONNECT INSTALLATION PROCEDURE (CONCL)

MINIMUM AVERAGE SKILL LEVEL: AUTOMOTIVE MECHANIC		
INSTALLATION AND ADJUSTMENT PROCEDURE	TOOLS, EQUIPMENT AND FACILITIES	TIME (MIN.)
13. Connect wire from one side of solenoid vacuum valve to ground.	a. Hand tools b. Electric wire	2
14. Connect wire from other side of solenoid vacuum valve to speed switch.	a. Hand tools b. Electric wire	2
15. Connect wire from other side of speed switch to fuse panel.	a. Hand tools b. Electric wire	2
16. Start engine and adjust carburetor for best lean idle setting.	Exhaust analyzer	15
	Total Time	2.25 hr

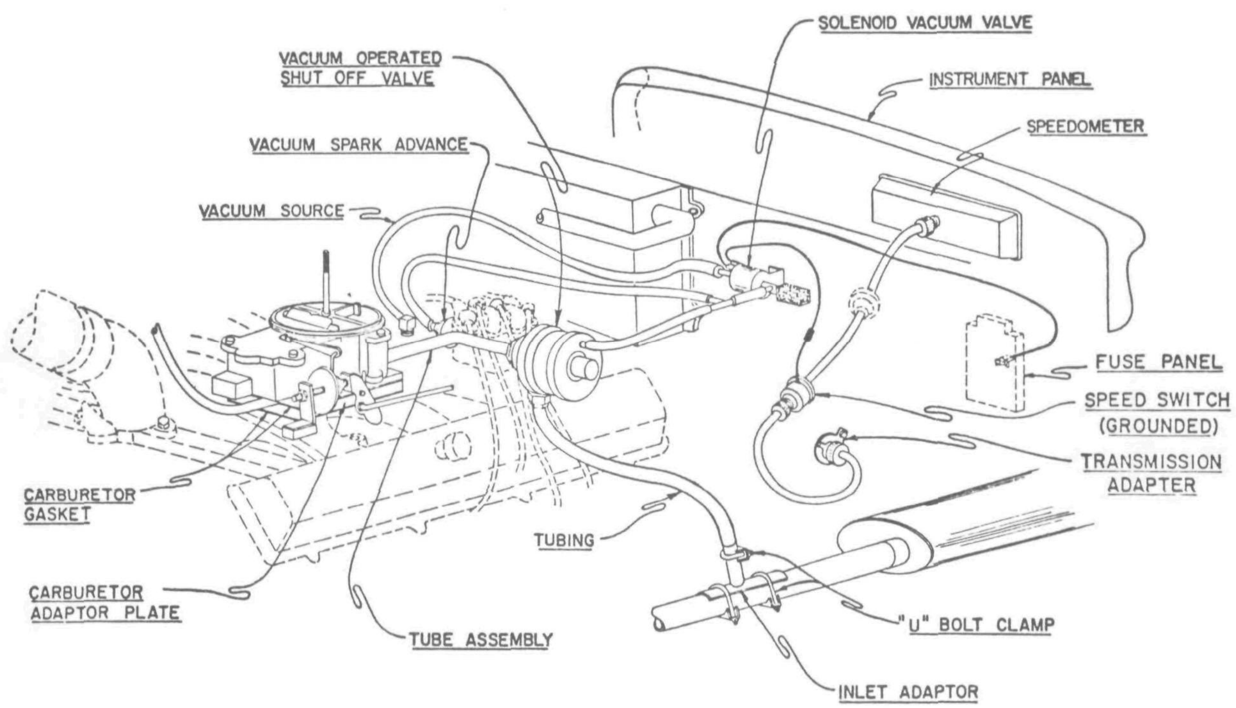


Figure 4-20. DEVICE 246 SPEED-CONTROLLED EGR WITH VACUUM ADVANCE DISCONNECT INSTALLATION (DEVELOPER SKETCH)

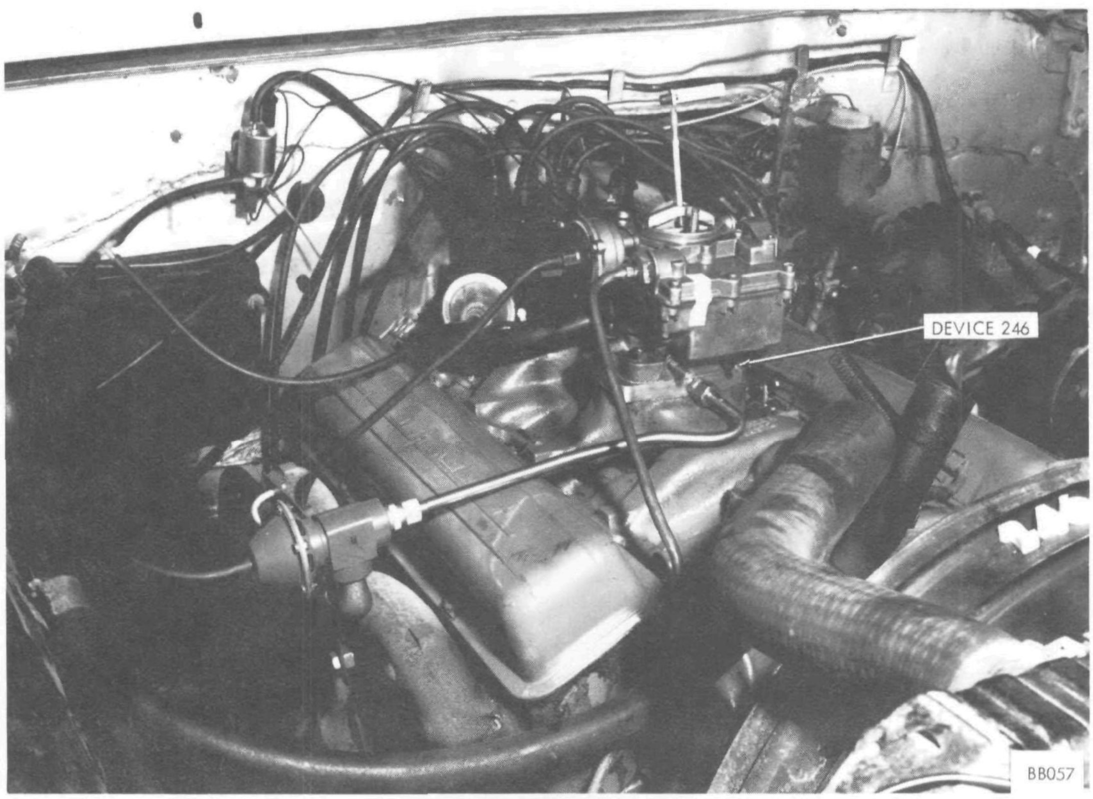


Figure 4-21. DEVICE 246 TYPICAL INSTALLATION ON RETROFIT PROGRAM TEST VEHICLE

Table 4-40. DEVICE 246 SPEED-CONTROLLED EGR WITH VACUUM ADVANCE DISCONNECT INITIAL AND RECURRING COSTS

ITEM	DESCRIPTION	LABOR HOURS OR ITEM QUANTITY	COST (DOLLARS)
Initial Cost:			
Material			
1. Device	a. Adapter plate b. Inlet adapter for exhaust line c. Vacuum operated shutoff valve d. Solenoid vacuum valve e. T-connection f. Speedometer cable with speed switch		61.00
2. Miscellaneous	a. Studs for intake manifold b. Gaskets V clamps for exhaust adapter c. Metal tubing for exhaust gas d. Screws e. Rubber hose f. Clamps for hose g. Electric wire		(Included in above)
Labor			
1. Installation	Table 4-39	2 hr	25.00
2. Test and adjust		0.25 hr	3.12
		Total Initial Cost	$89.12
50,000-Mile Recurring Cost:			
Material			
1. Fuel	Fuel miles per gallon increase of 7 percent	280-gal. fuel savings x $0.35/gal. over 50,000 miles (1)	-98.00
Labor			
1. Inspection	Paragraph 4.2.3.5	0.5 hr/6,000-mile intervals @ $12.50/hr	50.00
		Total Recurring Cost	-$48.00
		TOTAL COSTS	$41.12

(1) Based on an assumed national average of 10,000 miles per year at 12.5 mpg.

4.2.4. Device 294: Exhaust Gas Recirculation With Carburetor Modification

Although the developer of this device did not respond to the retrofit data survey questionnaire, emission data were obtained from an EPA test report (Reference 96). The device apparently consists of an exhaust gas recirculation system in combination with an experimental carburetor. The EGR should reduce NOx emissions, but the principles of emission control used in the carburetor are not known.

The results of EPA tests are summarized in Table 4-41. The results shown with the device operating on a 1970 Chevrolet with 350-CID engine and automatic transmission are about the same as tests performed on a 1970 Valiant with 225-CID engine and automatic transmission. For the latter vehicle, HC was 4.5, CO was 83, and NOx was 3.9 grams per mile, using the same test procedure with the device operating.

Table 4-41. DEVICE 294 EMISSION TEST RESULTS REPORTED BY EPA (REFERENCE 96) (1)

VEHICLE CONFIGURATION	POLLUTANT (GM/MI)		
	HC	CO	NOx
Without Device	3.8	67	4.0
With Device	6.8	60	2.8
Percent Reduction	-78.9	10.4	30.0

(1) Results obtained using 1972 Federal Test Procedure (Reference 3) on a 1970 Chevrolet with 350-CID engine and automatic transmission, one test with and without device installed.

The EPA report noted that the vehicle (with and without the device) did not meet any of the emission standards for the model-year vehicle. HC was reduced with the standard carburetor for that model-year of vehicle installed.

The EPA report concluded that more work appears to be necessary to achieve any emission reduction effectiveness by means of the device. This conclusion apparently was based on the overall effectiveness of the device for control of all three pollutants against future emission standards. The reduction shown for NOx indicates potential effectiveness for control of that pollutant. Further test would be required on a range of representative vehicles to verify this effectiveness for used cars.

4.3 INTAKE MANIFOLD MODIFICATION - RETROFIT SUBTYPE 1.2.3

This type of retrofit device approaches emission control by some form of modification to the air induction system. The approaches generally were based on various aids to improve fuel mixing and vaporization. The concept back of these devices appears to be that mixing of the air-fuel mixture downstream of the carburetor will enhance more complete combustion of the mixture and thereby decrease the formation of exhaust pollutant byproducts.

4.3.1 Device 172: Intake Manifold Modification

This prototype device is an induction system modification wherein conical metering inserts are mounted between the intake manifold and intake port of each cylinder and smaller size jets are used in the carburetor. The conical inserts, referred to as intake "rams" by the developer, are sized to volumetrically equalize the amount of air-gas mixture flowing into each cylinder. The small end of the conical inserts protrudes into the manifold space, and this feature is said by the developer to prevent "wet fuel droplets from entering the combustion chamber." The inserts are patented under Patent No. 3,429,303.

The improved air-fuel diffusion apparently provided by this device permits use of smaller carburetor primary jets, resulting in fuel lean operation. Limited tests conducted by the developer indicated that this device may be effective in reducing HC and CO emissions. An NOx increase was observed in limited cold start tests with a small decrease in NOx emission observed in hot start tests.

The developer has recently combined an exhaust recirculation system with the induction system modifications in order to more effectively reduce NOx emissions; however, since little information was provided on the combination system, only the induction system modifications are described.(1)

4.3.1.1 Physical Description

This system consists of the following elements:

1. Conical shaped (truncated cone), stainless steel intake "rams" mounted between the intake manifold and each intake port of the engine.

2. Smaller sized primary jets installed in the carburetor.

The stainless steel intake rams are actually metering orifices sized to equalize the air-fuel flow between each cylinder. In some engine models all "rams" are of the same size. Other engine models require one or more different sizes of "rams" on the cylinders in order to achieve equalized flow. A typical ram insert is illustrated in Figure 4-22.

The primary carburetor jet modification employs a standard jet configuration with a smaller diameter metering hole.

(1) The only information provided on the combination EGR system was fuel consumption data. These data from the developer indicated an average fuel consumption decrease of 35 percent.

4.3.1.2 Functional Description

This device functions to equalize air-fuel charge between cylinders and reduce the flow of fuel droplets into the cylinders. The improved carburetion is said by the developer to permit use of smaller primary fuel jets, resulting in fuel-lean operation.

A set of rams must be flow calibrated for each engine model, because of induction system differences between engine models. Sizing of the intake "rams" to successfully balance or equalize flow is performed by first isolating the cylinder with the lowest incoming flow rate. This cylinder will have the largest flow opening. Rams for the other cylinders are then sized smaller to bring the flow of all other cylinders down to the level of the lowest cylinder.

The second function of preventing wet droplets from entering the combustion chamber is apparently accomplished by the insert's external configuration which is designed to create a droplet trap at the point where they are inserted into the manifold. Droplets trapped at this point are in a convective environment which eventually causes the droplets to vaporize the re-enter the flow stream into the cylinder. It was not explained by the developer whether this occurs under both cold and hot start conditions.

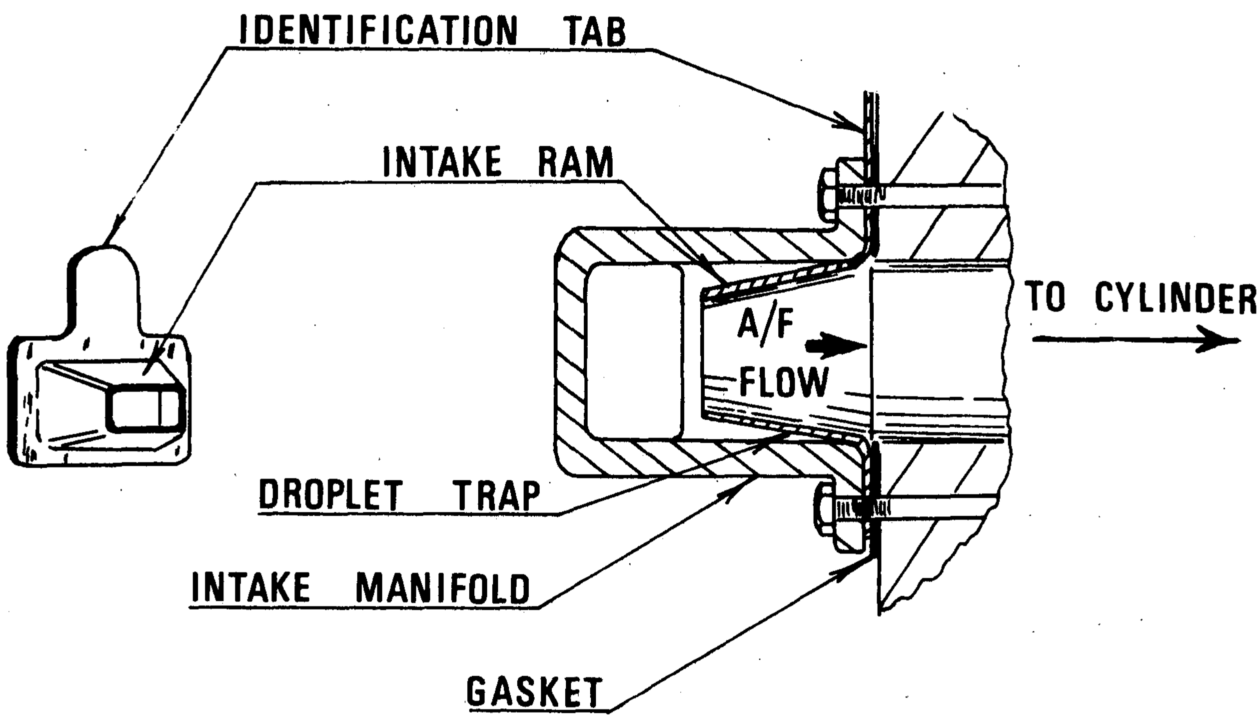


Figure 4-22. DEVICE 172 INTAKE MANIFOLD MODIFICATION (DEVELOPER SKETCH)

4.3.1.3 Performance Characteristics

Table 4-42 summarizes the emission performance characteristics of Device 172 based on information supplied by the developer. Emission tests conducted under HEW Contrack CPA 70-51 NAPCA are summarized in Table 4-43. For the latter tests the carburetor was modified to incorporate lean main jets and an undefined camshaft revision was made.

Examination of the Table 4-42 emission data supplied by the developer indicates that the conical inserts are effective in reducing HC and CO emissions. NOx emissions are increased. The Table 4-43 EPA test data indicates some HC increase with no CO reduction. NOx was reduced 27%.

Table 4-42. DEVICE 172 INTAKE MANIFOLD MODIFICATION EMISSION TEST RESULTS REPORTED BY DEVELOPER (1)

VEHICLE CONFIGURATION (2)	POLLUTANT (GM/MI)		
	HC	CO	NOx
Without Device	2.33	52.14	6.10
With Device	1.61	16.80	6.67
Percent Reduction	30.9	67.78	-9.34

(1) Results obtained using 1970 Federal Test Procedure (Reference 15). One test with and without conical inserts installed in intake manifold. No engine modifications or adjustments other than the inserts were made. Carburetor jets were standard for the vehicle tested.

(2) 1970 Plymouth Valiant with 225-CID 6-cylinder engine and automatic transmission (approximately 10,000 miles indicated on the odometer).

Table 4-43. DEVICE 172 EPA EMISSION TEST RESULTS (REFERENCE 97) (1)

VEHICLE CONFIGURATION (2)	POLLUTANT (GM/MI)		
	HC	CO	NOx
Without Device	3.4	43	3.7
With Device	3.9	43	2.7
Percent Reduction	-15	0	27

(1) Results of one test with and without device, using 1972 Federal Test Procedure (Reference 3).

(2) 1970 Plymouth Duster with a 225-CID 6-cylinder engine and automatic transmission, and with lean main jets in the carburetor and revised camshaft, in addition to Device 172. Conical inserts to intake manifold.

4.3.1.4 Reliability

This induction modification device contains no moving parts and becomes an integral part of the fuel inducation system. It is assumed that the reliability of the induction system will be unchanged as a result of the modification, provided the devices are designed and fabricated to preclude structural failures in the use environment. The leaner carburetor jets should have no effect on carburetor reliability, but they must be properly selected to avoid engine degradation.

Based on these considerations, Device 172 should have a reliability in excess of 75,000 MMBTF.

4.3.1.5 Maintainability

No maintenance attributable to the device would be required. The changed carburetor jets would require the same maintenance at the same intervals as the original equipment jets.

4.3.1.6 Driveability and Safety

This device was not tested in the retrofit study. The referenced EPA report indicated that the device had a small adverse effect on performance at high loads; however, this may not be so attributable to the intake manifold modification as to the other vehicle changes that were tested in combination with the device.

Developer tests indicate that a vehicle equipped with the conical inserts drove as well as or better than the unmodified vehicle. A 1968 Ford Fairlane was driven 10,000 miles by the developer with no loss of emission reduction effectiveness.

Developer driveability tests have also indicated that some fuel economy may be provided by the device. With the same 1970 Plymouth used in emission tests (Table 4-42), fuel consumption test results were obtained as shown in Table 4-44.

Table 4-44. DEVICE 172 INTAKE MANIFOLD MODIFICATION FUEL CONSUMPTION DATA REPORTED BY DEVELOPER (1)

VEHICLE CONFIGURATION (2)	AVERAGE MILEAGE PER GALLON			AVERAGE PERCENT REDUCTION
	45 MPH	55 MPH	65 MPH	
Without Device	28.3	22.0	20.3	
With Device	30.2	28.6	23.1	
Percent Reduction	7	30	15	17

(1) Each test was run over a 75-mile interstate highway route, out and back, for a total of 150 miles. One test was performed at each mph increment with and without the conical inserts installed.

(2) Same vehicle as described in Table 4-42, Note (2), with over 36,000 miles indicated. No tuneup was made before test.

No safety hazards are indicated by the device. This assumes that:

1. The induction modification inserts maintain structural integrity so as to preclude their ingestion through the intake valves, with consequent catastrophic engine failure.

2. Excessive lean carburetor jets are not used, because they could result in significant engine performance deterioration or catastrophic failure under potentially hazardous circumstances.

4.3.1.7 Installation Description

Installation of this device consists in removing the intake manifold and inserting the intake rams and replacing the primary carburetor jet with one producing a leaner air-fuel ratio. Adjustment consists in setting the engine idle rpm and the idle mixture.

Table 4-45 contains a more detailed description of the installation procedure and identifies tools and special equipment required. Installation can be accomplished in a normally equipped repair shop with average skills.

Table 4-45. DEVICE 172 INTAKE MANIFOLD MODIFICATION INSTALLATION PROCEDURE

MINIMUM AVERAGE SKILL LEVEL: AUTOMOTIVE MECHANIC		
INSTALLATION AND ADJUSTMENT PROCEDURE	TOOLS, EQUIPMENT AND FACILITIES	TIME (MIN.)
1. Remove carburetor from intake manifold	Hand tools	10
2. Remove intake manifold from cylinder heads	Hand tools	20
3. Install intake rams into intake manifold	a. Hand tools b. Intake rams c. Gasket	5
4. Reinstall intake manifold on cylinder heads	Hand tools	20
5. Remove standard primary jets from carburetor	Hand tools	5
6. Install new primary jets giving a leaner air fuel ratio	a. Hand tools b. Primary jet	5
7. Reinstall carburetor on intake manifold	Hand tools	10
8. Adjust engine to factory specifications for idle rpm and adjust for best lean mixture	Tachometer	15
	Total Time	1.5 hrs

4.3.1.8 Initial and Recurring Costs

Table 4-46 summarizes the costs for this device. The developer estimated that the cost of this device should be $40 to $60, depending on the size and type of engine. From the information available, it is estimated that the initial cost for this device, including labor and material, would be $58.74 to $78.74. No recurring cost would be expected, as the device should not require any maintenance.

Table 4-46. DEVICE 172 INTAKE MANIFOLD MODIFICATION INITIAL AND RECURRING COSTS

ITEM	DESCRIPTION	LABOR HOURS OR ITEM QUANTITY	COST (DOLLARS)
Initial Cost:			6-cyl 8-cyl
Material			
1. Device	a. Intake rams b. Primary jet for carburetor		$40 - $60
2. Miscellaneous	Gasket		(Included in above)
Labor			
1. Installation	Table 4-45	1.25 hrs	$15.62
2. Test and adjust	Table 4-45	0.25 hr	$3.12
		Total Initial Cost	$58.74-$78.74
50,000-Mile Recurring Cost:			
Material			
1. Fuel	17 percent savings (Table 4-44)	680 gal @ $0.35 per gal over 50,000 mi. (1)	-$238.00
		Total Recurring Cost	-$238.00
		TOTAL COSTS	-$159.26

(1) Based on an assumed national average of 10,000 miles per year and 12.5 mpg.

4.3.1.9 Feasibility Summary

This device, as an intake manifold modification, would appear to be a technically feasible retrofit device for reduction of CO and HC emissions in the configuration reported in Table 4-42. Although the initial cost is moderately high, the device would apparently require virtually no maintenance and could have some fuel economy benefits. Further testing would be required to verify the emission reduction effectiveness and fuel economy benefits for a range of used cars, as well as the specific device configuration for these cars.

4.3.2 Device 430: Induction Modification

This device consists of a conical nozzle and screen assembly mounted below the carburetor throttle plate, between the carburetor base and the intake manifold. The purpose of the nozzle-screen assembly apparently is to improve vaporization of the air-fuel mixture. Use of this device is combined with engine adjustments described later.

The developer has fabricated two units, installed them on two pre-1968 vehicles, and conducted tests with and without the device in accordance with the 1970 Federal Test Procedure (Reference 15).

4.3.2.1 Physical Description

As shown in Figure 4-23, the device consists of a conical nozzle insert into which is fitted a porous conical cup made of three layers of steel screen. The conical nozzle and porous cup are installed between the carburetor and intake manifold as shown in Figure 4-24.

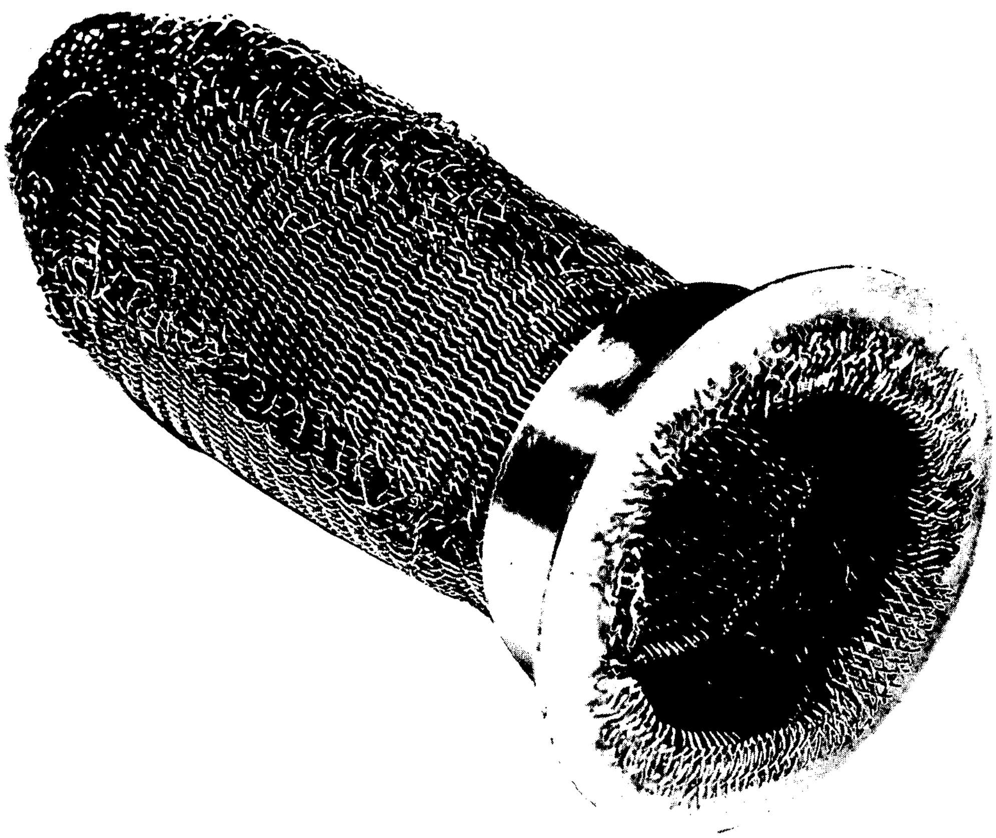


Figure 4-23. DEVICE 430 INTAKE MANIFOLD NOZZLE SCREEN CONFIGURATION

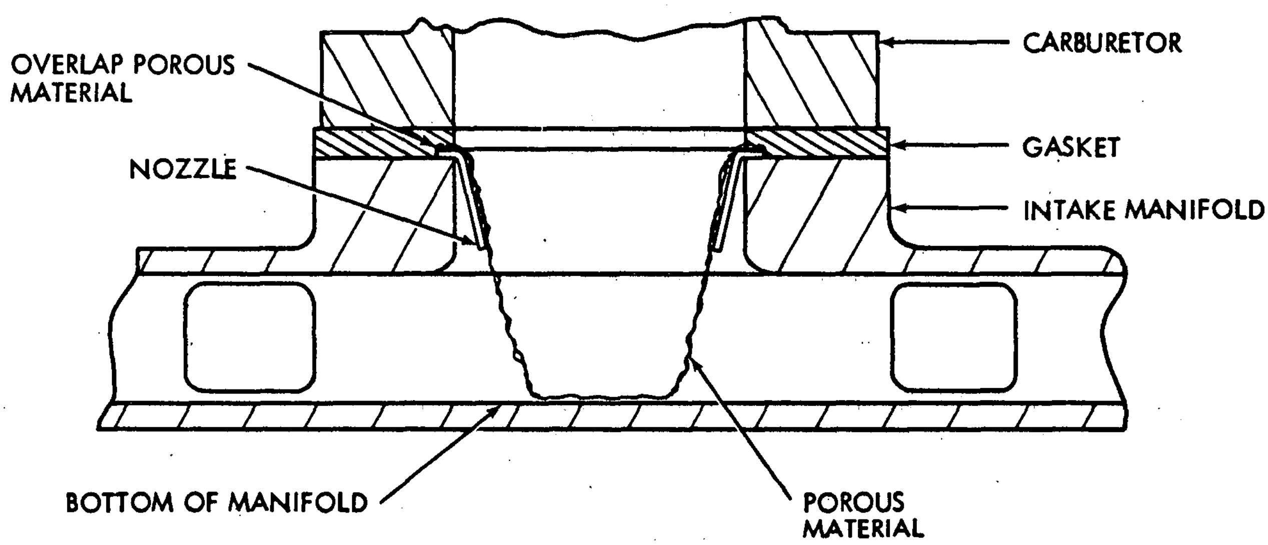


Figure 4-24. DEVICE 430 INTAKE MANIFOLD NOZZLE SCREEN INSTALLATION

4.3.2.2 Functional Description

The conical nozzle section of this device has a throat area approximately equal to that of the carburetor venturi. The wire mesh cup apparently is intended to provide a high surface area for fuel droplet impingement and subsequent vaporization.

In addition to installation of the vaporizer, the developer also disconnects the vacuum advance, and adjusts the carburetor automatic choke and idle mixture to maximum lean settings. Disconnecting the vacuum advance should reduce combustion chamber temperature, and decrease NOx formation.

4.3.2.3 Performance Characteristics

Performance data provided by the developer are presented in Table 4-47.

4.3.2.4 Reliability

The vaporizer device contains no moving parts and becomes an integral part of the fuel induction system. It is assumed that the mean-miles-before-total-failure of the induction system would be unchanged as a result of the modification, provided the vaporizer is compatible with the specific induction system configuration. The device reliability should be more than adequate for the 50,000-mile service life required of a retrofit device. MMBTF should be in excess of 75,000 miles.

4.3.2.5 Maintainability

The device should be inspected and cleaned or replaced whenever the carburetor is cleaned or overhauled (25,000 MMBM). Maintenance time attributable to the device itself is estimated to be less than 5 minutes (0.08 hr MTTM). The device is nonrepairable.

Table 4-47. DEVICE 430 INDUCTION MODIFICATION EMISSION TEST RESULTS PROVIDED BY DEVELOPER (1)

VEHICLE CONFIGURATION	POLLUTANT (GM/MI)			NUMBER OF TESTS
	HC	CO	NOx	
1966 Pontiac (2)				
Without Device	8.55	51.7	3.38	1
With Device	3.83	52.36	2.32	2
Percent Reduction	55.0	-1.0	31.0	
1963 Dodge (3)				
Without Device	3.96	73.73	5.06	1
With Device	3.46	58.60	2.93	1
Percent Reduction	13.0	20.0	42.0	
Mean Percent Reduction	34.0	9.5	36.5	

(1) Tests conducted in accordance with the 1970 Federal Test Procedure (Reference 15) by Scott Research Laboratories.

(2) 1966 Pontiac GTO with 389-CID engine.

(3) 1963 Dodge Dart with 235-CID engine and automatic transmission.

4.3.2.6 Driveability and Safety

Evaluation of device driveability was not possible, as the developer supplied no driveability data.

No safety hazards with the device are indicated. In the event of structural failure of the nozzle screen, it does not appear likely engine failure would be immediately catastrophic.

4.3.2.7 Installation Description

Table 4-48 itemizes installation requirements for this device. The installation consists in removing the carubretor, installing the vaporizer screen in the manifold, replacing the carburetor, reducing accelerator pump travel, and sealing off the distributor vacuum advance. Adjustment consists in regulating idle rpm to new values, setting idle mixture screws to obtain minimum CO and HC emissions, and setting the automatic choke to the leanest acceptable setting.

It is estimated that installation should take about 0.75 hour. Installation can be accomplished in a normally equipped repair shop by the average mechanic.

Table 4-48. DEVICE 430 INDUCTION MODIFICATION INSTALLATION PROCEDURE

MINIMUM AVERAGE SKILL LEVEL: AUTOMOTIVE MECHANIC		
INSTALLATION AND ADJUSTMENT PROCEDURE	TOOLS, EQUIPMENT AND FACILITIES	TIME (MIN.)
1. Remove carburetor and carburetor mounting gasket.	Hand tools	10
2. Clean carburetor mounting and intake manifold mounting surfaces.	Hand tools	2
3. Install vaporizer in manifold making sure that porous material (screen) touches bottom of manifold and overlaps the top edge of the nozzle.	Vaporizer device	2
4. Place carburetor gasket on top of vaporizer and reinstall carburetor.	Hand tools	10
5. Reduce accelerator pump travel 60 percent of its former value.	Hand tools	2
6. Remove vacuum advance hose and seal connections. (Applicable only if the distributor has both centrifugal and vacuum advance mechanisms.)	Hand tools	2
7. Start engine and check for air leaks.		2
8. Set idle speed, with engine at operating temperatures:	Tachometer	8
a. At 620 rpm with automatic transmission in drive.		
b. At 700 rpm with manual transmission in neutral.		
9. Set idle mixture screws to leanest acceptable running or minimum HC if instrument available.	Tachometer or engine analyzer	3
10. Recheck idle speed and adjust to recommended values as necessary.	Tachometer	
11. Set automatic choke to leanest acceptable running setting.	Hand tools	2
	Total Time	0.75 hr

4.3.2.8 Initial and Recurring Costs

Table 4-49 summarizes the installation costs for this device. From the information available, it is estimated that the cost for installing this device, including material, would be \$14.37 to \$19.37. Recurring costs are not estimated since it is assumed that any inspection of the device would be required only at the time carburetor maintenance is performed, and the maintenance cost attributable to the device would be insignificant.

Table 4-49. DEVICE 430 INDUCTION MODIFICATION INITIAL AND RECURRING COSTS

ITEM	DESCRIPTION	LABOR HOURS OR ITEM QUANTITY	COST (DOLLARS)
Initial Cost:			
Material			
1. Device	Vaporizer device		5.00 - 10.00
Labor			
1. Installation	Table 4-48	0.5 hr	6.25
2. Test and adjust	Table 4-48	0.25 hr	3.12
		Total Initial Cost	14.37 - 19.37
50,000-Mile Recurring Cost (Refer to paragraph 4.3.2.8)			

4.3.2.9 Feasibility Summary

The feasibility of this device for retrofit application is considered to be inconclusive until controlled testing is performed to determine the extent to which the device and the related engine tuneup modifications contribute to the emission reduction effectiveness indicated. It is undeterminable from the data provided whether the reduced emissions indicated by test data were achieved because of adjustments made at the time of device installation (vacuum advance disconnect, lean idle mixture, high idle speed, etc.), or because of the device.

4.3.3 Device 440: Intake Deflection Plate

This device operates on the same air-fuel vaporization principle as Device 430, but the means of implementing the principle is different.

4.3.3.1 Physical Description

Device 440, shown in Figure 4-25, consists of one component, a plate which fits between the carburetor and the manifold. The plate has varied shaped deflectors which extend into the manifold, and the configuration varies for different model-year vehicles. The plate is coated with a nonwettable fluorochemical coating.

4.3.3.2 Functional Description

There are apparently two principles of operation for this device:

1. Deflection of the air-fuel mixture to aid in its vaporization
2. Provision of a nonwettable surface to avoid filming of the mixture on the deflection prongs.

According to the developer, a nonwettable surface is designed to prevent film formation on the device plate. Figure 4-26 shows a cross section of a carburetor with the plate installed and typical configurations of the deflectors that have been tried by the developer. The shapes of these deflectors are dependent upon the venturi area and volumetric flow through the particular carburetor.

The following is an extraction from documents supplied by the developer relating ' the theory of operation of the device:

> "This invention offers a simple and effective means for improving engine induction system performance through elimination of wet film wall flow and by more uniform fuel distribution. This is accomplished through application of a space age fluorochemical to a sheet metal plate interposed between carburetor and manifold.
>
> "The operative principles are both simple and familiar. Any science student who has ever spilled a drop of mercury onto a surface it does not wet remembers vividly how it shattered into a myriad of small spheres. It is well understood among combustion engineers that liquid gasoline will not burn and that the speed of vaporization is proportional to the exposed liquid surface area. A bit of simple arithmetic confirms that if a film of liquid is dispersed into spheroids of comparable size scale by being swept onto a surface it cannot wet, the aggregate exposed area of the spheroids is many times greater than that of the film."

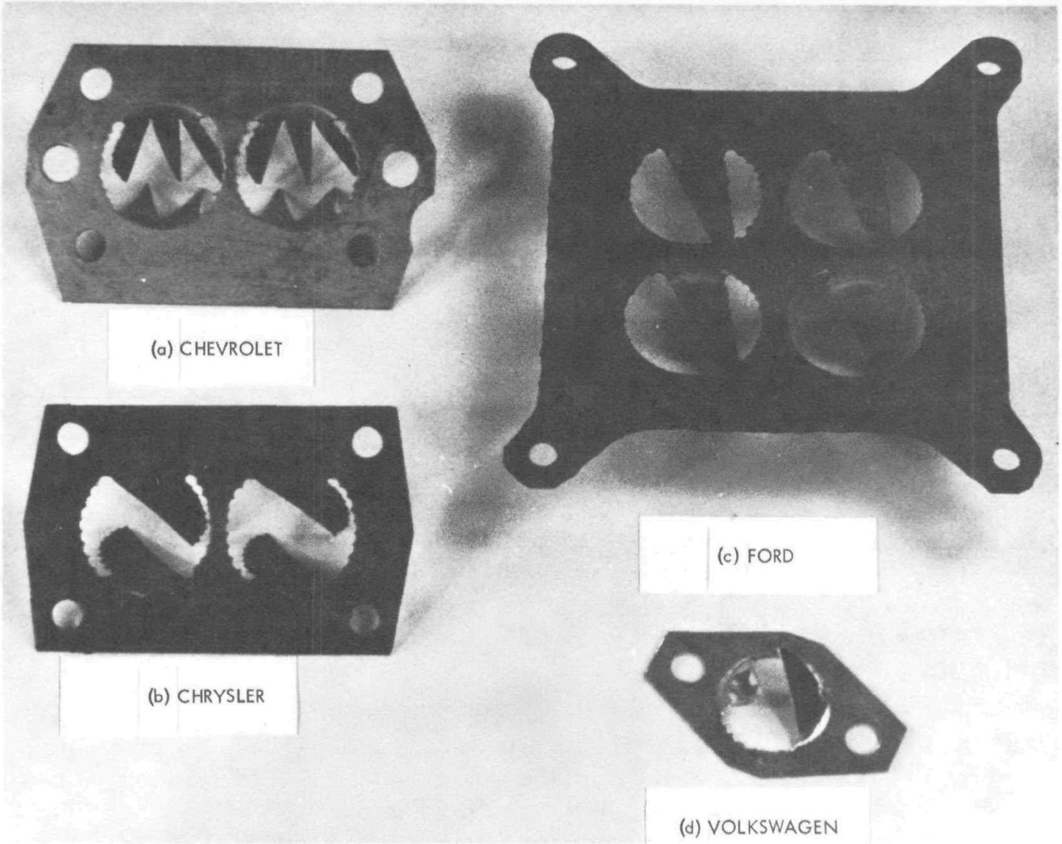


Figure 4-25. DEVICE 440 INTAKE DEFLECTION PLATE VEHICLE MANUFACTURER CONFIGURATIONS

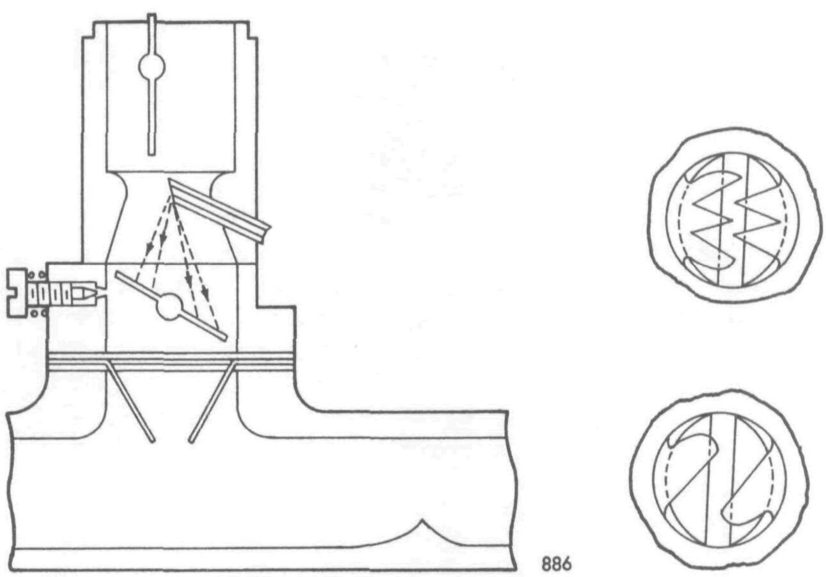


Figure 4-26. DEVICE 440 INTAKE DEFLECTION PLATE INSTALLED AND TYPICAL VARIATIONS (DEVELOPER SKETCH)

4.3.3.3 Performance Characteristics

Emission data were not obtainable from the developer of this device. The only testing indicated has been qualitative driveability and fuel consumption runs made on 11 automobiles. A summary of the performance indicated by these trials is shown in Table 4-50, as provided by the developer.

Table 4-50. DEVICE 440 INTAKE DEFLECTION PLATE TEST EXPERIENCE SUMMARY PROVIDED BY DEVELOPER

1. Chevrolet 283 2-Barrel Rochester Overdrive Transmission	Ragged low speed performance and 14-15 MPG fuel consumption provoked invention. Original carburetor calibration represented best possible compromise and changes further degraded performance without improving economy. Installation of device cured tendency to stumble after cornering, made the engine impressively more responsive and boosted mileage to 19 MPG. With the device operating to eliminate liquid fuel flow through engine it became constructive to reduce the original 0.056 main jets to as small as 0.048 with 21.8 MPG economy at highway speeds. Optimum performance and 20.7 MPG at 65-70 MPH is realized with 0.051 jets. Driveability does not degrade when vacuum enrichment is disabled.
2. Ford Mustang 289 2-Barrel Automatic Transmission Air Conditioned	Distinct improvement in responsiveness. Economy improvement from 15.5-16.5 MPG to 20.3 in owners' service. Slight further improvement on reducing main jets from 0.059 to 0.045.
3. Ford Mustang 289 4-Barrel, 4-Speed	Distinct improvement in responsiveness and in idle smoothness and adjustment tolerance. Economy improved from 15-17 MPG to 19-20. Further gain of about 1 MPG accompanied primary jet reduction from 0.048 to 0.045.
4. Oldsmobile F-85 Rochester Quadrajet Hydrametic	Sufficient improvement in responsiveness to be quickly noticed by owner. Economy improved from 15 to 17 MPG on identical trip. No change attempted in calibration.
5. 1965 Chevrolet 6-194	Noticeable smoother performance and 20-60 MPH acceleration time was reduced from 22.2 to 19.6 seconds on installation of device alone. Retimed at 22.7 seconds when main jet was subsequently reduced from 0.060 to 0.056. Car which is driven mainly in local service is not in first class condition. Economy is reported improved from about 16 to 18 MPG.

Table 4-50. DEVICE 440 INTAKE DEFLECTION PLATE TEST EXPERIENCE SUMMARY PROVIDED BY DEVELOPER (CONCL)

6. 1962 Chevrolet 6-235 Rochester 1-Barrel Powerglide Transmission	Owned and driven in short trip service by secretary who is enthusiastic about improved performance. Says it moves out like a big car. (This after jet was reduced from 0.055 to 0.047). No meaningful economy data available.
7. Volkswagen 1300 Solex Carburetor	This recent installation yields perhaps the most convincing performance improvement, in the matter of improving low speed flexibility to permit smooth acceleration from less than 10 MPH in third gear. Idle mixture adjustment which was verified and marked before installation of device shifted 30° toward lean afterwards; owner reports economy in his local use improved from 27 to 30 and 34 MPG on two checks.
8. Ford 1965 LTD - 352 4-Barrel C5AF-1 Automatic Transmission	On this installation in which idle mixture settings were carefully checked before and after device installation, a change of nearly 90° or 1/4 turn leaner for speed decline was experienced. Owner reports 15.5 MPG on return trip to Charlotte with air conditioner running versus 13.8 MPG northbound in morning chill. Jets have not yet been changed.
9. Dodge Dart 330 2-Barrel Stromberg WW Code Stamped 3-199 Automatic Transmission	Responsiveness definitely improved. Owner reports quicker starting. No economy data yet available. Idle adjustment on this installation did not shift.
10. 1962 Chrysler Newport 361 Engine Stromberg WWC Carburetor Code 3-201 Manual Transmission	Noticeable flat spot and stumbling just above idle definitely cured. Idle adjustment much less tempermental. No economy data yet available.
11. 1965 Chevrolet 327 Rochester 4-Barrell Automatic Transmission Air Conditioned	Recent installation on Patent Attorney's car. Idle smoothness measurably improved and adjustment rendered more definite and less temperamental. No economy data.

4.3.3.4 Reliability

The device contains no moving parts and becomes an integral part of the fuel induction system. It is assumed that the mean-miles-before-total-failure of the induction system would be unchanged as a result of installing the device, provided that the device is designed and fabricated to preclude structural failures in the use environment (also refer to paragraph 4.3.3.6). Therefore, the retrofit device standard reliability requirement of a 50,000 MMBF service life should be equaled or exceeded. An MMBTF of over 75,000 miles should be achieved.

4.3.3.5 Maintainability

The device should be inspected and cleaned or replaced whenever the carburetor is cleaned or overhauled (25,000 MMBM). Maintenance time attributable to the device is estimated to be less than 5 minutes (0.08 hr MTTM). The device is nonrepairable.

4.3.3.6 Driveability and Safety

Driveability information provided by the developer (Table 4-50) indicates that the device may enhance vehicle performance. This information is qualitative, and data from formal driveability procedures would have to be reviewed to evaluate all driveability characteristics quantitatively.

No safety hazards are indicated. In the event of structural failure of the device, it is not likely that engine failure would be immediately catastrophic.

4.3.3.7 Installation Description

Installation is accomplished by inserting the device between the carburetor and intake manifold. Adjustment consists in setting the engine idle rpm and the idle mixture.

The developer estimated that installation will take about one-half hour. Table 4-51 itemizes the installation requirements, which indicate an installation time of 0.75 hr. Installation can be accomplished in a normally equipped repair shop by the average mechanic.

Table 4-51. DEVICE 440 INTAKE DEFLECTION PLATE INSTALLATION PROCEDURE

MINIMUM AVERAGE SKILL LEVEL: AUTOMOTIVE MECHANIC		
INSTALLATION AND ADJUSTMENT PROCEDURE	TOOLS, EQUIPMENT AND FACILITIES	TIME (MIN.)
1. Remove carburetor from intake manifold	Hand tools	10
2. Insert device between carburetor and intake manifold	Device	2
3. Install carburetor, reconnect linkage	Hand tools	18
4. Adjust idle rpm and idle mixture	Engine analyzer	15
	Total Time	0.75 hr

4.3.3.8 Initial and Recurring Costs

The developer estimated the cost of the device to be $3. Table 4-52 summarizes the installation costs for this device. From the information available, it is estimated that the cost for installing this device, including material, would be $12.37. There should be no recurring costs of significance.

Table 4-52. DEVICE 440 INTAKE DEFLECTION PLATE INITIAL AND RECURRING COSTS

ITEM	DESCRIPTION	LABOR HOURS OR ITEM QUANTITY	COST (DOLLARS)
Initial Cost:			
Material			
1. Device	Deflection Plate	One per carburetor	3.00
Labor			
1. Installation	Table 4-51	0.50 hr	6.25
2. Test and adjust	Table 4-51	0.25 hr	3.12
		Total Initial Cost	12.37
50-000-Mile Recurring Cost (Refer to paragraph 4.3.3.8)			

4.3.3.9 Feasibility Summary

The determination of the feasibility of this device depends on the results of exhaust emission tests on representative used cars. No exhaust emission data were supplied for this device. All other characteristics of the device appear to be satisfactory.

4.3.4 Device 384: Air-Fuel Mixture Diffuser

This device is similar to Device 430 (paragraph 4.3.2) in providing a screening process for the air-fuel mixture as it enters the intake manifold. The screening approach is different, however, and is claimed by the developer to induce a "catalytic reaction" in the air-fuel mixture.

4.3.4.1 Physical Description

The developer calls Device 384 a "carburetor catalyst." It consists of a plate fitted with one or more conical screen cups, each cup made up of two separated wire mesh screens. The plate contains one conical cup for each carburetor barrel. A two-cup plate assembly for a two-barrel carburetor is shown in Figure 4-27. The plate assembly is shaped to install as an adapter between the carburetor and the intake manifold.

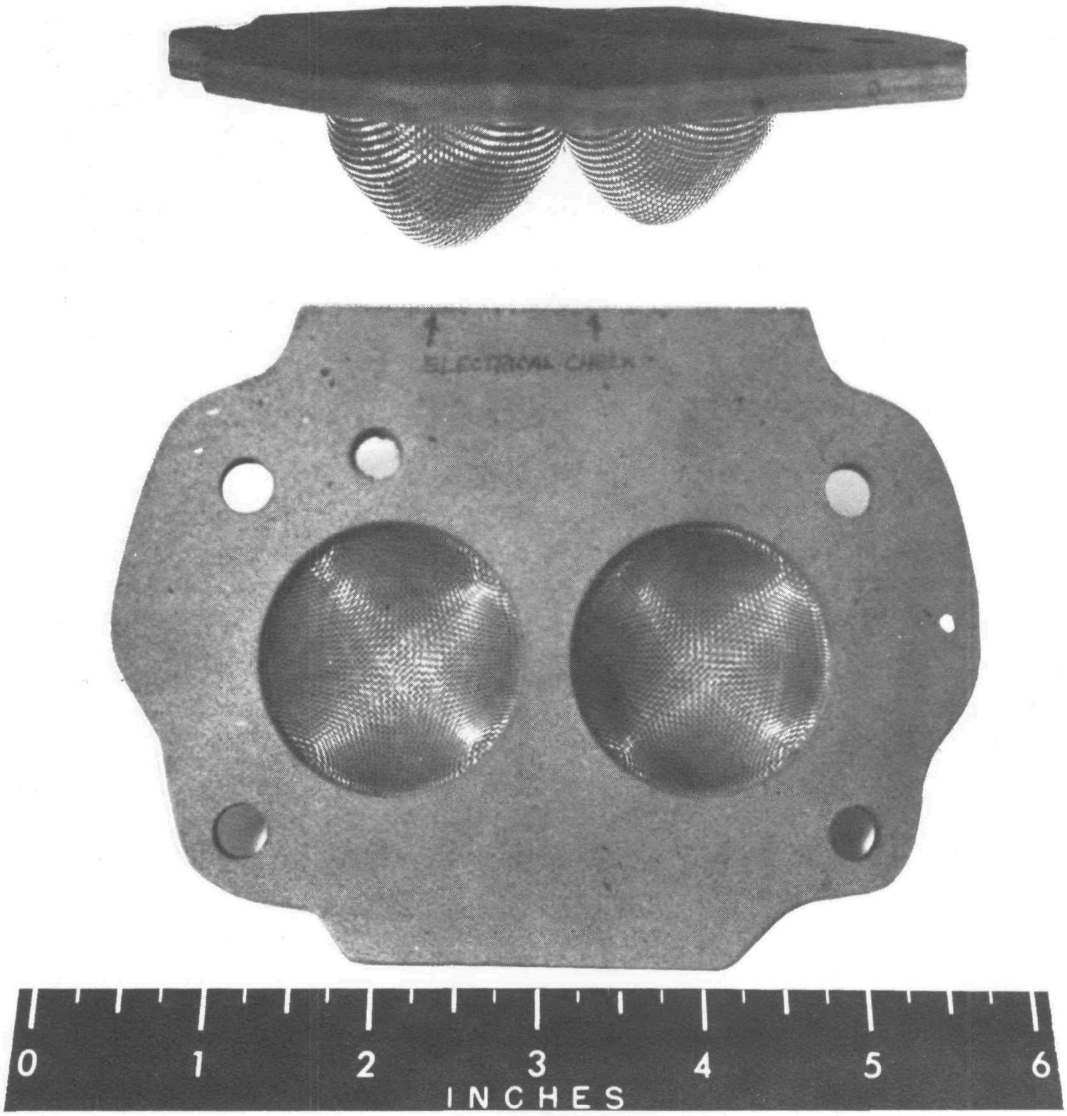


Figure 4-27. DEVICE 384 AIR-FUEL MIXTURE DIFFUSER (CONFIGURATION FOR TWO-BARREL CARBURETOR)

4.3.4.2 Functional Description

Figure 4-28 illustrates the installation details of this device. The wire mesh cup is apparently intended to provide a high surface area for fuel droplet impingement and subsequent evaporation. The two screen cups are separated from contact with each other.

The developer states there are many desirable side effects which improve the combustion process itself. According to the developer, the device provides: "A catalytic reaction of the fuel-air mixture prior to entry into the engine to complete combustion in the combustion chamber." This is claimed by the developer to reduce "sludge buildup in engine and oil" and to increase mileage and spark plug life. Also, he claims that: "Use of the carburetor catalyst, as manufactured by the developer, allows the maintenance of present levels of engine design efficiency using lower octane, low lead fuels meeting proposed federal fuel standards.

4.3.4.3 Performance Characteristics

Performance data submitted by the developer are presented in Table 4-53. These data indicate that the developer also uses leaner carburetion and timing retardation in combination with the device. These engine tuning exhaust modifications would tend to decrease CO and NOx exhaust emissions, respectively.

4.3.4.4 Reliability

The device contains no moving parts and becomes an integral part of the fuel induction system. It is assumed that the mean-miles-before-total-failure (MMBTF) of the induction system will be unchanged as a result of the modification, provided the device is compatible with the specific induction system configuration. Therefore, a device reliability requirement of 75,000 MMBTF should be equaled or exceeded.

4.3.4.5 Maintainability

The device should be inspected and cleaned or replaced whenever the carburetor is cleaned or overhauled (25,000 MMBM). Maintenance time attributable to the device is estimated to be less than 5 minutes (0.08 hr MTTM).

The device itself appears to be nonrepairable and would be replaced if it fails. Mean-time-to-repair (MTTR) would thus be the same as the installation time (paragraph 4.3.4.7).

4.3.4.6 Driveability and Safety

The developer did not provide data as to the effect of the device on vehicle driveability.

No safety hazards are apparent. In the extent of structural failure of the device, it is not probable that engine failure would be immediately catastrophic. As with any of the intake manifold screen devices, clogging of the screen could degradate vehicle performance. This would probably occur gradually and should not therefore constitute a safety problem.

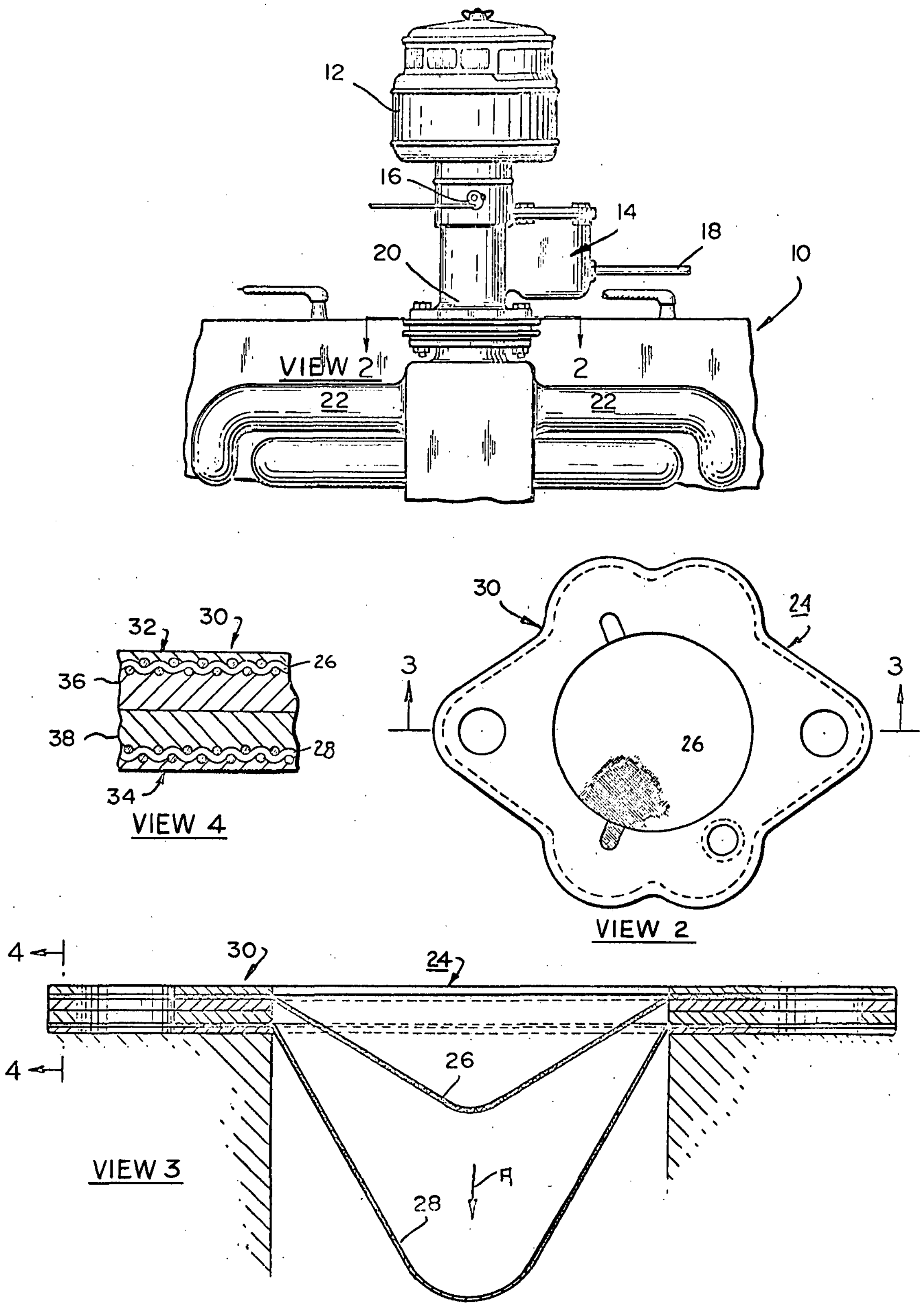


Figure 4-28. DEVICE 384 AIR-FUEL MIXTURE DIFFUSER INSTALLATION SKETCH (FROM DEVELOPER'S PATENT DISCLOSURE)

Table 4-53. SUMMARY OF DEVICE 384 AIR-FUEL MIXTURE DIFFUSER EXHAUST EMISSION DATA PROVIDED BY DEVELOPER (1)

Test No.	Date (2)	Test Type	Device	Timing (°BTDC)	Idle Mixture (3)	HC (ppm-C_6)	CO (%)	NO (ppm)
1965 Ford Galaxie								
1	1/19/71	Cold	None	10	1 + 1 1/4	604	3.65	1,161
		Hot				517	4.92	839
		Composite				547	4.48	951
2	1/19/71	Hot	None	10	3/4 + 1	426	4.34	876
3	1/19/71	Hot	Carb. Cat.	9	7/16 + 3/4	464	4.88	895
4	3/01/71	Hot	Carb. Cat.	10	1/4 + 3/8	310	3.25	1,034
1967 Chrysler 300								
1	1/27/71	Cold	None	12	1 7/8 + 2 3/4	579(4)	7.14	415
		Hot				416	5.08	568
		Composite				473	5.80	514
2	1/27/71	Hot	None	12	1 5/8 + 2 1/2	354	4.63	640
3	1/27/71	Hot	Carb. Cat.	12	1 1/3 + 2	368	3.99	899
4	3/01/71	Hot	Carb. Cat.	10	3/4 + 1 3/4	298	2.23	904
5	3/01/71	Cold	Carb. Cat. & Modulator	9	3/4 + 1 3/4	346(4)	5.74	293
		Hot				168	2.99	429
		Composite				230	3.95	381
Percent Reduction (4):						40.2	19.6	29.4

(1) 7-cycle, 7-mode test procedure.

(2) Mileage values = 1/19/71 Ford 48,156
3/01/71 Ford 50,185
1/27/71 Chrysler 40,074
3/01/71 Chrysler 43,793

(3) Number of turns from closed (driver side and passenger side).

(4) Cold start data used as baseline and retrofit values for evaluating Device 384 emission reduction potential in retrofit study program.

4.3.4.7 Installation Description

The installation of this device consists in removing the carburetor, installing the carburetor catalyst on the intake manifold, and replacing the carburetor. The carburetor catalyst is made so that the carburetor bolts will center the "catalytic cups" in the manifold bore with at least 0.040 inch clearance. The developer stated that the "catalyst" will not function if it is installed in contact with other metallic surfaces. Special adapter plate assembly configurations would possibly be required for different vehicles.

It is estimated that installation would take about one-half hour. Table 4-54 contains a more detailed description of the installation procedure and identifies the tools and special equipment required. Installation could be accomplished in a normally equipped repair shop or service station with average skills.

4.3.4.8 Initial and Recurring Costs

The developer did not provide sufficient data on which to base an estimate of initial and recurring costs. Because of the screen insulation design requirements of the device, it would appear that the cost of this device might be higher than the other air-fuel vaporizing devices evaluated. Whether this initial cost would be offset by recurring savings in fuel economy is not known.

4.3.4.9 Feasibility Summary

Based on the emission data provided by the developer, the specific contribution of the device to emission control could not be determined in relation to the engine tuneup adjustments used. Further testing for emission, fuel consumption, and driveability effects would be required on a variety of used cars, to establish the overall cost effectiveness of the device for retrofit applications.

Table 4-54. DEVICE 384 AIR-FUEL MIXTURE DIFFUSER INSTALLATION PROCEDURES

MINIMUM AVERAGE SKILL LEVEL: AUTOMOTIVE MECHANIC		
INSTALLATION & ADJUSTMENT PROCEDURE	TOOLS, EQUIPMENT & FACILITIES	TIME (MINUTES)
1. Disconnect fuel line, automatic choke, vacuum line, and throttle linkage to carburetor.	Hand Tools	5
2. Replace carburetor to manifold bolts so carburetor can be lifted at least 3 inches.	Hand Tools	5
3. Remove old gasket from carburetor/manifold.	Hand Tools	1
4. Place carburetor catalyst on manifold with catalyst cups centered down into the manifold cavity.		1
5. Place the carburetor on top of the gasketed carburetor catalyst and attach carburetor bolts or nuts (loosely).	Hand Tools	3
6. Tighten all carburetor and manifold fasteners to 10 ft-lb with torque wrench.	Torque Wrench	5
7. Connect fuel line, automatic choke, vacuum line and throttle linkage to carburetor. Replace throttle spring.	Hand Tools	8
8. Electrical check of device for shorts. Start engine and check for vacuum leaks.	Volt-ohmmeter	1
Total Time		0.5 hr

4.4 CARBURETOR MODIFICATION - RETROFIT SUBTYPE 1.2.4

The retrofit study indicated that modification of the carburetor alone is seldom used as a means of controlling vehicle emissions. More often a change to the carburetor tuning, such as leaning the air-fuel ratio, is used in combination with other control methods, such as vacuum advance disconnect, to achieve emission control. The basic principle that can be used in controlling emissions by means of the carburetor is that of lean air-fuel mixture (high air-fuel ratio). This has the effect of not only decreasing the amount of fuel by which pollutants can be formed during combustion, but of providing the air needed to oxidize CO and HC, into carbon dioxide and water. A second principle implementable through the carburetor is that of providing improved fuel vaporization and homogeneous mixing. This can extend the mixture lean limit of engine operation (Reference 98).

Possibly the reason carburetors themselves are not often modified by retrofit developers to operate on the lean air-fuel mixture principle is that an air-bleed tube to the intake manifold accomplishes the same effect, and it also provides a marketable product. Similarly, air-fuel vaporization and mixing can be accomplished more expediently by inserting another device between the carburetor and the intake manifold, rather than modifying the carburetor - a process that for either lean mixture or improved mixing would require carburetor teardown. So the approach in most cases has been to leave the carburetor untouched, except for lean idle adjustment, and to devise add-ons to achieve the desired effects.

Of the 65 devices studied, five were classified as carburetor modifications, because they directly involve changes to the carburetor components and mode of operation (see Table 4-1). The emission reduction principles vary. Device 33 appears to produce the same effect as an air bleed device, but accomplishes this by decreasing the pressure in the fuel bowl, under intake manifold vacuum, thereby increasing the air-fuel ratio. Device 56, which bleeds heated air and crankcase blowby through the carburetor throttle plate, also acts as an air bleed. Device 288 provides more thorough air-fuel mixing. Device 317 provides a combination of air bleed and fuel augmentation to the carburetor base with vacuum advance disconnect. Device 295 represents a completely redesigned carburetor that features a variable venturi to optimize the air-fuel ratio and mixing qualities according to engine operating requirements.

Thus it would appear that this type of device most frequently incorporates the air-fuel leaning principle associated with CO exhaust emission control, with some control of HC through improved air-fuel mixing. Only Device 317 incorporates a specific combination control for NOx reduction; although as discussed later, Device 295 also indicates some NOx control.

4.4.1 Device 33: Carburetor Modification, Main Jet Differential Pressure

This device produces the effect of an air bleed to intake manifold by decreasing the pressure differential between the carburetor venturi and the fuel bowl during engine operating modes in which there is high vacuum in the intake manifold. The device was one of 11 tested during the retrofit study.

4.4.1.1 Physical Description

Figure 4-29 shows Device 33 installed on a standard carburetor. The device consists of an adjustable valve located in a metal tube that attaches between the carburetor throttle plate and the fuel bowl. The valve is about 1/2-inch in diameter by 1 inch long and is connected by 3/16-inch diameter tubing. The valve adjustment is of the needle-valve type.

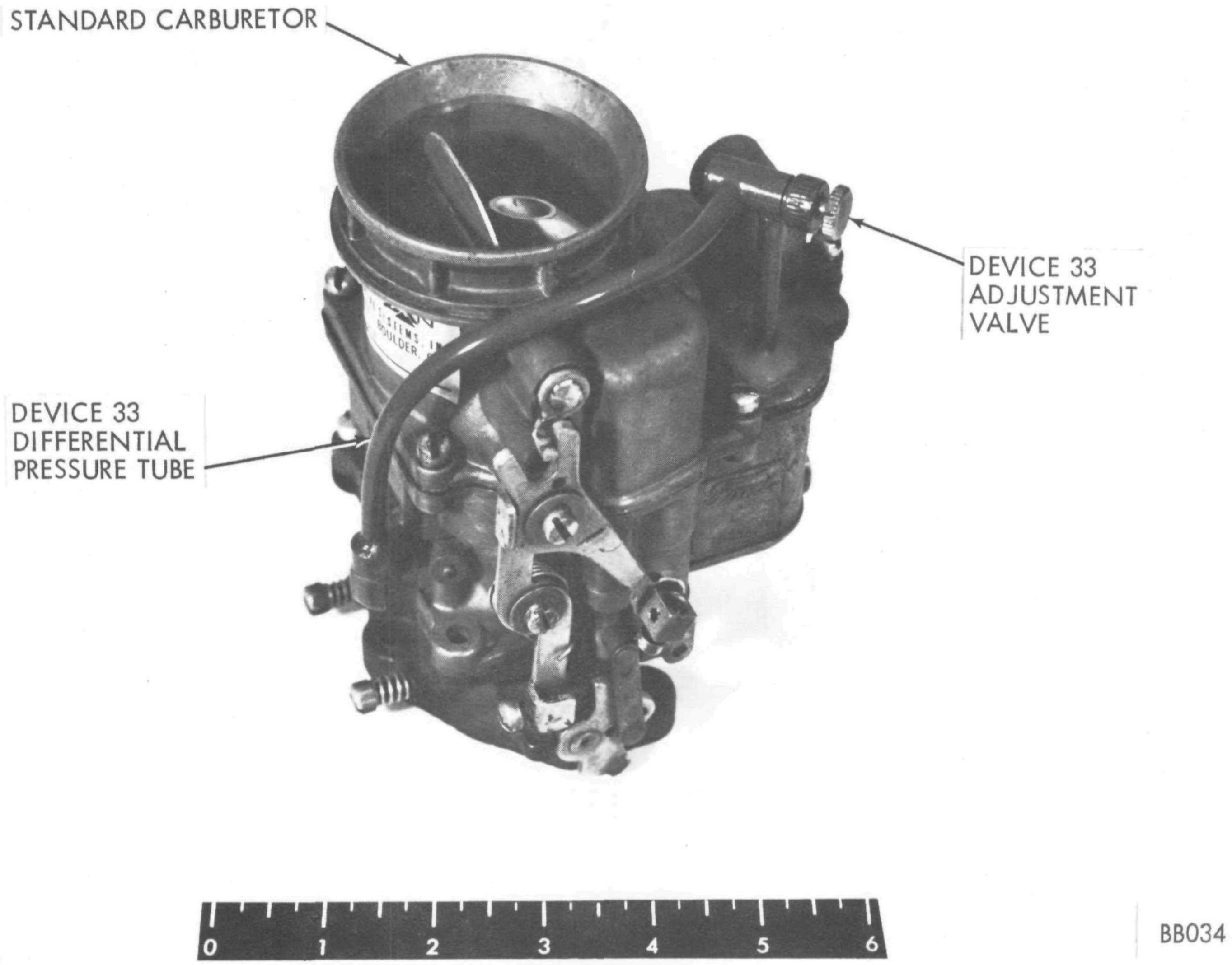


Figure 4-29. DEVICE 33 CARBURETOR MODIFICATION (MAIN JET DIFFERENTIAL PRESSURE) CONFIGURATION

4.4.1.2 Functional Description

One of the controls of the air-fuel ratio in a carburetor is the difference in pressure across the main fuel jet between the fuel bowl and the venturi. Normally the fuel bowl is vented to the atmosphere externally and/or to the air cleaner. The pressure difference between the carburetor venturi and the fuel bowl depends on air flow through the carburetor venturi. The air-fuel mixture ratio becomes higher (leaner) as the difference in pressure is reduced between the bowl and the venturi.

With Device 33 the fuel bowl vent to the air cleaner or atmosphere is sealed, and is vented instead to the intake manifold. Under low manifold conditions, such as acceleration modes, this venting has little effect on the normal air-fuel ratio of the carburetor; but, under higher manifold vacuum conditions, (such as during idle or deceleration), the venting lowers the pressure differential and then the air-fuel mixture is leaner than normal, because less fuel is drawn into the venturi.

In effect, the device constitutes a parallel vacuum circuit to that of the venturi. This parallel vacuum counterbalances venturi vacuum so as to reduce the amount of fuel in the air-fuel mixture. On starting there is little or no vacuum, so the carburetor system functions as it normally would. Also, in full throttle situations the manifold vacuum drops and the extra fuel needed for acceleration is available.

4.4.1.3 Performance Characteristics

A test program was conducted by the developer to determine the air-fuel ratio characteristics of carburetors with the device installed. Three test cars were chosen as representative of the various type of older cars on the highway today:

1. A 1964 Plymouth Valiant with a 170-CID, six-cylinder engine and a single-barrel carburetor. This car had 65,000 miles without a major overhaul.

2. A 1965 Rambler with a 232-CID, six-cylinder engine and a two-barrel carburetor. This car had 105,000 miles without a major overhaul.

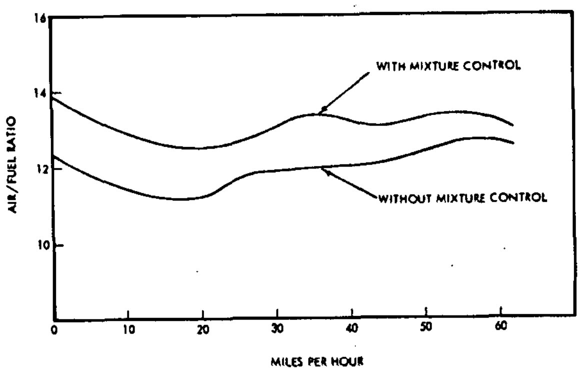
3. A 1968 Checker with a standard V-8 engine (a Chevrolet 327-CID) with a quadrajet carburetor. This car had 41,000 miles without a major overhaul.

Each car was first tested in the "as-received" condition and then given a minor tuneup to factory specifications. Each car was then tested on a dynamometer to determine the air-fuel ratio versus miles per hour. The dynamometer was set up to require 18 horsepower at 50 mph, and the car was run from 0 to 60 mph in 5-mph increments. The air-fuel ratio was recorded at each increment. The car was then stopped and the mixture control was set to produce an air-fuel ratio of 14:1 at idle.

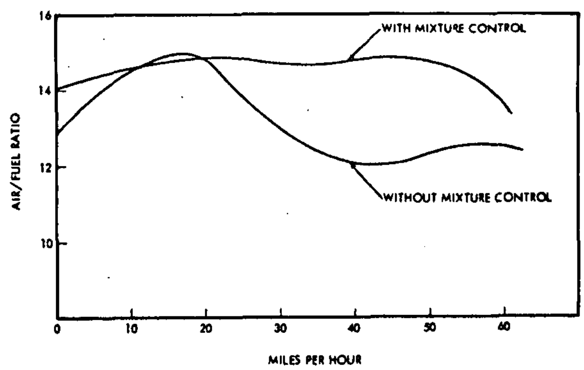
With the mixture control operating, the test was repeated. Since the Valiant would not idle at 14:1 air-fuel ratio, the test was run at 13.8:1 ratio. On the Rambler, the miles per gallon of fuel were recorded at each 5-mph increment.

The tests were repeated at least three times on each car to check repeatability. The starting characteristics and the fuel throttle characteristics of each car were carefully observed.

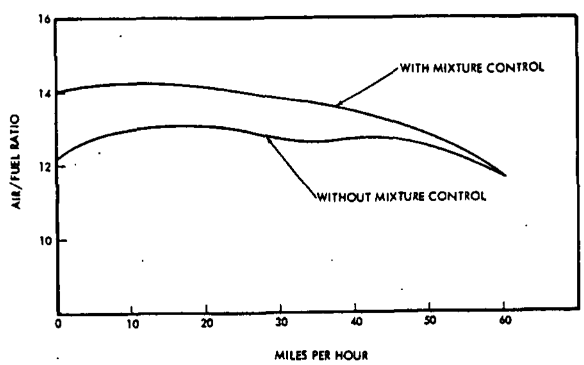
Figure 4-30 shows the typical values of air-fuel ratio versus miles per hour for the Valiant, the Rambler and the Checker, respectively. The percentage increase in the air-fuel ratio was the same for the as-received and the tuned cases. Along with increased air-fuel ratio, fuel mileage apparently increased 30 percent at 30 mph and 20 percent at 60 mph (Figure 4-30d).



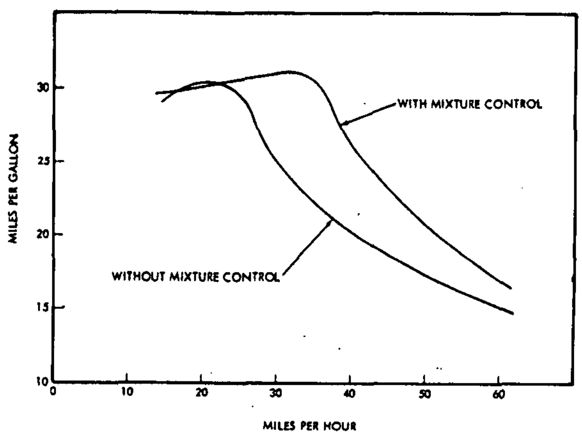
(a) 1964 Valiant



(b) 1965 Rambler



(c) 1968 Checker



(d) Rambler Fuel Mileage

Figure 4-30. DEVICE 33 CARBURETOR MODIFICATION (MAIN JET DIFFERENTIAL PRESSURE) AIR-FUEL RATIO TEST RESULTS (DEVELOPER DATA)

Table 4-55 summarizes the results of emission tests reported by the developer with Device 33 installed on these vehicles. Table 4-56 shows the results obtained by

Table 4-55. DEVICE 33 CARBURETOR MODIFICATION (MAIN JET DIFFERENTIAL PRESSURE) EMISSION TEST RESULTS REPORTED BY DEVELOPER (1)

VEHICLE CONFIGURATION (2)	POLLUTANT (GM/MI)		
	HC	CO	NOX
Without Device	9.07	104.86	2.52
With Device	6.27	44.69	2.68
Percent Reduction	31	57	-6.3

(1) Average of emission results for two 7-cycle, 7-mode tests with and without device installed.

(2) 1965 Rambler (232-CID) and a 1968 Checker (Chevrolet 327-CID).

Table 4-56. DEVICE 33 CARBURETOR MODIFICATION (MAIN JET DIFFERENTIAL PRESSURE) EMISSION REDUCTION AND FUEL CONSUMPTION PERFORMANCE (1)

VEHICLE YEAR/MAKE/CID	ANAHEIM TEST RESULTS			
	POLLUTANT GRAMS/MILE			FUEL MILES/ GALLON
	HC	CO	NOx	
1965 Ford 289				
Without Device	10.55	181.80	1.02	11.40
With Device	4.99	67.56	2.26	15.43
Percent Reduction	52.7	62.8	-121.6	-35.4
1965 Chev 327				
Without Device	7.92	80.01	2.32	14.24
With Device	6.89	57.08	1.51	12.80
Percent Reduction	13.0	28.7	34.9	10.5
Mean Percent Reduction	32.9	45.8	-43.4	-12.5

(1) Emission results obtained by Olson Laboratories in tests performed under Contract 68-04-0038 using 1972 Federal Test Procedure (Reference 3). Fuel consumption was measured during these tests.

Olson Laboratories in tests to the 1972 Federal Test Procedure during the retrofit study program. The two sets of data shown in these tables indicate the same emission control characteristics for the device. The results in both cases appear to be typical of an air bleed device. HC and CO decreased substantially in both test programs, indicating effective control of those pollutants. NOx increased on the average of these tests. Additional tests should be conducted to establish the effect of this device on NOx levels.

4.4.1.4 Reliability

The developer reported that no system failures have occurred in over 90,000 miles of driving accumulated on test cars during a 15-month period. Considering that the system consists of only a vacuum line and a fixed orifice (a valve only adjusted during maintenance), it is estimated that system reliability should exceed 75,000 mean-miles-before-total-failure.

The reliability analysis indicated the possibility of a critical secondary failure mode (primary failure mode not related to the device) which is discussed under safety.

4.4.1.5 Maintainability

No routine maintenance would appear to be required, although occasional verification of the optimum orifice adjustment might be desirable. Such adjustment would normally be made during exhaust emissions inspections.

4.4.1.6 Driveability and Safety

This device was tested for driveability on two cars at the Olson Laboratories' Anaheim facility. Table 4-57 summarizes the results of these tests. The device indicated driveability characteristics similar to an air bleed device.

A potential safety hazard could occur. In the event the carburetor float bowl shutoff valve failed in the open position and no fluid check valve were incorporated in the vacuum line, raw gasoline could be pumped into the intake manifold and constitute a fire hazard.

4.4.1.7 Installation Description

The installation of this device consists in drilling a hole in the top of the carburetor fuel bowl and in the intake manifold (or below the carburetor's butterfly valve), and connecting these two points with the air tube and adjustment valve. Proper adjustment of the valve after installation can be verified by road test or by dynamometer test.

The developer estimated that the cost of the kit and parts would be $8.65 and that it would take 1 hour of labor for installation. Installation can be accomplished in the normally equipped garage by the average mechanic, with the exception of the alternative dynamometer test for adjustment.

Table 4-58 presents the detailed installation procedures and identifies equipment required for installation, as well as installation time.

Table 4-57. DEVICE 33 CARBURETOR MODIFICATION (MAIN JET DIFFERENTIAL PRESSURE) DRIVEABILITY TEST RESULTS

DRIVEABILITY CHARACTERISTICS	1965 CHEV. 194 CID	1965 FORD 289 CID	1965 PLY. 318 CID	1965 CHEV. 327 CID	1965 FORD 390 CID	1961 CHEV. 283 CID
	ANAHEIM, CALIF., DRIVEABILITY TEST RESULTS					
	CAR NO. 1	CAR NO. 2	CAR NO. 3	CAR NO. 4	CAR NO. 5	CAR NO. 6
CRITICAL DRIVEABILITY	(1)	No effect	(1)	No effect	(1)	(1)
GENERAL DRIVEABILITY		Hesitation during cold start acceleration; increased number of start during hot start		Increased start attempts in cold start; surge in hot start acceleration		
0 - 60 MPH ACCELERATION TIME (SECONDS)		Increased from 9.8 to 10.5		Increased from 11.3 to 11.7		
60 - 40 MPH DECELERATION TIME (SECONDS)		Decreased from 23.8 to 22.7		Decreased from 24.5 to 22.7		
GAS MILEAGE PER GALLON	Average increase of 12.5 percent (reference Table 4-56)					

(1) Device No. 33 was not tested on these vehicles.

Table 4-58. DEVICE 33 INSTALLATION PROCEDURE

MINIMUM AVERAGE SKILL LEVEL: AUTOMOTIVE MECHANIC		
INSTALLATION AND ADJUSTMENT PROCEDURE	TOOLS, EQUIPMENT AND FACILITIES	TIME (MIN.)
1. Drill and tap a hole in the top of the carburetor fuel bow.	a. Electric drill b. Hand tools	15
2. Drill and tap a hole in the carburetor throttle assembly.	a. Electric drill b. Hand tools	15
3. Screw nipple into hold in carburetor and hole in manifold. Seal airtight.	a. Hand tools b. Nipples (2 ea)	10

Table 4-58. DEVICE 33 INSTALLATION PROCEDURE (CONCL)

MINIMUM AVERAGE SKILL LEVEL: AUTOMOTIVE MECHANIC		
INSTALLATION AND ADJUSTMENT PROCEDURE	TOOLS, EQUIPMENT AND FACILITIES	TIME (MIN.)
4. Attach vacuum hose to both nipples. This hose must have adjustment valve to regulate vacuum.	a. Vacuum hose b. Adjustment valve c. Hose clamps	5
5. Adjust the system initially by running the on a chassis dynamometer. Adjust by opening valve until operation at the desired fuel-air ratio is achieved.	Chassis dynamometer	15
or		
Make adjustment by road test where at a steady state cruise condition the valve is opened until a slight drop is noted in rpm on tachometer. Close valve slightly and lock in position.	Tachometer	15
	Total Time	1 hr

4.4.1.8 Initial and Recurring Cost

Table 4-59 summarizes the costs for this device. From the information available, it is estimated that the installation cost including material would be about $21.15.

4.4.1.9 Feasibility Summary

The emission test data indicate that Device 33 is capable of lowering HC and CO emissions effectively. Additional tests should be conducted to establish the effect of the device on NOx emissions. Although there is a potential safety hazard with the present design, this problem could be corrected by further design effort. If this is done, then the combination of the relatively low cost, simplicity, and emission reduction capability should make the device feasible for retrofit emission control, particularly on older vehicles.

Because many of the post-1968 cars already are designed and tuned to run on lean air-fuel mixture, the device may not be as cost effective on those vehicles. Driveability of these cars might be substantially degraded by further air-fuel ratio increase.

At present, the developer has no plans for marketing the device in the configuration evaluated, but is developing an improved configuration for retrofit use.

A cost benefit of the device may be its fuel economy. Further testing would be required to verify this benefit as well as the indicated emission reduction effectiveness and driveability characteristics over a range of used cars.

Table 4-59. DEVICE 33 INITIAL AND RECURRING COSTS

ITEM	DESCRIPTION	LABOR HOURS OR ITEM QUANTITY	COST (DOLLARS)
Initial Cost:			
Material			
1. Device	Adjustment valve		8.65
2. Miscellaneous	a. Nipples for pipe connections b. Vacuum hose c. Hose clamps		(Included above)
Labor			
1. Installation	Table 4-58	0.5 hr.	6.25
2. Test and adjust	Table 4-58	0.5 hr.	6.25
		Total Initial Cost	21.15
50,000-Mile Recurring Cost:			
Material			
1. Fuel	Average fuel savings of 12 percent (1)	500-gallon fuel reduction x $0.35 per gallon over 50,000 miles (2)	-175.00
		Total Recurring Cost	-175.00
		TOTAL COSTS	-153.85

(1) Based on only two tests. More tests would be necessary to determine the statistical significance of the fuel consumption variations due to the retrofit device.

(2) Based on an assumed national average of 10,000 miles per year at 12.5 mpg.

4.4.2 Device 56: Crankcase Blowby and Idle Air Bleed Modification

This device illustrates the use of a heated air bleed to the intake manifold, in combination with heated recirculation of blowby from the crankcase.

4.4.2.1 Physical Description

As shown in Figure 4-31, Device 56 apparently consists of a specially modified throttle assembly that fits between the carburetor and the intake manifold. There are two heating elements, one to heat the crankcase blowby passed through the PCV valve, and one to heat air which is injected through special air bleed idle jets. The special idle jets, a spacer to accept the blowby gases, and a vacuum switch to activate the heaters are part of the system. The only part provided for evaluation in the form of hardware was an idle jet.

From pictures and a diagram provided by the developer, the spacer appears to be about 1 inch thick and is shaped to match the carburetor-to-manifold interface. The heaters are about 3/4-inch in diameter and 3 inches long. The configuration of the air bleed idle jets is shown in Figure 4-32.

4.4.2.2 Functional Description

The basic principle of operation of this device appears to be to bleed heated air into the idle jets, thereby leaning the idle air-fuel ratio under medium and high vacuum conditions and improving the vaporization of the air-fuel mixture, particularly during cold engine operations. The system heats the injected air and also heats the crankcase blowby passed by the PCV valve into the intake manifold. The system has a vacuum operated switch to activate the battery-operated heaters in the two lines. Since the switch would operate off of intake manifold vacuum, the heaters would apparently be operative during idle and deceleration and other periods of high intake vacuum.

The effect of heating the air prior to injection is unknown. The concept might be to enhance vaporization and mixing of the fuel, the blowby, and the air. Since test results with and without the air heat are not available, no evaluation could be made of this feature.

4.4.2.3 Performance Characteristics

Emissions data were provided by the developer for three cars tested with the device. No baseline data were included, so it was not possible to determine if the device reduced or increased emissions. The developer's data, as summarized in Table 4-60, indicate that the device may have potential for meeting California emission standards for retrofit devices of 350 ppm HC and 2 percent CO. The heated air bleed and crankcase blowby gases appear to have had some controlling effect on the CO generation during cold start.

The developer supplied information from which these data were obtained indicates that the device configuration was being modified from test to test. The details of these modifications were not reported by the developer. The test report for the 6-5-70 test indicated that the carburetor modification resulted in slightly richer mixture and higher emissions.

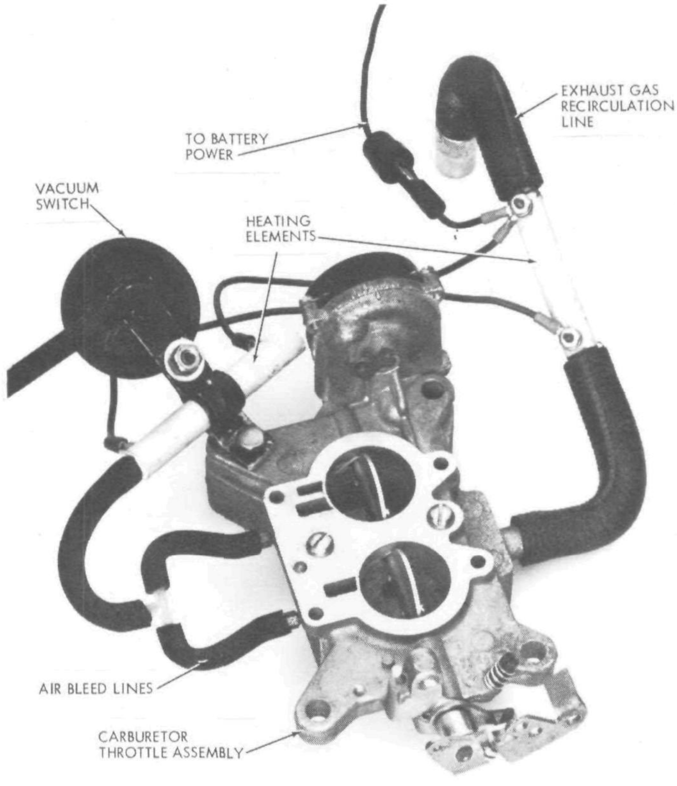


Figure 4-31. DEVICE 56 CRANKCASE BLOWBY AND IDLE AIR BLEED MODIFICATION (DEVELOPER PHOTO)

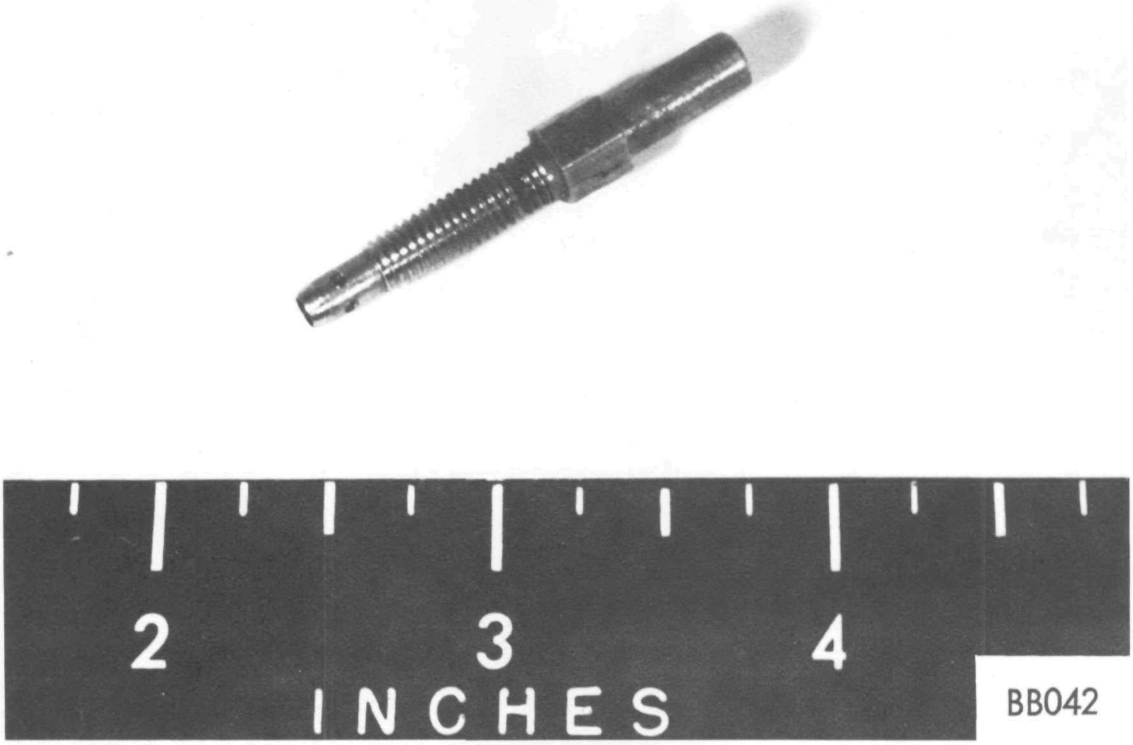


Figure 4-32. DEVICE 56 SPECIAL AIR BLEED IDLE JET

Table 4-60. DEVICE 56 CRANKCASE BLOWBY AND IDLE AIR BLEED MODIFICATION: SUMMARY OF EXHAUST EMISSION DATA REPORTED BY DEVELOPER

TEST DATE	VEHICLE CONFIGURATION	POLLUTANT			TEST TYPE
		HC (PPM)	CO (%)	NOx (PPM)	
3-27-67	1965 Ford Fairlane 289-CID engine and device	274	0.9	(Not measured)	(1)
3-28-67	Same	330	1.9	(Not measured)	(2)
3-30-67	Same	348	0.4	(Not measured)	(1)
6-3-70	Same (with unspecified engine modifications)	420	0.53	1,378	(2)
6-5-70	Same (with unspecified carburetor modification)	437	0.84	1,814	(2)
9-22-71	1967 Ford with 289-CID engine and device	5.20 gm/mi	45.72 gm/mi	3.23 gm/mi	(3)

(1) Two 7-mode hot cycles.

(2) One 7-cycle, 7-mode test.

(3) 1972 Federal Test Procedure (Reference 3).

4.4.2.4 Reliability

Functionally, the device consists of two heating elements and a vacuum switch. Proper design of the heating elements, and selection of the switch for adequate load rating should result in a potential device reliability of over 75,000 MMBTF.

4.4.2.5 Maintainability

Maintenance requirements would be anticipated during the 12,000-MMBM routine vehicle maintenance period. These requirements would include:

1. Inspection of hoses for deterioration
2. Inspection of heating elements for thermal output
3. Inspection of vacuum switch for function
4. Cleaning/replacement of air bleed line filter
5. Cleaning of idle jet air bleed holes.

It is estimated that the indicated maintenance could be performed in less than 20 minutes (0.3 hr MTTM).

Repair times would be dependent upon the specific vehicle installation configuration. However, mean-time-to-repair (MTTR) of the above items should not exceed 0.75 hr.

4.4.2.6 Driveability and Safety

Since this device was not tested in the retrofit study and the developer provided no driveability data, the effects of this device on driveability could not be determined.

The heating elements must be designed to fail in the open circuit mode as opposed to shorted turns (if wire-wound), to preclude excessive temperatures which could cause a fire hazard. Thermal cut-outs could be provided to eliminate the potential overtemperature hazard.

4.4.2.7 Installation Description

The installation of this device appears to consist in replacing the idle mixture screws in the carburetor throttle assembly with special air bleed screws, mounting a vacuum switch and heater assemblies for the air bleed and the blowby lines, connecting the heater electrical leads, installing the assembly between the carburetor and intake manifold, and connecting the air and PCV hoses. Table 4-61 summarizes the installation requirements.

Table 4-61. DEVICE 56 INSTALLATION PROCEDURE

MINIMUM AVERAGE SKILL LEVEL: AUTOMOTIVE MECHANIC		
INSTALLATION AND ADJUSTMENT PROCEDURE	TOOLS, EQUIPMENT AND FACILITIES	TIME (MIN.)
1. Replace idle mixture screws with air bleed screws	a. Hand tools b. Idle mixture screws	10
2. Mount vacuum switch/heater assemblies on convenient location on carburetor along with air bleed and EGR hoses	a. Hand tools (may require drill and tap) b. Vacuum switch	20
3. Attach heater electrical connection to engine-run side of ignition switch	Hand tools	15
4. Install adapter plate between carburetor and intake manifold and connect air bleed and blowby hoses	a. Hand tools b. Adapter plate	30
5. Adjust idle rpm and idle mixture	Tachometer	15
	Total Time	1.5 hr

4.4.2.8 Initial and Recurring Costs

Table 4-62 summarizes the installation costs for this device. From the information available, it is estimated that the initial cost of installing this device, including material, would be about $53.74. Recurring maintenance cost would be about $3.75 every 12,000 miles (MMBM), based on 0.3-hr MTTM and $12.50 per hour labor rate.

4.4.2.9 Feasibility Summary

The feasibility of this device could not be determined, because of the lack of emission data comparing device performance to the same test vehicle without the device installed.

Table 4-62. DEVICE 56 INITIAL AND RECURRING COSTS

ITEM	DESCRIPTION	LABOR HOURS OR ITEM QUANTITY	COST (DOLLARS)
Initial Cost:			
Material			
1. Device	a. Adapter plate b. Vacuum switch c. Idle mixture screws		35.00
2. Miscellaneous	Hose		(Included in above)
Labor			
1. Installation	Table 4-61	1.25 hr	15.62
2. Test and adjust	Table 4-61	0.25 hr	3.12
		Total Initial Cost	53.74
50,000-Mile Recurring Cost:			
Labor			
1. Periodic maintenance	Refer to paragraph 4.4.2.5	0.3 hr every 12,000 miles @ $12.50/hr	15.00
		Total Recurring Cost	15.00
		TOTAL COSTS	68.74

4.4.3 Device 288: Carburetor Main Discharge Nozzle Modification

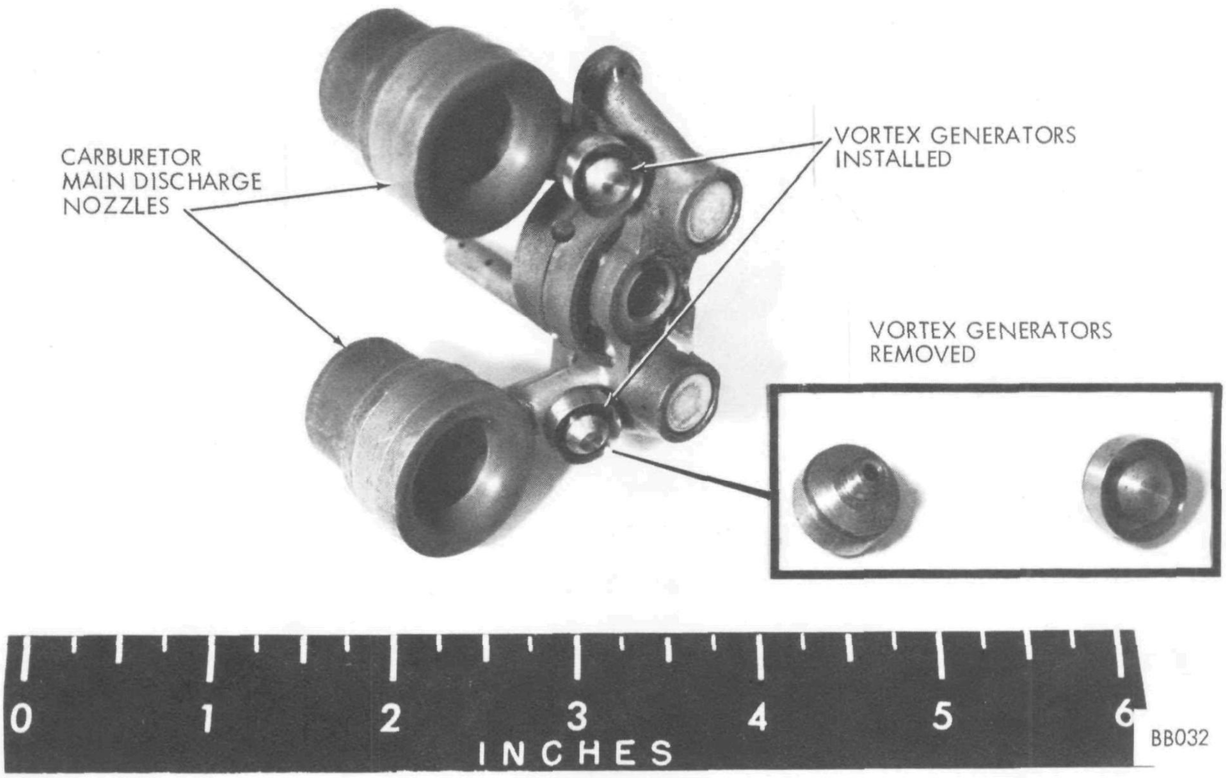
This device provides a modification to the carburetor main discharge nozzle to improve air-fuel mixing. It was tested for emission reduction effectiveness, fuel consumption, and driveability in the retrofit test program.

4.4.3.1 Physical Description

Figure 4-33 shows the components that comprise Device 288. The basic device is known as a vortex generator. It mounts inside the carburetor above the main jet outlet to the venturi. One vortex generator is required for each carburetor venturi. Each is about 1/2-inch in diameter and 1/2-inch long.

4.4.3.2 Functional Characteristics

The Device 288 vortex generator operates on the principle of improving the air-fuel vaporization by initiating the air-fuel mixing within the main fuel nozzle, rather than in the venturi itself. The vortex generator also is intended to promote turbulence within the venturi, further diffusing the air and fuel mixture when it is discharged into the venturi. According to the developer, this should prevent laminar flow in the venturi, provide more complete vaporization of the mixture, and reduce fuel filming and depositing on the walls of the carburetor and manifold.



Device 288 Vortex Generators Installed on 2-Barrel Carburetor Main Discharge Nozzle

Figure 4-33. DEVICE 288 CARBURETOR MAIN DISCHARGE NOZZLE MODIFICATION

4.4.3.3 Performance Characteristics

During the retrofit test program, two cars were tested by the 1972 Federal Test Procedure with Device 288 installed. The results of these tests show a substantial CO reduction and some NOx increase.

Table 4-63. DEVICE 288 CARBURETOR MAIN DISCHARGE NOZZLE MODIFICATION EMISSION REDUCTION AND FUEL CONSUMPTION PERFORMANCE (1)

VEHICLE YEAR/MAKE/CID	ANAHEIM TEST RESULTS			
	POLLUTANT GRAMS/MILE			FUEL MILES/ GALLON
	HC	CO	NOx	
1965 Ford 289				
Without Device	6.59	117.45	3.28	14.5
With Device	6.18	71.78	3.34	14.5
Percent Reduction	6.2	38.9	-1.8	0
1961 Chevrolet 283				
Without Device	4.54	70.78	2.39	16.8
With Device	4.45	46.13	3.24	14.8
Percent Reduction	2.0	34.8	-35.6	11.9
Mean Percent Reduction	4.1	36.9	-18.7	5.95

(1) Emission results obtained by Olson Laboratories in tests performed under Contract 68-04-0038 using 1972 Federal Test Procedure (Reference 3). Fuel consumption was measured during these tests.

Table 4-64 presents a summary of emission reduction data provided by the developer. The emission control configuration of the vehicles used in the Table 4-64 tests is not known.

4.4.3.4 Reliability

The vortex device contains no moving parts and becomes an integral internal part in the carburetor. It is assumed that the mean-miles-before-total-failure of the carburetor would be unchanged as a result of this modification. Reliability of the device should be more than adequate for a 75,000-mile (MMTBF) service life.

4.4.3.5 Maintainability

No additional routine maintenance is apparently required with the device installed.

Table 4-64. DEVICE 288 SUMMARY OF DEVELOPER-REPORTED MEASUREMENTS BY INDEPENDENT LABORATORIES

	CO		HC		NOx		Meaurements Taken By:
	%	gm/mi	ppm	gm/mi	ppm	gm/mi	
CARS MANUFACTURED PRIOR TO FACTORY INSTALLED EMISSION CONTROL SYSTEMS							
1962 FORD GALAXIE 352 cu.in.							
Hot Test: Base	1.64	39	2271	28.9	1476	5.8	Air Resources
Partially Equipped	.98		2048		1804		Air Resources
Totally Equipped	.44	10.5	326	4.30	1288	4.922**	Scott Research
Reduced by:	73%		85%		14%		
Check Out Measurement	.21	5.01	311	3.95	1351	5.27	Olson Laboratories
Reduced by:	87%		86%		10%		
1962 CHEVROLET (Pick-up Truck)							
Miles over 196,000							
Hot Test: Base	2.19		543		1573		Norris
Totally Equipped	0.79		215		1171		
Reduced by:	64%		61%		26%		
1963 CHEVROLET (6 Cylinder)							
Hot Test: Base	4.77		398		415		Norris
Equipped	2.07		255		466		
Reduced by:	56%		36%		11%*		
1964 VOLKSWAGEN							
Hot Test: Base	6.47	78.29	3060	19.73	969	1.82	Olson Laboratories
Equipped	2.09	25.32	645	4.16	696	1.28	Olson Laboratories
Reduced by:	67%		78%		29%		
	CO		HC		NO_x		MEASUREMENTS TAKEN BY:
	%	gr/m	ppm	gr/m	ppm	gr/m	
1965 CHEVROLET (Impala)							
Hot Test: Base	1.39	31.44	470	5.96	1227	4.49	Olson Laboratories
Equipped	0.60	14.28	229	2.90	818	2.90	
Reduced by:	55%		51%		35%		
CARS MANUFACTURED AFTER 1965							
1968 FOLD GALAXIE 302 cu.in.							
Hot Test: Base	.95	22.6	192	2.44	947	3.69	Air Resources ***
Partially Equipped	.27		59	.74	854		Air Resources
Reduced by:	71.5%		69%		9%		
Totally Equipped	.18	4.29	253	3.40	906	3.41	Scott Research **
Check Out Measurement	.17	4.05	355	4.51	542	2.11	Olson Laboratories
Reduced by:	82%		40%*		43%		
Average of 1968 FORD 302 cu.in.	1.49		338		1389		ARB Publication
1969 PLYMOUTH FURY							
Hot Test: Base	0.48	11.43	203	2.57	2428	8.68	Olson Laboratories
Equipped	.29	6.90	156	1.97	2146	7.71	
Reduced by:	40%		24%		8%		
1971 FORD MAVERICK 250 cu.in.							
Hot Test: Base	.85	14.41	98	1	1277	4.00	Olson Laboratories
Equipped	.43	8.29	92	.94	1148	3.36	Olson Laboratories
Reduced by:	50%		6%		17%		
1971 CHRYSLER NEWPORT 383 cu.in.							
Hot Test: Base	.96	25.91	80	1.14	864	3.62	Olson Laboratories
Equipped	.18	4.85	40	.57	940	3.89	Olson Laboratories
Reduced by:	81%		50%		8%*		
	CO		HC		NO_x		MEASUREMENTS TAKEN BY:
	%	gr/m	ppm	gr/m	ppm	gr/m	
CARS MANUFACTURED AFTER 1965							
1971 CHRYSLER NEWPORT 383 cu.in.							
Hot Test: Base (Repeat)	.96	25.91	80	1.14	864	3.62	Olson Laboratories
Specifically Set for NO Control	.22	5.99	34	.48	684	2.70	Olson Laboratories
Reduced by:	77%		57.5%		25%		
Non P_b (Non-Leaded)	.19	5.13	26	.37	767	3.23 ****	
Reduced by:	80%		67%		11%		
Existing Federal Standard		45		2.5		8.0	
1972 California Standard		23		1.5		3.0	
1975 Proposed Standard		11		.5		.9	
Present Used Car California Standard	2.0	50	350	5.0	800	3.0	

*Deterioration
**During the test, fuel consumption was measured and according to Scott report 16% to 21% less consumption was registered.
***Low Octane
****Lead-Free

	CO	HC	NOx
Average reduction:	69%	55%	15%

Note: One 7-cycle, 7-mode test was performed for each test condition.

4.4.3.6 Driveability and Safety

Table 4-65 summarizes the driveability results of retrofit program tests. Baseline driveability data on Car 2 were obtained but the driveability test with the device installed was aborted. The car stalled during this test and would not restart. The exact cause for the failure to start could not be determined at that time.

During the installation of the device by the developer on Car 6, the vacuum advance was plugged and the choke plate was partially cut away to provide clearance for the installed device. This procedure was not carried out on the installation on Car 2 and may have been the reason for different results.

The retrofit study driveability tests indicate that some increase in fuel consumption may be attributable to the device. No safety hazards were indicated.

Table 4-65. DEVICE 288 CARBURETOR MAIN DISCHARGE NOZZLE MODIFICATION DRIVEABILITY TEST RESULTS

DRIVEABILITY CHARACTERISTICS	1965 CHEV. 194 CID	1965 FORD 289 CID	1965 PLY. 318 CID	1965 CHEV. 327 CID	1965 FORD 390 CID	1961 CHEV. 283 CID
	ANAHEIM, CALIF., DRIVEABILITY TEST RESULTS					
	CAR NO. 1	CAR NO. 2	CAR NO. 3	CAR NO. 4	CAR NO. 5	CAR NO. 6
CRITICAL DRIVEABILITY	(1)	This test was aborted. The car stalled during the test with the device installed and would not restart	(1)	(1)	(1)	Decreased stall during start deceleration
GENERAL DRIVEABILITY						Decreased start time during cold start; decreased stumble during cold start acceleration
0 - 60 MPH ACCELERATION TIME (SECONDS)						Decreased from 18.0 to 14.9
60 - 40 MPH DECELERATION TIME (SECONDS)						Increased from 26.0 to 30.0
GAS MILEAGE PER GALLON	Average decrease of 5.95 percent (reference Table 4-63)					

(1) Device No. 288 was not tested on these vehicles.

4.4.3.7 Installation Description

The installation of this device consists in removing and disassembling the carburetor, replacing the main nozzle assembly with a modified nozzle with vortex generator installed, reassembling the carburetor, and replacing it on the engine. Tuneup consists in adjusting the carburetor idle to provide smooth operation. The developer estimated one-half hour labor for installation, and estimated cost of the device at $18 to $25. From the actual installation of this device, it appears that 1.25 hours for installation is a more realistic figure.

Table 4-66 describes the installation requirements. Installation can be accomplished in a normally equipped repair shop with average mechanic skills.

Table 4-66. DEVICE 288 CARBURETOR MAIN DISCHARGE NOZZLE MODIFICATION INSTALLATION PROCEDURE

MINIMUM AVERAGE SKILL LEVEL: AUTOMOTIVE MECHANIC		
INSTALLATION AND ADJUSTMENT PROCEDURE	TOOLS, EQUIPMENT AND FACILITIES	TIME (MIN.)
1. Remove and disassembly carburetor	Hand tools	10
2. Remove main jet nozzle assembly; drill and tap threads	Hand tools	30
3. Insert device into main nozzle assembly	Hand tools, device	5
4. Reinstall nozzle assembly into carburetor	Hand tools	10
5. Reinstall carburetor onto intake manifold	Hand tools	5
6. Adjust carburetor idle	Exhaust analyzer	15
	Total Time	1.25 hr

4.4.3.8 Initial and Recurring Costs

Table 4-67 summarizes the costs for installation and operation of this device. From the information available, it is estimated that the total cost of this installation, including material, would be from $33.62 to $40.62. As noted, no recurring maintenance costs are indicated.

4.4.3.9 Feasibility Summary

Tests conducted by Olson Laboratories during the performance of this contract showed that the device reduced CO emissions by 30 to 40 percent, but had no desirable effect on HC and NOx emissions. Considerable modification was required to the carburetor to install the device, and if the device was to be removed, new parts for the carburetor would be required. Because of the cost and labor involved in modifying the carburetor, and the relatively small changes in emission results, this device does not appear practical as a retrofit device for older cars.

Table 4-67. DEVICE 288 CARBURETOR MAIN DISCHARGE NOZZLE MODIFICATION INITIAL AND RECURRING COSTS

ITEM	DESCRIPTION	LABOR HOURS OR ITEM QUANTITY	COST (DOLLARS)
Initial Cost:			
Material			
1. Device	Venturi assembly		18.00-25.00
Labor			
1. Installation	Table 4-64	1.00 hr	12.50
2. Test and Adjust	Table 4-64	0.25 hr	3.12
		Total Initial Cost	33.62-40.62
50,000-Mile Recurring Cost:			
Material			
1. Fuel	Average increase in fuel consumption of 5.95 percent (refer to Table 4-66) (1)	238-gallon fuel increase x $0.35 per gallon over 50,000 miles (2)	83.30
2. Labor	None (no maintenance assumed - refer to paragraph 4.4.3.5)		
		Total Recurring Cost	83.30
		TOTAL COSTS	123.92

(1) Based on only two tests. More tests would be necessary to determine the statistical significance of the fuel consumption variations due to the retrofit device.

(2) Based on an assumed national average of 10,000 miles per year at 12.5 mpg.

4.4.4 Device 295: Variable Venturi Carburetor

This device was the single retrofit device incorporating a completely redesigned carburetor. Device 295 has been tested by the developer with and without exhaust gas recirculation. During the retrofit study, the device was tested using the carburetor alone as the control method.

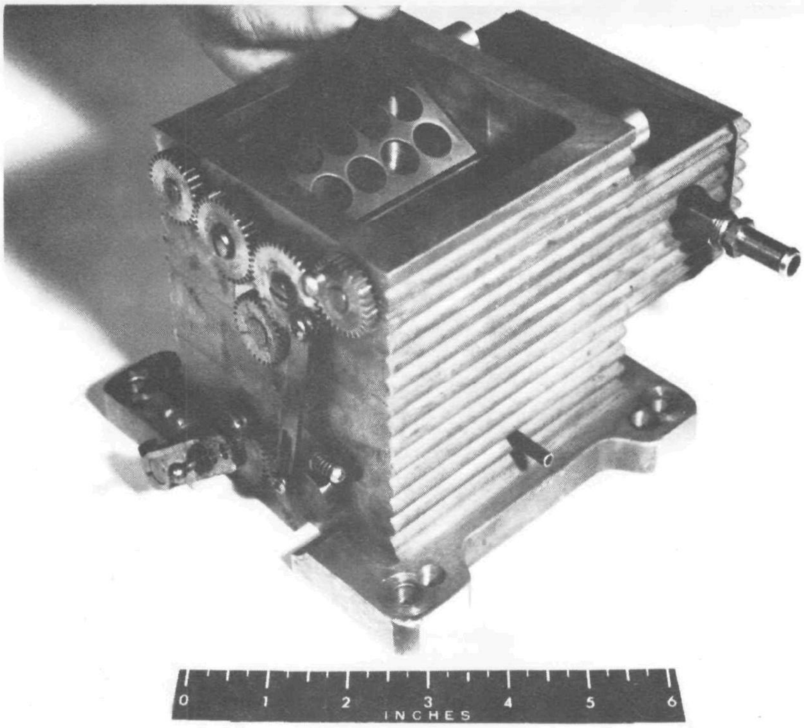
4.4.4.1 Physical Description

Device 295 is called a variable venturi carburetor. As shown in Figure 4-34, this device is intended to replace the conventional carburetor in its entirety. The unit provided by the developer for evaluation in the retrofit study program replaces the standard four-barrel carburetor and is similar in size and weight to that carburetor.

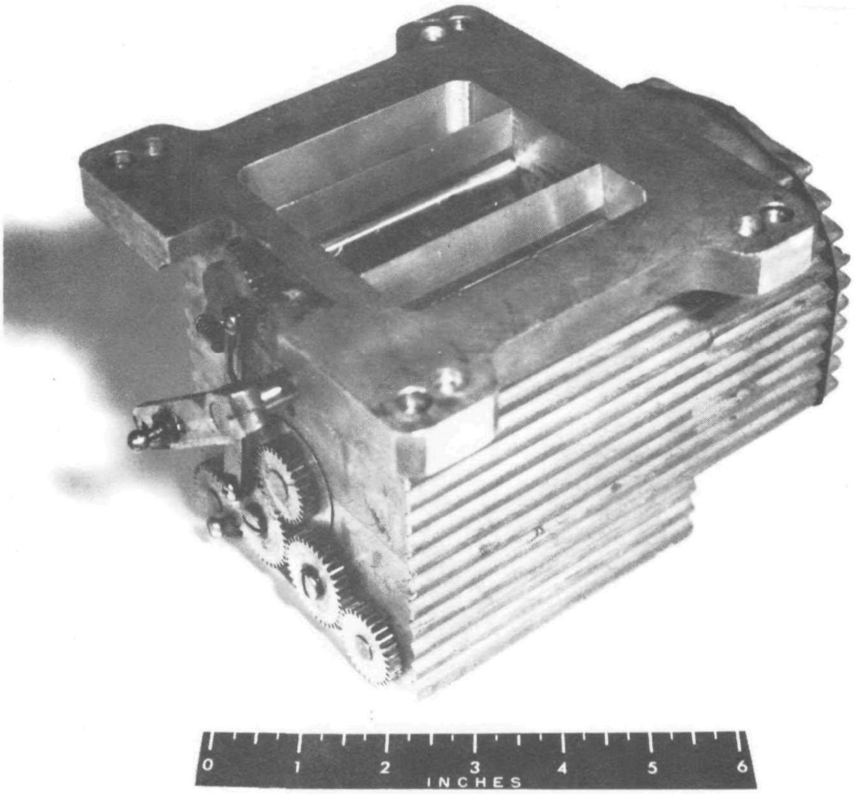
4.4.4.2 Functional Description

The following design and functional description of the variable venturi carburetor has been extracted from information supplied by the developer:

> "Design Description - When compared to contemporary carburetors, the variable venturi carburetor appears to be very simple, because it contains relatively few parts (approximately 65 for the VVC and about 255 for a competitive four-barrel model). This low-parts count is due, for the most part, to the method by which fuel is metered. Metering is directly governed by the magnitude of air mass flow at the moment and the associated calibration of the variable orifice mechanism. The orifice size is determined mechanically by the relative deflection of spring loaded venturi plates, which are immersed in the carburetor inlet air flow.
>
> "The angular deflection of these plates is proportional to the aerodynamic force acting upon them and, since the force is directly related to properties of the flowing air mass, the force will change in proportion to changes in ambient air density. It may be shown that, with proper geometric design of the carburetor intake and venturi plates, the carburetor performance will remain relatively unaffected by normally experienced extremes in driving altitude (or by humidity and temperature).
>
> "Very good vaporization of the fuel and mixing with the air is achieved by the use of a fuel distributing nozzle bar which extends across the throat of the carburetor. Appropriate aerodynamic shaping and the proper location of fuel orifices ensure a good dispersion of fuel into the airstream. This arrangement of fuel introduction and the geometry of the throat cross-section and throttle valves ensure a favorable distribution of the air-fuel mixture at the entry to the intake manifold.
>
> "Carburetor Functional Description - Figure (4-35) presents a coded schematic drawing of the variable venturi carburetor. In operation, fuel is supplied under pump pressure through



(a) Top View



(b) Bottom View

Figure 4-34. DEVICE 295 VARIABLE VENTURI CARBURETOR

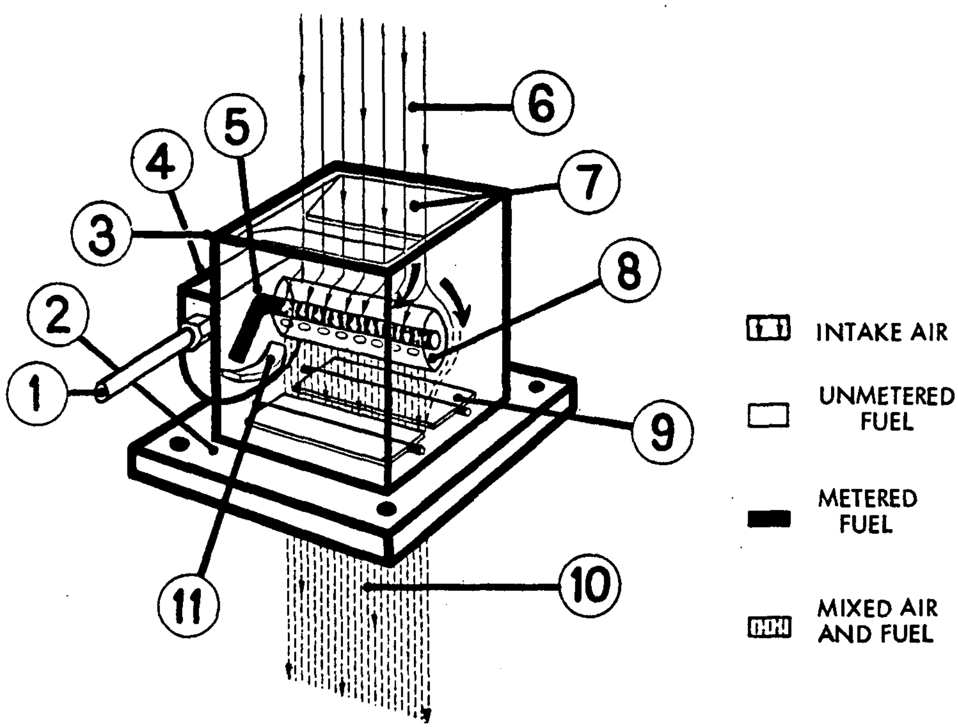


Figure 4-35. DEVICE 295 VARIABLE VENTURI CARBURETOR FUNCTIONAL DIAGRAM (DEVELOPER SKETCH)

a fuel line (1) into the float chamber (4). The fuel level is maintained by the now quite standard float actuated needle valve mechanism. The spring loaded venturi plates (7) take a position from closed, at engine off, to an open position proportional to the unbalanced pressures between aerodynamic force produced by the incoming air (6) and the engine manifold pressure in the nozzle bar chamber. The amount of air induced into the venturi is determined by the manually controlled position of the throttle plates (9). Fuel, in correct proportion to the air flow mass, is metered through the variable orifice existing between the end of the fuel pickup arm (5) and the calibrated fuel ramp (11). The position of the fuel pickup arm, relative to the ramp, is determined by mechanical connection through gearing to the positioning of the variable venturi plates. Fuel is induced into the fuel pickup arm (5) and into the fuel distributor nozzle bar (8) by the differential in pressure between air in the float chamber and that at the fuel orifices in the nozzle bar. The air-fuel mixture (10) then passes by the throttle plates and into the intake manifold.

"For acceleration, rapid opening of the throttle plates, in the presence of a lag in opening of the venturi plates, produces a pressure in the nozzle bar chamber which is lower than that which will be reached in the steady-state condition. This tends to accelerate fuel flow to compensate for the normal liquid inertia under such conditions. In addition, the inertia of the venturi plates carry them (upon opening) somewhat further open than that required by the steady-state condition, thereby allowing a larger fuel metering orifice. Together, these mechanisms, accommodated by design for proper spring constants and damping, eliminate the need for an acceleration pump. During deceleration, the characteristic of this carburetor is somewhat better than that of conventional equipment because the fuel flow can come from only one orifice which is in its minimum size (idle) configuration.

"A choking action for cold starts is inherent in the design, but can be adjusted for special cases by inclusion of one over-ride bimetallic spring at the venturi plates."

4.4.4.3 Performance Characteristics

Testing performed on the variable venturi carburetor by the developer with and without exhaust gas recirculation, is described in the following excerpts from information supplied by the developer, followed by retrofit program test results with the carburetor alone:

"Early Prototype Carburetor Test Results - Development testing has been accomplished on various engine and chassis dynamometers and on private as well as competitive automobiles. In large part, the detail elements of the carburetor were proven and/or improved by this process. In the performance category of testing, both horsepower results and economy have been shown to be at least as good as those from late model vehicles. In every case, where comparisons were made, it was ascertained that the complete engine and components package were well maintained and adjusted to manufacturers' specifications. Examples in the performance category are as follows:

"Results of Preliminary Exhaust Emission Tests - In January 1971 and later in March, preliminary testing was conducted at the Scott Research Laboratories facilities in Wilmington, California. The early tests were run to evaluate the variable venturi carburetor relative to the new motor vehicle emission standards. The criterion was established that the carburetor would be adjusted for satisfactory driveability on a lean fuel-air mixture setting. A second set of tests were conducted in March to evaluate the VVC for application to modify used cars of model years 1955-1965. In these tests, the carburetors were set to richer mixtures, and an exhaust recycle was introduced (but not in optimum configuration) for some of the runs.

"The test vehicle was a 1966 Ford Mustang, specially equipped with the Atlantic Richfield Corporation (ARCO) exhaust gas recycle system. The system was "locked out" for the January test and for one of the tests run in March. When it was connected for March testing, no attempt was made to properly synchronize the recycle valve and the throttle. Therefore, the results, although quite satisfactory, are not as good as they can be.

"The standard federal seven-mode driving cycle was followed (from hot start because these were development tests); approximate corrections have been made to the data to convert to the expected values for "cold" start. A Scott Auto Exhaust Analysis System (Model 103-11) was used in conjunction with a Scott driver aid (Model 201-A). Bag samples were also taken for all runs to provide average full-cycle data for HC, CO and NOx.

"The vehicle was operated on a Clayton chassis dynamometer. The January tests, showing the "Standard" vehicle data and the data for the vehicle with the VVC and no exhaust recycle, are presented below:

	HC GM/MI	CO GM/MI	NOx GM/MI
Vehicle in Standard Condition (with Exhaust Recycle)	1.84	9.3	0.87* Approximately
Vehicle with VVC Carburetor (no Exhaust Recycle)	1.28	8.5	2.07

* This value would be about 8 times higher without exhaust recycle.

"Because these results on the VVC were achieved with an air-fuel ratio of 15:1 or more experience indicates that a richer mixture, while increasing HC and CO, will be accompanied by a good reduction of NOx. The emission values are then expected to be close to the required values of the standards for 1974 new vehicles. If exhaust recycle is incorporated, the value may be close to the 1975 required standards.

"The March test data, as previously stated, reflects an attempt to measure the performance of the VVC relative to the requirements for modification to the used car population of model years 1955-1965. These data in preliminary form are presented below.

	HC GM/MI	CO GM/MI	NOx GM/MI
Used Car Standard	3.6	39	2.5
VVC (No Recycle) Rich	1.8	42	2.47
VVC (Recycle) Lean	2.86	32	1.22

"With optimized exhaust recycle, both the rich and the lean condition carburetors would show some improvement."

During the retrofit study, Device 295 was tested on a 1965 Ford using the 1972 Federal Test Procedure. Table 4-68 summarizes the results of this test. These results indicate that the device, when used alone may provide a relatively small reduction of CO and NOx, but not a substantial amount. The device indicates a 10 percent loss in fuel economy over the vehicle with a standard carburetor.

Table 4-68. DEVICE 295 VARIABLE VENTURI CARBURETOR EMISSION REDUCTION AND FUEL CONSUMPTION PERFORMANCE (1)

VEHICLE YEAR/MAKE/CID	ANAHEIM TEST RESULTS			
	POLLUTANT GRAMS/MILE			FUEL MILES/ GALLON
	HC	CO	NOx	
1965 Ford 390				
Without Device	8.35	109.86	2.32	11.0
With Device	11.43	87.94	1.73	9.9
Percent Reduction	-36.9	20.0	25.4	10.0

(1) Emission results obtained by Olson Laboratories in one set of tests performed under Contract 68-04-0038 using 1972 Federal Test Procedure (Reference 3). Fuel consummation was measured during these tests.

4.4.4.4 Reliability

The developer stated that engineering judgment indicates that the variable venturi carburetor (VVC) should have much higher reliability than other existing carburetors. Because the VVC contains only about 25 percent of the parts of a conventional four-barreled carburetor, the developer's statement is reasonable for a fully production engineered VVC. The VVC reliability is estimated to be in excess of 75,000 mean-miles-before-total-failure.

4.4.4.5 Maintainability

The developer stated that no maintenance is required except for a simple spring adjustment done twice during lifetime of a vehicle. It is assumed that this spring is the one that controls the intake venturi plates.

Examination of the prototype VVC indicates that it would require cleaning similar to a conventional carburetor. No detail part maintenance would be anticipated prior to 50,000 miles: however, carburetor cleaning should be performed every 12,000 miles. Therefore, this device is estimated to have an overall MMBM of 12,000 miles. MTTM is estimated to be approximately 0.5 hour. These estimates would require review of the production VVC for verification.

4.4.4.6 Driveability and Safety

Table 4-69 summarizes the driveability results of tests performed during the retrofit study. The device was tested on one car at the Olson Anaheim facility, both with and without the device installed. It appeared that the starting difficulty could be attributed to the manual choke and the fact that there is no starting fuel groove cut in the acceleration ramp. During the performance of this test, the

Table 4-69. DEVICE 295 VARIABLE VENTURI CARBURETOR DRIVEABILITY TEST RESULTS

DRIVEABILITY CHARACTERISTICS	1965 CHEV. 194 CID	1965 FORD 289 CID	1965 PLY. 318 CID	1965 CHEV. 327 CID	1965 FORD 390 CID	1961 CHEV. 283 CID
	ANAHEIM, CALIF., DRIVEABILITY TEST RESULTS (1)					
	CAR NO. 1	CAR NO. 2	CAR NO. 3	CAR NO. 4	CAR NO. 5	CAR NO. 6
CRITICAL DRIVEABILITY	(1)	(1)	(1)	(1)	Increased stall during cold start deceleration	(1)
GENERAL DRIVEABILITY					Increased starting time and number of attempts to start during cold start; increased stall during cold start idle; increased stretchiness and stumble during cold start acceleration; decreased cranking time during hot start; increased hesitation during hot start acceleration	
0 - 60 MPH ACCELERATION TIME (SECONDS)					Increased from 9.2 to 10.3	
60 - 40 MPH DECELERATION TIME (SECONDS)					Increased from 23 to 27	
GAS MILEAGE PER GALLON	Average decrease of 10.0 percent (reference Table 4-68)					

(1) Device No. 295 was not tested on these vehicles.

ignition timing was inadvertently set wrong. Ignition timing should have been set at factory specifications and it was believed that this was the case before the test. It was discovered later that, in fact, the timing was retarded from what factory specifications called for. A retest was offered at a later date, but the developer did not bring all components of the device. No more test time was available for a second rescheduling.

No inherent safety hazard was identified. However, a critical review should be performed on each specific Device 295 installation and interface configuration to assure that the device cannot jam at full throttle.

4.4.4.7 Installation Description

Table 4-70 itemizes installation requirements for this device. The installation consists in removing the presently installed carburetor and replacing it with the variable venturi carburetor. Adjustment of the device is performed by adjusting the throttle linkage as required for it to operate properly. Adjustment of the engine consists in setting the idle mixture and idle rpm. The developer estimated one-half hour labor for installation and a retail cost of $65 to $70 for the device.

Table 4-70. DEVICE 295 VARIABLE VENTURI CARBURETOR INSTALLATION PROCEDURE

MINIMUM AVERAGE SKILL LEVEL: Automotive Mechanic		
INSTALLATION AND ADJUSTMENT PROCEDURE	TOOLS, EQUIPMENT AND FACILITIES	TIME (MIN.)
1. Remove carburetor.	Hand tools	6
2. Install adapter plate for specific engine .	a. Hand tools b. Adapter plate	2
3. Install new variable venturi carburetor.	a. Hand tools b. Variable venturi c. Carburetor	6
4. Install throttle linkage adapters as required.	Hand tools	3
5. Adjust throttle linkage and automatic transmission dashpot as required .	Hand tools	13
6. Adjust idle rpm and mixture.	Engine analyzer	15
	Total Time	0.75 hr.

Table 4-70 defines the installation requirements. Installation can be accomplished in a normally equipped repair shop with average mechanic skills.

4.4.4.8 Initial and Recurring Costs

Table 4-71 itemizes the overall costs required to purchase, install, and operate the device. It is estimated that the total cost of the installation, including material, would be from $74.37 to $79.37. Recurring cost might be incurred because of the indicated increase in fuel consumption (Table 4-68).

4.4.4.9 Feasibility Summary

In the single test conducted during the retrofit study program, Device 295 reduced CO by 19 percent and NOx by 25 percent, but increased HC by 36.9 percent. Driveability of the car with the device installed was poor, and gasoline mileage decreased significantly. Because of the resulting low cost effectiveness of the device, it appears that it would not be a reasonable retrofit device to control exhaust emissions on used cars. Additional testing would be required on a variety of used cars to verify these results conclusively.

Table 4-71. DEVICE 295 VARIABLE VENTURI CARBURETOR INITIAL AND RECURRING COSTS

ITEM	DESCRIPTION	LABOR HOURS OR ITEM QUANTITY	COST (DOLLARS)
Initial Cost:			
Material			
1. Device	a. Adapter plate b. Variable venturi c. Carburetor		65.00-70.00
2. Miscellaneous	Gaskets		(Included in above)
Labor			
1. Installation	Table 4-70	0.5 hr	6.25
2. Test and adjust	Table 4-70	0.25 hr	3.12
Total Initial Cost			74.37-79.37
50,000-Mile Recurring Cost:			
Material			
1. Fuel	Average fuel increase of 10 percent (refer to Table 4-68) (1)	400-gallon fuel increase x $0.35 per gallon over 50,000 miles (2)	140.00
Labor			
1. Cleaning	Paragraph 4.4.4.5	0.25 hr every 12,000 miles @ $12.50 per hr	12.50
Total Recurring Cost			152.50
Total Costs			231.87

(1) Based on one test only. More tests would be necessary to determine the statistical significance of the fuel consumption variations due to the retrofit device.

(2) Based on an assumed national average of 10,000 miles per year at 12.5 mpg.

4.4.5 Device 317: Carburetor Modification with Vacuum Advance Disconnect

This device apparently is based on the concept of augmenting the carburetor with a parallel air-fuel mixture circuit between the carburetor bowl and the intake manifold. The device appears to be basically an air bleed to the intake manifold that, under high vacuum, also draws fuel into the air bleed. At engine rpm above idle, the vacuum advance is also disconnected.

4.4.5.1 Physical Description

As shown in Figure 4-36, Device 317 consists of two basic components. One is a unit containing an expansion chamber, air bleed jet, and a gulp valve. It is about 1 inch in diameter and 3 inches long, and mounts on the carburetor. It is connected to the carburetor fuel bowl and to the intake manifold or carburetor base through a tube or hose.

The second component is a distributor vacuum advance disconnect valve about 3/4 inch in diameter and 3 inches long that connects to the throttle operating mechanism of the carburetor.

4.4.5.2 Functional Description

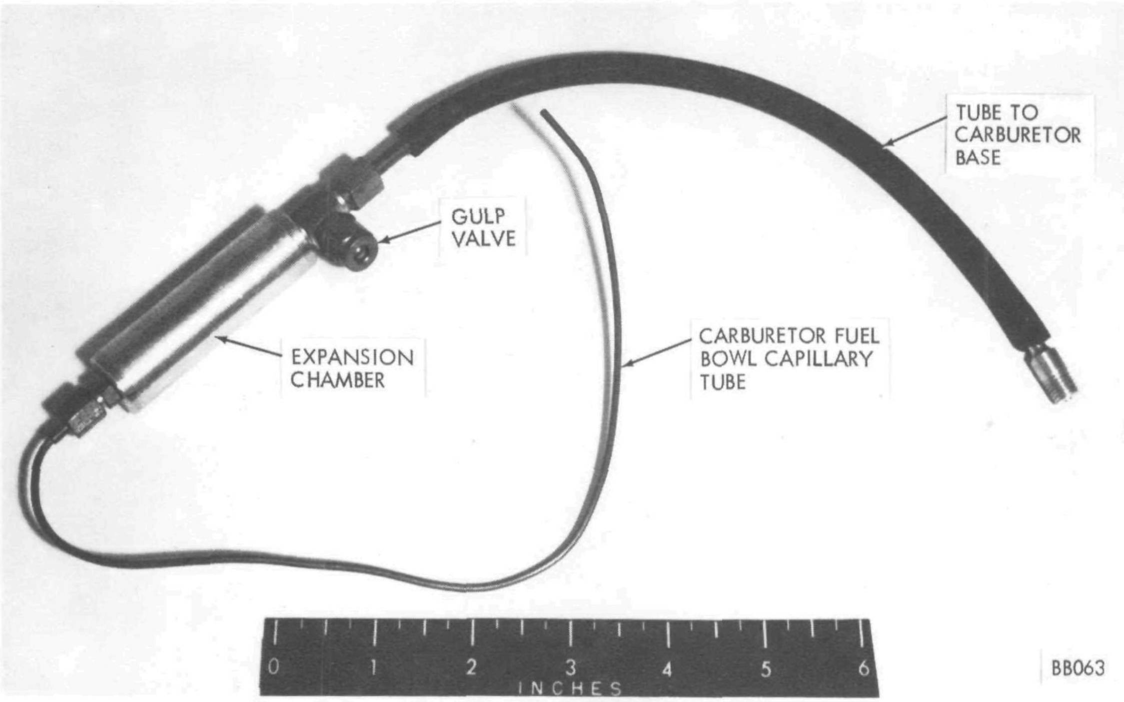
Device 317 operates on the principle of bleeding air and gasoline into the intake manifold according to manifold vacuum. Figure 4-37 shows a breakdown of parts in the device. The line to the fuel bowl is mounted in the carburetor with the end below the level of the fuel in the bowl. The other end of this line goes to the intake manifold or carburetor base to sense engine vacuum.

When vacuum is present, a small amount of gasoline flows from the fuel bowl through the line and mixes in the expansion chamber with air entering through the gulp valve. The flow is limited by the size of the jet and gasoline orifice. More air will be inducted through the gulp valve depending on increases in intake manifold vacuum. To make the engine run properly with the device installed, the idle air-fuel ratio of the carburetor must be reset to 15:1.

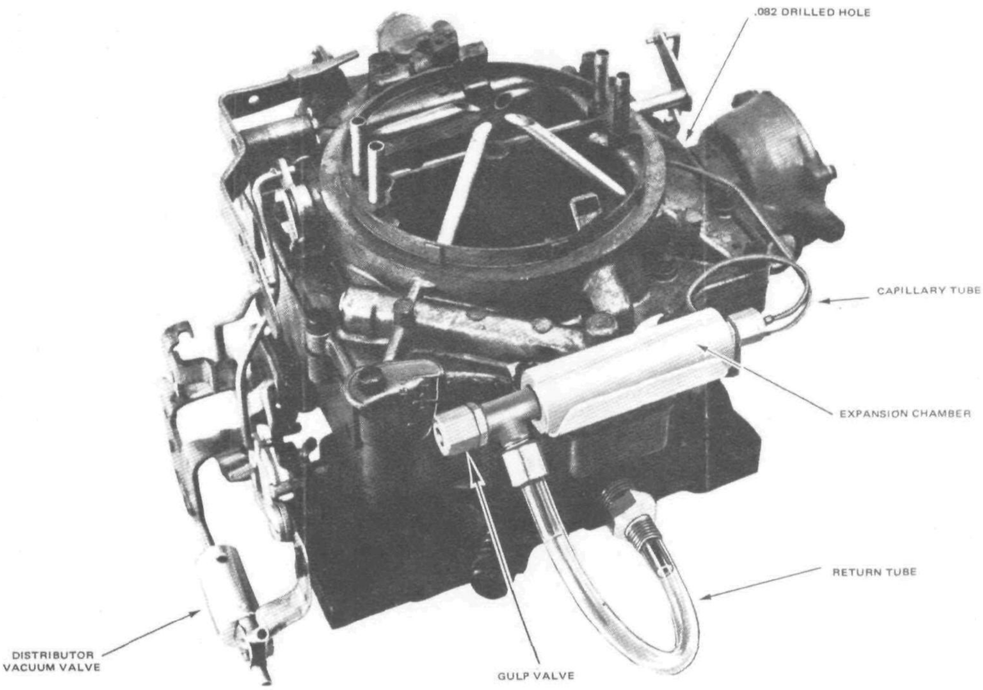
The distributor vacuum advance disconnect valve attaches to the throttle opening mechanism. No discussion of it was provided by the developer as to its theory of operation or installation instructions; however, it apparently disconnects the vacuum advance whenever the accelerator is actuated.

4.4.5.3 Performance Characteristics

Test data on exhaust emission submitted by the developer are summarized in Table 4-72. The data shows that the device has some capability to reduce NOx emission. HC and CO are reduced to a lesser extent.



(a) Device 317 Basic Air-Fuel Bleed Components



(b) Device 317 Component Installation

Figure 4-36. DEVICE 317 CARBURETOR MODIFICATION WITH VACUUM ADVANCE DISCONNECT INSTALLATION (DEVELOPER PHOTO)

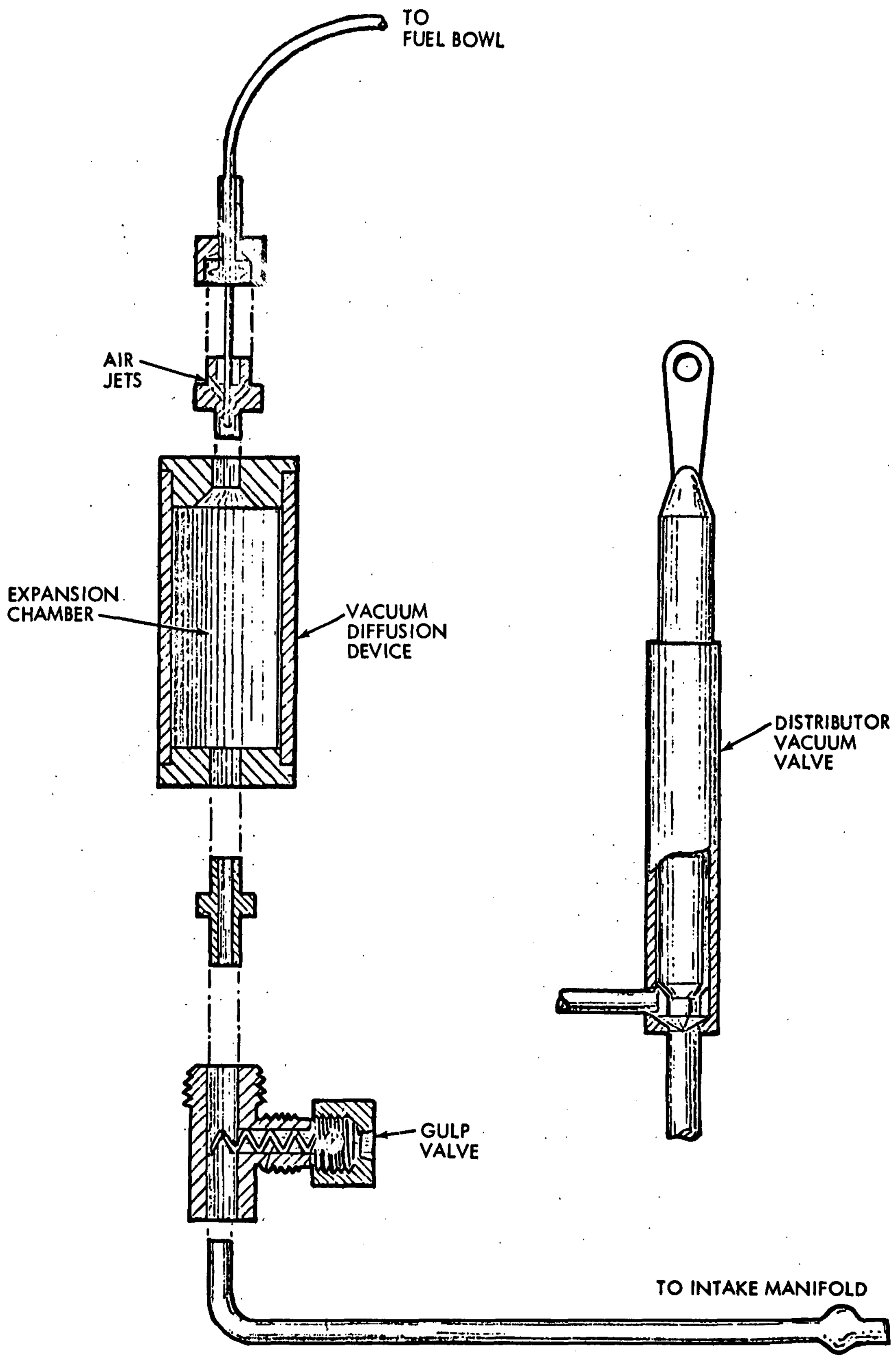


Figure 4-37. DEVICE 317 CARBURETOR MODIFICATION WITH VACUUM ADVANCE DISCONNECT: PRINCIPAL COMPONENTS (DEVELOPER SKETCH)

Table 4-72. DEVICE 317 EMISSION TEST RESULTS REPORTED BY DEVELOPER

TEST CONDITION	HC (PPM)	CO (%)	NO (PPM)	NUMBER OF TESTS
1963 Cadillac (1970 Federal Test Procedure - Reference 15)				
Without Device	332	2.55	1259	1
With Device	321	2.31	608	1
Percent Reduction	3.3	9	52	
1967 Cadillac (1970 Federal Test Procedure)				
Without Device	410	1.38	1245	1
With Device	272	2.13	590	1
Without Device	503	4.46	665	1
With Device	264	2.27	474	1
Without Device	509	2.71	600	1
With Device	334	1.91	790	1
Percent Reduction	32	22	35	3 sets
1967 Cadillac - California Air Resources Board Project 189 (7-Mode Hot Start)				
With Device	306	1.8	470	1
With Device	284	1.5	862	1

4.4.5.4 Reliability

The developer has driven over 30,000 miles with the device installed without any adjustment requirements or any noticeable change in vehicle performance. Considering that the device consists, essentially, of a vacuum line and a simple spring-ball valve, it is estimated that its reliability should exceed 75,000 MMBTF.

Analysis indicates the possibility of a critical secondary failure mode (primary failure mode not related to the device), which is discussed in paragraph 4.4.5.6.

4.4.5.5 Maintainability

Routine maintenance would include air-fuel ratio adjustment and inspection for any plugged fuel source, as indicated by a rough running engine at idle. A further maintenance requirement would be to inspect and clean the gulp valve when necessary. It is assumed that the valve would require cleaning no more frequently than air filters require cleaning (12,000-mile intervals under average driving conditions) and that cleaning could be accomplished within 10 minutes. Overall MMBM should be 12,000 miles, with 0.2-hour MTTM.

4.4.5.6 Driveability and Safety

Driveability data supplied by the developer indicates no adverse problems for this device provided that engine timing and air-fuel ratio are set correctly.

In the event the carburetor float bowl shutoff valve failed in the open position and no fluid check valve is incorporated in the vacuum line, raw gasoline could be pumped into the intake manifold and constitute a serious fire hazard. The condition could be induced, also, by improper installation of the device causing the carburetor float to jam either continuously or periodically.

4.4.5.7 Installation Description

The installation of this device consists in drilling a hole in the carburetor fuel bowl cover so that a capillary tube can be inserted, replacing the primary metering jets in the carburetor, mounting the expansion chamber on the bracket installed to the rear of the carburetor, connecting hose to the carburetor base, and tightening all connections. Adjustment of the engine consists in setting the timing, idle rpm, air-fuel ratio (15:1), and the choke (one notch rich from factory specifications). The developer states that prior to device installation, the engine must be properly tuned and all adjustments set to factory specifications. Piston rings and valves must be in good shape by checking the compression before installation or the device will not perform to its best advantage.

In addition, the developer estimated that installation of the device would take approximately one-half hour. Table 4-73, presenting a more detailed description of the installation procedure, indicates that 0.75 hour might be required. This table also identifies tools and special equipment required. Installation can be accomplished in a normally equipped repair shop by the average mechanic.

4.4.5.8 Initial and Recurring Costs

The developer estimated that the retail cost of the device installed will be $19.95. Table 4-74 summarizes the installation costs. From the information available, it is estimated that the cost for installing this device, including material would be $23.32.

4.4.5.9 Feasibility Summary

There appear to be some inherent safety hazards with the device, but they could be avoided by refinements in design as noted in the safety analysis.

The average emission reductions reported by the developer for Device 317 were 32 percent for HC, 22 percent for CO, and 35 percent for NOx on the 1967 Cadillac tests. The 1963 Cadillac tests showed a reduction of 52 percent in NOx, 3 percent in HC, and 9 percent in CO. Based on these data from the developer, Device 317 may have some technical feasibility for control of HC and NOx, provided that the correct combination of the device installation, the change in the main circuit carburetor jets, the adjustment of the gulp valve, and the timing of the engine can be established and maintained.

Table 4-73. DEVICE 317 CARBURETOR MODIFICATION WITH VACUUM ADVANCE DISCONNECT INSTALLATION PROCEDURE

MINIMUM AVERAGE SKILL LEVEL: AUTOMOTIVE MECHANIC		
INSTALLATION AND ADJUSTMENT PROCEDURE	TOOLS, EQUIPMENT, AND FACILITIES	TIME (MIN.)
1. Remove carburetor cover. Drill 0.082 inch hole in cover so as to clear float assembly.	a. Hand tools b. Electric drill	10
2. Install primary metering jet or jets included in kit.	a. Hand tools b. Metering jets	6
3. Reinstall carburetor cover with new gasket.	a. Hand tools b. Gasket	1
4. Insert capillary tube in the 0.082 inch hole drilled in the cover, pushing it all the way to the bottom, pull it back up 1/4 inch. Bend tube over top of carburetor so as to clear choke assembly.	Capillary tube	1
5. Install evaporation chamber to rear of carburetor with bracket from kit.	a. Hand tools b. Evaporation chamber	3
6. Install capillary tube assembly to evaporation chamber and tighten securely.	Hand tools	2
7. Remove PCV hose from carburetor base and insert the vacuum T with short hose and clamps from it.	a. Hand tools b. Vacuum T-fitting c. Hose d. Clamps	3
8. Install PCV hose and clamp on vacuum T.	Hand tools	2
9. Install short piece of 3/16-inch hose from kit from small outlet of vacuum T to small pipe on decel valve of the evaporation chamber.	Hose	2
10. Start motor and adjust timing and idle rpm.	Engine analyzer	3
11. Set carburetor air-fuel ratio at 15:1.	Engine analyzer	9
12. Set choke one notch rich from factory specifications.	Hand tools	3
	Total Time	0.75 hr

Table 4-74. DEVICE 317 CARBURETOR MODIFICATION WITH VACUUM ADVANCE DISCONNECT INSTALLATION COSTS

ITEM	DESCRIPTION	LABOR HOURS OR ITEM QUANTITY	COST (DOLLARS)
Initial Cost:			
Material			
1. Device	a. Metering jets		13.95
	b. Expansion chamber		
	c. Vacuum T-fitting		
2. Miscellaneous	a. Gasket		(Included above)
	b. Capillary tube		
	c. Hose		
	d. Clamps		
Labor			
1. Installation	} Table 4-73	0.50 hr	6.25
2. Test and adjust		0.25 hr	3.12
		Total Initial Cost	$23.32
50,000-Mile Recurring Cost:			
Labor			
1. Device components	Clean and adjust every 12,000 miles (refer to paragraph 4.4.5.6)	0.2 hr every 12,000 miles @ $12.50 per hour	10.00
		Total Recurring Cost	$10.00
		TOTAL COSTS	$33.32

4.5 TURBOCHARGED ENGINE - RETROFIT SUBTYPE 1.2.5

Only one approach of this type was found during the retrofit study. Turbocharging should improve vehicle performance by increasing the volumetric efficiency of the engine.

4.5.1 Device 100: Turbocharger

Although the retrofit developer did not respond to the retrofit data survey, information on this approach to vehicle exhaust emission control was obtained from an EPA test report (Reference 99).

The vehicle tested was a 1971 Volkswagen equipped with a turbocharger retrofit package that consisted of a new exhaust system, a revised heater system, and minor changes to the fuel, oil, and vacuum lines. The turbocharger operated off exhaust gas taken from the exhaust pipe in front of the muffler. Intake air to the turbocharger was ducted from the standard air filter and from the turbocharger to the carburetor venturi inlet. An electric fuel pump provided the fuel pressure required during high boost operation.

The vehicle was a standard production model VW with a four-speed manual transmission and 96-CID, air-cooled, opposed-four-cylinder engine.

Table 4-75 summarizes the emission test results obtained with the 1972 Federal Test Procedure. The EPA report noted that the stock vehicle emissions of the test car were equivalent to other VW's tested. The report also noted that it was not known whether the slight reduction shown for the turbocharged vehicle is due to the device or to lean carburetion.

Table 4-75. DEVICE 100 TURBOCHARGER EMISSION TEST RESULTS (REFERENCE 99) (1)

VEHICLE CONFIGURATION	POLLUTANT (GM/MI)		
	HC	CO	NOx
Without Device	3.5	41	2.5
With Device	3.0	36	2.3
Percent Reduction	14	12	8

(1) Results obtained using the 1972 Federal Test Procedure (Reference 3) and lean idle carburetor tuning. One test with and without device.

(2) 1971 Volkswagen (described in text)

Acceleration tests were also run by EPA on the test car. The results showed an improvement in acceleration of over 2 seconds from 0-60 mph for the turbocharged vehicle compared to the stock vehicle. From 50-80 mph, the acceleration time for the turbocharged car was about 10 seconds less, or a 30 percent improvement over stock.

The EPA report concluded that the turbocharger does not adversely affect emission levels (properly installed and adjusted), but does improve vehicle performance.

Based on the EPA exhaust emission results, it would appear that the device would not provide sufficient emission reduction effectiveness to classify it as a reasonable retrofit method for used car exhaust emission control.

4.6 FUEL INJECTION - RETROFIT SUBTYPE 1.2.6

Fuel injection as a method for controlling vehicle exhaust emissions may provide improved distribution, vaporization, and diffusion of the air-fuel mixture with resulting improvement in combustion and fewer pollutant byproducts. Only one example of this approach was found in the retrofit survey. Volkswagen currently uses electronically controlled fuel injection in some models to meet emission standards.

4.6.1 Device 22: Electronic Fuel Injection

The developer did not respond to the retrofit data survey, but limited information was obtained from an EPA test report (Reference 100). The test vehicle was a Ford Thunderbird completely converted to electronically controlled fuel injection; therefore no exhaust emissions data could be obtained for the test vehicle without fuel injection. The engine was tuned for minimum exhaust emissions with little consideration for driveability.

Table 4-76 presents the results of the emission tests reported in Reference 100. This reference indicated that the performance and driveability were adversely affected.

Table 4-76. DEVICE 22 ELECTRONIC FUEL INJECTION EMISSION TEST RESULTS REPORTED BY EPA (REFERENCE 100) (1)

TEST PROCEDURE	HC		CO		CO_2		OXIDES OF NITROGEN (GM/MI)					
	GM/MI		GM/MI		GM/MI		(SALTZMAN)		(NOx BOX)		(INFRARED)	
LA4 (2)	10.8	5.4	50	50	916	899	1.2	1.5	3.1	2.5	---	--- (5)
9 x 7 (3)	4.3	5.7	34	60	746	748	1.9	2.0	2.3	2.4	---	--- (5)
FTP (4)	2.3	2.3	21	22	---	--- (5)	---	--- (5)	---	--- (5)	1.6	1.5

(1) Ford Thunderbird test vehicle (model year unknown), 427-CID engine.

(2) CVS tests using LA4-S3 driving schedule (1972 Federal Test Procedure - Reference 3).

(3) Closed, constant volume sampling technique using 9 repeats of Federal emissions test cycle (9 CVS) - Reference 16.

(4) Standard 1970 Federal Test Procedure

(5) No data reported (---).

Acceleration tests were performed using a stock Thunderbird for comparison, with both vehicles carrying a 350-pound passenger load. Table 4-77 shows the average results of two runs with each vehicle in opposite directions along the same course. The retrofitted vehicle was faster only on the 0-60-mph run. There was objectionable hesitation on tip-in and surging on cruise with this vehicle. The overall driveability was rated "commercially unacceptable."

This was a limited evaluation of fuel injection as a vehicle exhaust emission control method, and it should not be considered as an evaluation of Device 22 for retrofit application.

Table 4-77. DEVICE 22 ELECTRONIC FUEL INJECTION ACCELERATION RESULTS

	DEVICE 22 T-BIRD (SEC)	STANDARD T-BIRD (SEC)
0-60 mph	10.6	10.8
20-50 mph	7.3	5.5
50-80 mph	13.0	9.0

SECTION 5

GROUP 1 RETROFIT METHOD DESCRIPTIONS: TYPE 1.3 - IGNITION CONTROL SYSTEMS

The approach taken with this group of devices is to control exhaust emissions through modifications to the ignition system. Two methods are used in this approach: (1) ignition spark timing modification, in which the timing advance is controlled; (2) ignition spark modification, in which the actual firing of the spark plug is controlled. Seven devices incorporating these methods were found to be either under development or in production. These devices are identified in Table 5-1.

Table 5-1. TYPE 1.3 IGNITION CONTROL SYSTEM RETROFIT DEVICES

IGNITION TIMING MODIFICATION - SUBTYPE 1.3.1	
DEVICE NO.	NOMENCLATURE
69 (2)	Electronic-Controlled Vacuum Advance Disconnect and Carburetor Lean Idle Modification
175 (2)(3)	Ignition Timing Modification with Lean Idle Adjustment
IGNITION SPARK MODIFICATION - SUBTYPE 1.3.2	
23 (1)	Electronic Ignition Unit
95 (1)	Ignition Spark Modification
259	Photocell-Controlled Ignition System
268	Capacitive Discharge Ignition
269	Ignition Timing and Spark Modification

(1) Previously tested by EPA.
(2) Tested under the retrofit method study program.
(3) Accredited for retrofit use in California.

Two of these devices had been tested previously by EPA. Data on the others were obtained from the developer, except that Devices 69 and 175 were also tested as part of the retrofit study program.

Ignition timing modification in the form of retarded spark timing has been found to be an effective control for used car emissions of NOx; and, when used in combination with lean idle mixture, an effective control for all three pollutants from used cars (Reference 120). The emission control principles of modifying the ignition spark have not been defined in literature known to date. Spark modifications have been used in the past as a means of engine performance improvement for high compression, high rpm engines.

5.1 IGNITION TIMING MODIFICATION - RETROFIT SUBTYPE 1.3.1

Ignition timing is a significant factor in effective exhaust emission control. Retarding ignition timing at idle tends to reduce exhaust emissions in two ways:

1. With retarded timing, exhaust gas temperatures are higher, thereby promoting additional burning of carbon monoxide and hydrocarbons in the exhaust manifold. Since combustion in the cylinder occurs later in the cycle, the peak combustion temperatures occurring in the cylinders are reduced, inhibiting the formation of NOx.

2. Retarded timing requires a slightly larger throttle opening (increased fuel and airflow) to obtain desired idle speed. The larger throttle opening results in better charge mixing and combustion at idle, thus decreasing the amount of CO and HC pollutant byproduct. The increased idle speed limits intake manifold vacuum on decelerations reducing HC and providing a more stable idle for lean mixtures (Reference 120).

The techniques used to retard timing for optimum emission control vary. Generally, it is desirable to have retard during idle, and full vacuum advance during closed throttle deceleration. These characteristics can be obtained either with vacuum systems incorporating both advance and retard capabilities, or with electronic sensing of engine speed or load which disconnects the distributor vacuum advance whenever spark retarded operation is required. Two retrofit devices incorporating ignition timing modification are described in this section.

5.1.1 Device 69: Electronic-Controlled Vacuum Advance Disconnect and Carburetor Lean Idle Modification

Device 69 is an ignition timing advance and idle mixture modification system. It incorporates a method of idle air-fuel mixture adjustment and an electronic method of monitoring and adjusting the distributor vacuum advance system. The objective of this device is to reduce emissions at idle and low speed operation through these methods based on the theory that:

1. Pre-1967 cars have carburetors which are adjusted for over-enrichment during idle and low engine speed, and a leaner air-fuel ratio can be achieved that both reduces HC and CO emissions while keeping driveability acceptable.

2. Retarding the spark reduces peak temperatures and NOx emissions, and extends the burning period into the exhaust system to further reduce CO and HC emissions.

3. Engine speed rather than vehicle speed is a better criterion for controlling the decision to retard ignition timing.

The device is in a prototype evaluation status. According to the developer, 35 prototype electronic spark control units have been manufactured and tests have been performed on about 24 different vehicles. He also has developed a special lean mixture screw assembly that has been provided for three different test cars. An alternative approach to controlling the mixture, already used on production cars, is to adjust, secure, and seal the factory-installed carburetor idle mixture adjustment screw.

5.1.1.1 Physical Description

Figure 5-1 shows a prototype electronic unit, which is approximately 4.5 inches long, 3 inches wide, and 2 inches high, excepting the mounting flange. The vacuum advance control valve body is approximately 1.5 inches on a side. The valve assembly is approximately 1 by 2-1/2 by 2-1/2 inches overall, including mounting bracket, electrical connections and tube fittings.

The developer's system layout drawing indicates that the lean mixture screw assembly, which replaces each of the standard idle mixture screws, extends about 2 inches from the carburetor body. The system also includes an engine temperature sensor, approximately ½ inch in diameter. The remainder of the system installation comprises the wiring and vacuum advance hoses (the latter replacing tubing which connects the carburetor and distributor in the production vehicle configuration).

5.1.1.2 Functional Description

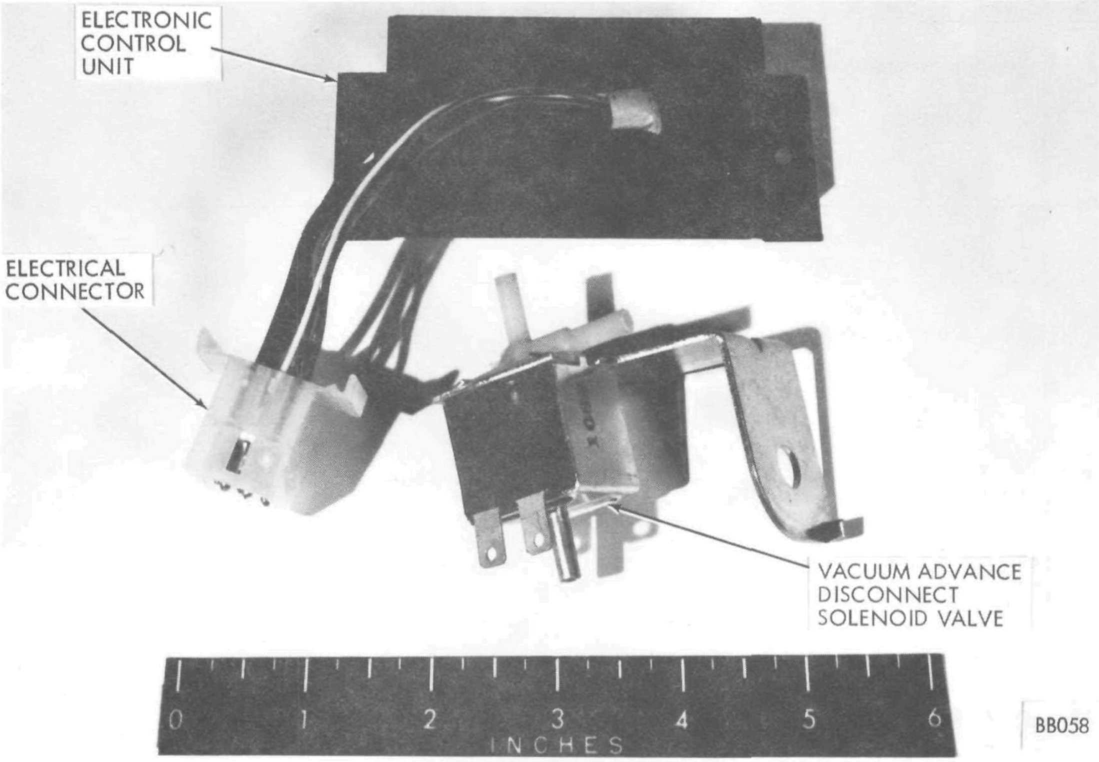
This system's function is to optimize the emission characteristics at low engine speeds by both air-fuel mixture adjustment and ignition timing control. The idle mixture is adjusted to an air-fuel ratio which provides acceptable emission levels and acceptable low speed engine performance for engine speeds from 1,600 rpm to idle. This is accomplished by making an initial adjustment at slow idle, and then trimming the adjustment at 1,500 rpm.

Figure 5-2 is a functional diagram of the ignition timing control, and identifies most of the hardware involved in this device. The electronic control unit, or "logic" as it is denoted by the developer, accepts data from three sources, the principal source being the ignition coil. The electronic unit connects to the low voltage side of the coil where it obtains both power to function, and the pulsed signal proportional in rate to engine rpm. The logic functions to sense whether the engine is indicating greater or less than 1,600 rpm.

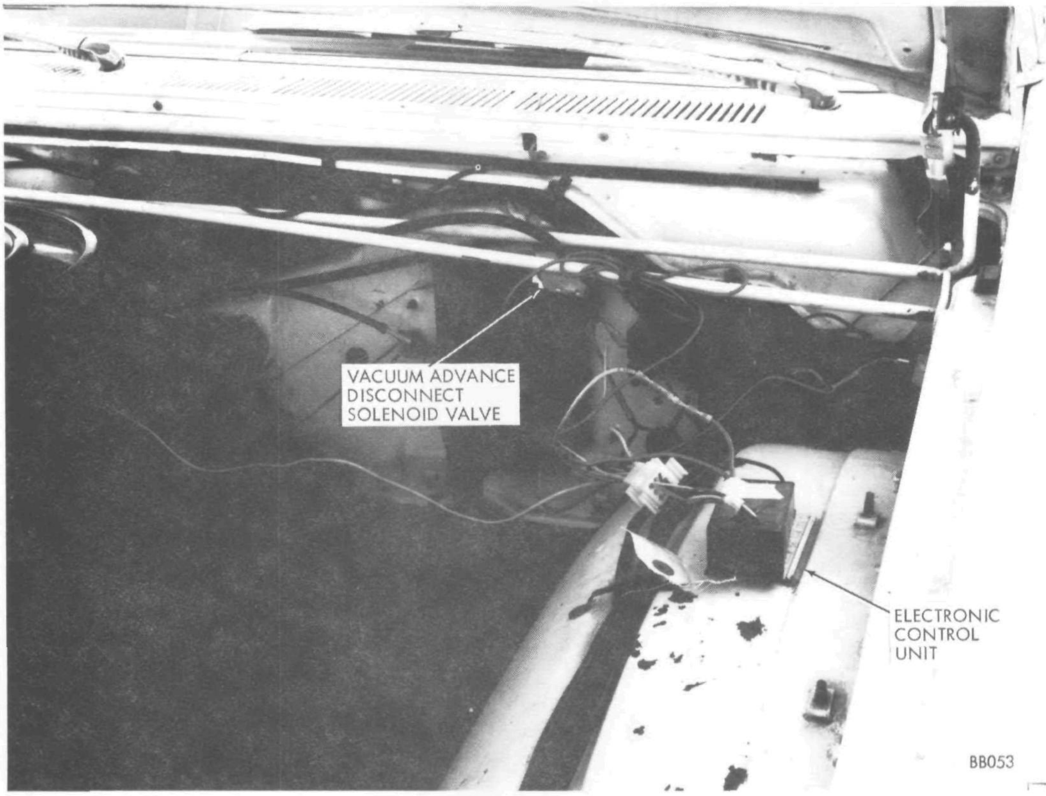
The second data source is the brake light switch, which is used to identify periods of rapid deceleration. The third data source is a thermistor (temperature sensing device) to sense engine over-temperature condition. The developer states that in production units the sensor will be installed in the electronic control unit, and that the unit installation instruction will call for mounting to the radiator.

The logic decision (the function of the electronic unit) will be that if engine rpm is less than 1,600 rpm or the brake switch is actuated and the engine has not overheated, the vehicle vacuum advance system will be bypassed through the normally open bleed tube of a solenoid valve installed in the distributor vacuum line. If engine rpm is greater than 1,600 rpm and the driver is not applying brakes, the valve is energized, closing the bleed tube and opening the distributor vacuum line to the carburetor (manifold inlet) vacuum source. An engine overheat condition will also result in a logic decision to energize the valve.

The brake switch connection is considered optional and would be connected in accordance with the installation instructions for a specific vehicle.



(a) Device 69 Components



(b) Device 69 COMPONENT INSTALLATION

Figure 5-1. DEVICE 69 ELECTRONIC-CONTROLLED VACUUM ADVANCE DISCONNECT WITH CARBURETOR LEAN IDLE MODIFICATION

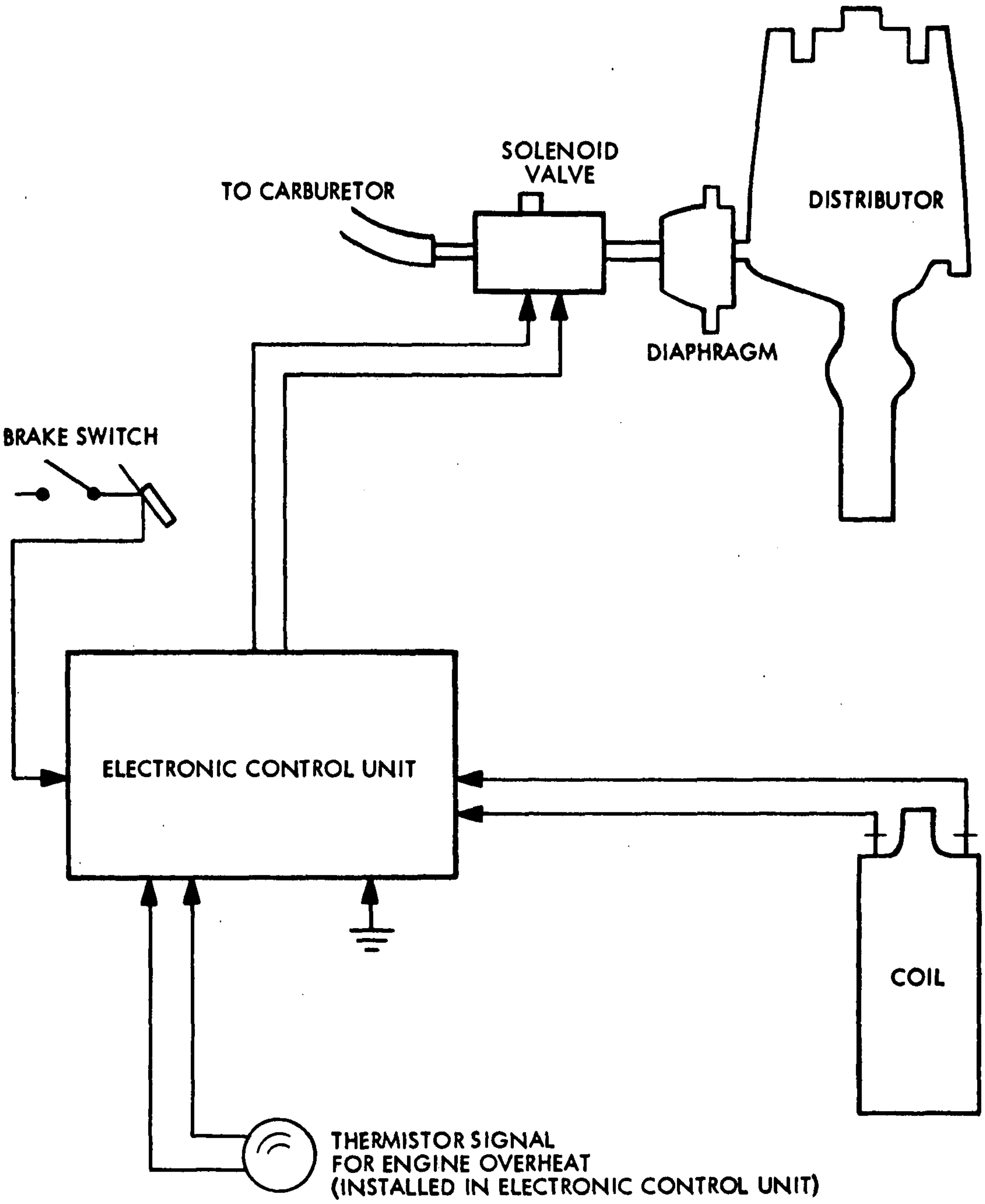


Figure 5-2. DEVICE 69 ELECTRONIC-CONTROLLED VACUUM ADVANCE DISCONNECT FUNCTIONAL SCHEMATIC (DEVELOPER SKETCH)

5.1.1.3 Performance Characteristics

Table 5-2 summarizes the results of emission tests performed in the retrofit study program. Overall, the device appeared to improve the HC, CO and NOx emission reduction characteristics without severe impact on other vehicle performance characteristics. There were variations in vehicle driveability during the tests, but usually very little, and some of which may be attributed to the test vehicle. Fuel economy degraded 15 to 20 percent on two vehicles and improved over 20 percent on the third. The impact of the device on fuel economy cannot be conclusively determined due to the small number of tests.

5.1.1.4 Reliability

The developer stated a device reliability of 50,000 MMBTF. No partial failure mode is identifiable that could occur prior to the estimated MMBTF.

In the event the solenoid fails such that the vacuum advance is continuously inoperative and/or the thermistor fails, engine overheating could occur.

Table 5-2. DEVICE 69 ELECTRONIC-CONTROLLED VACUUM ADVANCE DISCONNECT AND CARBURETOR LEAN IDLE MODIFICATION EMISSION REDUCTION AND FUEL CONSUMPTION PERFORMANCE (1)

VEHICLE YEAR/MAKE/CID	ANAHEIM TEST RESULTS			
	POLLUTANT GRAMS/MILE			FUEL MILES/ GALLON
	HC	CO	NOx	
1965 Plymouth 318				
Without Device	5.49	69.55	5.14	13.0
With Device	3.34	48.59	3.49	11.9
Percent Reduction	39.2	30.1	32.1	8.4
1965 Chevrolet 327				
Without Device	5.28	62.86	3.37	13.2
With Device	3.83	39.23	3.56	11.4
Percent Reduction	27.5	37.6	-5.6	14.0
1965 Ford 390				
Without Device	8.00	88.37	3.49	10.9
With Device	5.55	70.68	1.86	13.2
Percent Reduction	30.6	20.0	46.7	-21.4
Mean Percent Reduction	32.4	29.2	24.4	0

(1) Emission results obtained by Olson Laboratories in tests performed under Contract 68-04-0038 using 1972 Federal Test Procedure (Reference 3). Fuel consumption was measured during these tests.

5.1.1.5 Maintainability

The developer recommends standard 12-month or 12,000-MMBM service cycle, including inspection of the solenoid and lean mixture screw, the solenoid operation, and the electronic controller. The device should be tested for actuation of the solenoid at the appropriate engine rpm, at which point the solenoid operability can be verified.

It would be desirable if the device had test points to assess the condition of the thermistor, which senses radiator temperature. If the brake light option is part of the configuration, its operability should be verified also. It is estimated that periodic maintenance attributable to the device can be performed within 20 minutes (0.3 hr MTTM).

5.1.1.6 Driveability and Safety

This device was tested for driveability on three cars during the retrofit study program. Tests were run on Cars 3, 4, and 5. Table 5-3 summarizes the driveability results of these tests.

Table 5-3. DEVICE 69 DRIVEABILITY TEST RESULTS

DRIVEABILITY CHARACTERISTICS	1965 CHEV. 194 CID	1965 FORD 289 CID	1965 PLY. 318 CID	1965 CHEV. 327 CID	1965 FORD 390 CID	1961 CHEV. 283 CID
	ANAHEIM, CALIF., DRIVEABILITY TEST RESULTS					
	CAR NO. 1	CAR NO. 2	CAR NO. 3	CAR NO. 4	CAR NO. 5	CAR NO. 6
CRITICAL DRIVEABILITY	(1)	(1)	Increased stall during cold start deceleration	Increased stall during cold start deceleration	No effect	(1)
GENERAL DRIVEABILITY			Increased hesitation during cold start acceleration	Increased hesitation during cold start acceleration; increased cranking time during hot start; decreased detonation during hot start cruise	Increased start attempts during cold start; increased rough idle during cold start idle	
0 - 60 MPH ACCELERATION TIME (SECONDS)			Increased from 12.7 to 13.4	Decreased from 11.9 to 11.6	Decreased from 9.1 to 9.0	
60 - 40 MPH DECELERATION TIME (SECONDS)			Decreased from 26.1 to 22.4	Increased from 22.3 to 24.6	Increased from 26.5 to 31.8	
GAS MILEAGE PER GALLON	No significant change overall (Reference Table 5-2)					

(1) Device 69 was not tested on these vehicles.

During the period of these tests, Car 4 had an intermittently bad starter solenoid and the starting problems encountered might have been induced by this defect. In addition, Car 4 had a tendency toward detonation at all times when the hot start tests were run. This problem may or may not be due to the installation of the device. Similarly, Car 3 exhibited a tendency toward hesitation caused by carburetor settings and the problem encountered in these tests may or may not be due to the installation of the device.

There appear to be no safety hazards with the device in operation on a vehicle.

5.1.1.7 Installation Description

The installation of this device consists in replacing the existing idle adjusting screw in the carburetor with a special lean mixture screw, installing a spark retard thermistor on the upper radiator reservoir tank, installing a solenoid valve in the vacuum spark advance line, installing the electronic controller, and connecting the wires from the device to the solenoid and coil. Adjustments consist in setting engine idle rpm, adjusting air-fuel ratio, and setting the ignition timing. The developer estimated that retail price for the complete kit would be less than $50 and that the installation could be made in less than one hour by a qualified mechanic.

Table 5-4 presents a detailed description of the installation requirements. Installation can be accomplished in a normally equipped garage by the average mechanic. From the information available, it is estimated that the total cost of this installation, including material, would be $62.50.

Table 5-4. DEVICE 69 ELECTRONIC-CONTROLLED VACUUM ADVANCE DISCONNECT AND CARBURETOR LEAN IDLE MODIFICATION INSTALLATION PROCEDURE

MINIMUM AVERAGE SKILL LEVEL: AUTOMOTIVE MECHANIC		
INSTALLATION AND ADJUSTMENT PROCEDURE	TOOLS, EQUIPMENT AND FACILITIES	TIME (MIN.)
1. Remove the existing idle adjusting screw from the carburetor and replace it with the lean mixture screw (2 for dual- and four-barrel carburetors)	a. Hand tools b. Lean mixture screw	4
2. Adjust idle speed to 600 rpm in drive for automatic transmissions and to 700 rpm in neutral for standard transmissions	Tachometer	3
3. Adjust the air-fuel ratio to 14:1 or to 1.5% CO at idle	Engine analyzer	4
4. Adjust the air-fuel ratio to 16:1 at 1500 rpm	Engine analyzer	4
5. Install the spark retard thermistor on the upper radiator reservoir tank using pressure-sensitive tape on epoxy	a. Hand tools b. Spark retard device c. Tape or epoxy	3

Table 5-4. DEVICE 69 ELECTRONIC-CONTROLLED VACUUM ADVANCE DISCONNECT AND CARBURETOR LEAN IDLE MODIFICATION INSTALLATION PROCEDURE (CONCL)

MINIMUM AVERAGE SKILL LEVEL: AUTOMOTIVE MECHANIC		
INSTALLATION AND ADJUSTMENT PROCEDURE	TOOLS, EQUIPMENT AND FACILITIES	TIME (MIN.)
6. Install the solenoid valve in the vacuum spark advance line between the carburetor and the distributor	a. Hand tools b. Solenoid valve	15
7. Install the electronic controller and connect the electrical leads from the device to the solenoid valve and to the ignition coil	Hand tools	15
8. Set the ignition timing to the manufacturer's specifications	Engine analyzer	12
	Total Time	1 hr

5.1.1.8 Initial and Recurring Costs

Table 5-5 itemizes the initial and recurring costs for this device over a 50,000-mile service life.

5.1.1.9 Feasibility Summary

Device 69 appears to be technically feasible and has effective exhaust emission reduction. The fail-safe aspects should bear further considerations from a point of view of device failure modes and their impact on the vehicle. The developer stated that simple changes can be made to accommodate any desired failure mode characteristics.

The installation and adjustment requirements and the costs appear to be reasonable for this type of device, assuming that fuel consumption does not increase. The basic device concept should facilitate design and manufacture for reliability, and the developer's initial-cost estimate of less than $50 per kit seems valid.

Table 5-5. DEVICE 69 ELECTRONIC-CONTROLLED VACUUM ADVANCE DISCONNECT AND CARBURETOR LEAN IDLE MODIFICATION INITIAL AND RECURRING COSTS

ITEM	DESCRIPTION	LABOR HOURS OR ITEM QUANTITY	COST (DOLLARS)
Initial Cost:			
Material			
1. Device	a. Lean mixture screw for carburetor b. Spark retard device c. Solenoid valve		50.00
2. Miscellaneous	Pressure-sensitive tape or epoxy		(Included in above)
Labor			
1. Installation	Table 5-4	0.75 hr	9.38
2. Test and adjust	Table 5-4	0.25 hr	3.12
		Total Initial Cost	62.50
50,000-Mile Recurring Cost:			
Labor			
1. Inspection	Refer to paragraph 5.1.1.5	0.33 hr every 12,000 miles at $12.50/hr	16.68
		Total Recurring Cost	16.68
		TOTAL COSTS	79.18

5.1.2 Device 175: Ignition Timing Modification with Lean Idle Adjustment

This device is designed to control HC and NO emissions by means of electronic control of engine ignition timing. CO is controlled by adjusting the carburetor idle mixture to a lean setting. Ignition control is regulated in two ways: (1) electronic regulation of the distributor signal, and (2) regulation of the distributor vacuum advance mechanism. Both means of regulation act to retard the basic timing. The device consists of an ignition control assembly which is attached to the fender well under the vehicle hood.

Device 175 has been certified for installation on pre-1966 used cars in California by the California Air Resources Board (Reference 78). The device was one of four representative retrofit devices tested during the retrofit study on used cars at both the Olson, Anaheim, California, and Taylor, Michigan, test facilities.

5.1.2.1 Physical Description

The device control system includes the following electronic circuits and components:

1. A solenoid actuated valve which connects or disconnects the distributor vacuum advance.

2. An ignition circuit which regulates the distributor point signal to a retarded condition at vehicle speeds below 35 mph.

3. A sequencing circuit and switch which senses vehicle speed and controls the regulation provided by the first two items.

The device has two hose connections which attach to the carburetor distributor vacuum port and distributor vacuum advance chamber. Three wire connections are made: (1) one wire connects between the distributor points and the device, (2) a second wire connects from the device to the distributor terminal on the coil, and (3) a third wire connects between the device and the battery terminal on the coil. Figure 5-3 shows the electronic control module installed.

5.1.2.2 Functional Description

The following is quoted from developer's functional definition for Device 175:

> "The system is designed to control HC and NO emissions by means of electronic control of engine ignition timing. CO is controlled by means of a carburetor adjustment technique. The basic function of the control unit is to regulate the ignition spark advance and sequence the regulation according to vehicle operating modes. The spark advance is regulated in two ways: (1) electronic regulation of the distributor ignition signal and (2) regulation of the distributor vacuum advance mechanism. Both means of regulation act to retard the basic timing.
>
> "Electronic regulation of the distributor ignition signal is accomplished by means of an electronic circuit within the control unit. Electrical power is supplied to the unit through one of the wires in the unit electrical cable. This wire connects to the vehicle electrical system at the ignition coil. The wire from the distributor points which normally

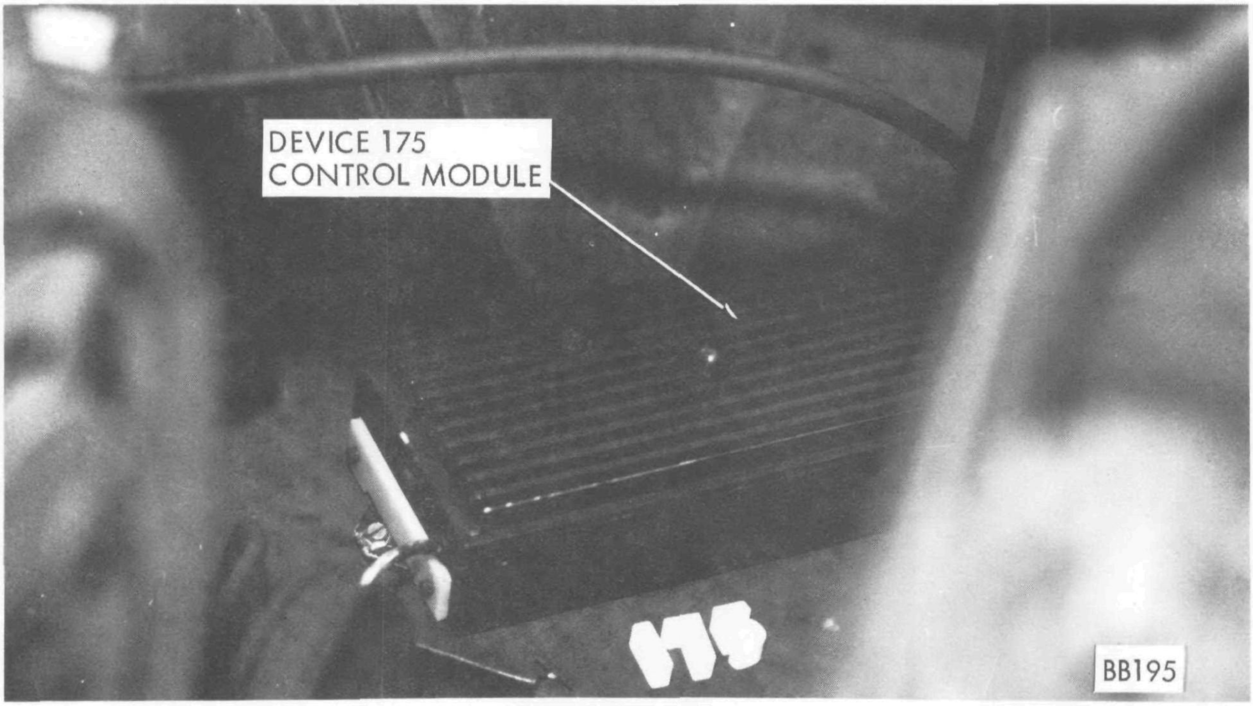


Figure 5-3. DEVICE 175 ELECTRONIC CONTROL MODULE INSTALLED ON FENDER WELL

connects to the ignition coil, is disconnected and attached to the second wire in the control unit electrical cable. In operation, the distributor point signal, when routed to the control unit, is regulated by the electronic circuit and then routed back to the ignition system through the third wire which is connected to the ignition coil. The regulation in the ignition point signal causes the ignition timing to be retarded which effects a reduction in HC and NO emissions. The amount of regulation desired is adjusted by means of a switch within the control unit. This switch is set by the mechanic when the unit is installed. The distributor vacuum advance is regulated by means of an electronically controlled solenoid within the control unit. This solenoid is connected to the carburetor and distributor vacuum advance mechanism by the two rubber hoses on the control unit. In operation, the solenoid disconnects the vacuum advance from the carburetor causing the ignition timing to be retarded which also affects a reduction in HC and NO emissions.

"The ignition spark advance regulation, when coupled with the carburetor adjustment procedure, results in a further reduction in HC. The carburetor adjustment procedure which reduces CO also reduces HC emissions. The procedure is to adjust idle speed and mixture. The idle speed is increased 50 to 75 rpm above manufacturer's specifications and the mixture is adjusted for best lean idle conditions. The lean mixture tends to reduce

HC and the higher idle rpm reduces HC during deceleration modes.

"In addition to regulating the ignition spark advance, a sequencing system is provided in the control unit. The function of the sequencing system is to control the time at which regulation occurs. The purpose of sequencing the timing regulation is to prevent idle overtemperature conditions and maintain fuel economy and drive quality. A sequencing control switch is also located in the control unit with the regulator switch, and adjusted at time of installation. In operation, the timing regulation is sequenced to allow full vacuum advance at idle and low speed engine operation, which eliminates high engine temperature and reduced fuel economy during prolonged periods of idle and creep speed conditions (traffic jams, etc.). At high speed operation (above approximately 35 mph) the sequencing restores the ignition spark advance timing to its normal operating condition, thereby maintaining acceptable fuel economy and drive quality."

5.1.2.3 Performance Characteristics

Table 5-6 presents a summary of performance data based on information submitted by the developer. Table 5-7 presents emission data measured during the retrofit study test program. The device shows consistent effectiveness in decreasing CO and NOx emissions, with less benefit in HC reduction. Gasoline mileage is 10% less on the average.

Table 5-6. DEVICE 175 IGNITION TIMING MODIFICATION WITH LEAN IDLE ADJUSTMENT EMISSION TEST RESULTS SUBMITTED BY DEVELOPER

VEHICLE CONFIGURATION	POLLUTANT		
	HC (PPM)	CO (%)	NOx (PPM)
Without Device	696 (1)	3.25 (1)	1,170 (1)
With Device	235 (2)	1.50 (2)	538 (2)
Percent Reduction	66	53	54

(1) 7-cycle, 7-mode hot start average 17 used cars.

(2) 7-cycle, 7-mode cold start average of 17 used cars at start of accreditation program. HC, CO, and NOx values for four cars at end of 25,000 miles were 224 ppm, 1.54 percent, and 533 ppm, respectively.

Table 5-7. DEVICE 175 IGNITION TIMING MODIFICATION WITH LEAN IDLE ADJUSTMENT EMISSION REDUCTION AND FUEL CONSUMPTION PERFORMANCE (1)

VEHICLE YEAR/MAKE/CID	ANAHEIM TEST RESULTS				TAYLOR TEST RESULTS			
	POLLUTANT GRAMS/MILE			FUEL MILES/ GALLON	POLLUTANT GRAMS/MILE			FUEL MILES/ GALLON
	HC	CO	NOx		HC	CO	NOx	
1965 Chev 194								
Without Device	10.67	71.56	2.20	(2)				
With Device	9.17	63.41	1.24	14.78				
Percent Reduction	14.1	11.4	43.6	(2)				
1965 Ford 289								
Without Device					3.69	57.16	3.87	14.00
With Device					3.07	13.43	1.68	13.22
Percent Reduction					16.8	76.5	56.6	6.0
1965 Ply 318								
Without Device	10.55	133.27	3.00	11.57	4.04	56.10	3.79	12.60
With Device	7.06	104.58	1.71	9.87	2.97	11.96	2.18	13.22
Percent Reduction	33.1	21.5	43.0	15.0	26.5	78.7	42.5	-5.1
1965 Chev 327								
Without Device	6.70	75.96	1.95	14.24	4.68 5.18	40.82 46.82	3.82 5.03	14.24 16.12
With Device	6.38	69.77	1.66	13.69	3.79 3.11	15.89 12.45	1.66 2.83	11.60 12.00
Percent Reduction	4.8	8.1	14.9	4.0	19.0 40.0	61.1 73.4	56.5 42.8	18.8 26
1965 Ford 390								
Without Device	8.35	111.73	2.19	11.57	3.43	50.91	2.34	12.15
With Device	10.10	122.66	1.42	9.74	2.59	12.87	2.27	13.00
Percent Reduction	-21.0	-9.8	35.2	16.0	24.5	74.7	3.0	-7.0
1961 Chev 283								
Without Device	5.57	(2)	1.29	(2)	4.36	38.52	2.88	13.22
With Device	6.09	98.01	1.34	(2)	2.89	12.70	1.89	10.60
Percent Reduction	(2)	(2)	(2)	(2)	33.7	67.0	34.4	20.0
Pooled Mean Percent Reduction (3)	HC 19.2				CO 46.3		NOx 37.2	Fuel 10

(1) Emission results obtained by Olson Laboratories in tests performed under Contract 68-04-0038 using 1972 Federal Test Procedure (Reference 3). Fuel consumption was measured during these tests.

(2) Test data invalid.

(3) Anaheim and Taylor results combined.

5.1.2.4 Reliability

The developer claimed a reliability of 75,000 mean-miles-before-total-failure (MMBTF) and has performed extensive road testing of the system. No partial failure modes which could occur prior to the estimated MMBTF were identifiable. The system contains 63 electronic components and a solenoid actuated valve. The primary solenoid failure mode is wear-out, which should not occur prior to 75,000 miles if components are properly selected. It appears that the developer's estimate of reliability is reasonable.

In the event the solenoid valve fails such that the distributor vacuum advance is continuously inoperative, engine overheating could occur.

5.1.2.5 Maintainability

No maintenance apparently is required on the system other than to perform an inspection, during routine vehicle maintenance, to assure that the unit is functioning. Repair is not possible. In the event of failure, removal and replacement with a new unit is required. It is estimated by the developer that the replacement time would be 0.75 hour.

5.1.2.6 Driveability and Safety

Device 175 was tested for driveability at the Olson Laboratories, Anaheim, California and Taylor, Michigan, test facilities. Table 5-8 summarizes the driveability results of these tests.

During the performance of tests with Car 1, it was discovered that the ignition points were not closing properly since the dwell angle was too small. The results obtained were probably not due to the device. A second test run was made and there was no effect on the driveability.

The device showed 10% less gasoline mileage on the average. This would impact recurring costs adversely as noted in Table 5-10.

5.1.2.7 Installation Description

The installation of this device consists in mounting the control unit on the fender well in the engine compartment, connecting the wires to the distributor and battery, and connecting the vacuum advance. Adjustment of the device consists in adjusting switches inside the cover plate of the control unit. Adjustment of the engine consists in setting idle speed 50 to 75 rpm over manufacturer's specifications, and adjusting idle mixture for best lean idle conditions.

Table 5-9 provides a description of the installation requirements. Installation would require a qualified automotive mechanic and tuneup equipment.

5.1.2.8 Initial and Recurring Costs

Table 5-10 provides a summary of the estimated costs. From the information available, it is estimated that the total cost of this installation, including material, would be about $44.50.

Table 5-8. DEVICE 175 DRIVEABILITY TEST RESULTS

DRIVEABILITY CHARACTERISTICS	1965 CHEV. 194 CID	1965 FORD 289 CID	1965 PLY. 318 CID	1965 CHEV. 327 CID	1965 FORD 390 CID	1961 CHEV. 283 CID
	ANAHEIM, CALIF., DRIVEABILITY TEST RESULTS					
	CAR NO. 1	CAR NO. 2	CAR NO. 3	CAR NO. 4	CAR NO. 5	CAR NO. 6
CRITICAL DRIVEABILITY	No effect	(1)	No effect	No effect	No effect	Increased stall during cold test acceleration.
GENERAL DRIVEABILITY	Increased surge on hot start acceleration; increased hesitation on cold start acceleration	(1)	No effect	No effect	No effect	Increased stumble during cold test acceleration
0 - 60 MPH ACCELERATION TIME (SECONDS)	Decreased from 19.8 to 15.4	(1)	Decreased from 12.5 to 11.5	Increased from 11.0 to 12.2	Increased from 8.8 to 9.2	Decreased from 16.6 to 16.1
60 - 40 MPH DECELERATION TIME (SECONDS)	Decreased from 19.5 to 17.8	(1)	Decreased from 25.5 to 22.3	Decreased from 23.2 to 20.7	Decreased from 22 to 18.5	No data
GAS MILEAGE PER GALLON	Average decrease of 11.7 percent (Reference Table 5-7)					
	TAYLOR, MICH., DRIVEABILITY TEST RESULTS					
	CAR NO. 16	CAR NO. 8	CAR NO. 9	CAR NO. 10	CAR NO. 11	CAR NO. 12
CRITICAL DRIVEABILITY	No effect	Car stalled on cold start acceleration - rough idle for both hot and cold start tests	Car stalled on cold start	No effect	Car stalled on cold start - detonation on hot start acceleration	No effect
GENERAL DRIVEABILITY	Increase in hesitation on acceleration for both hot and cold start phases.	Increase in cranking time for hot start and decreased for cold start	No change on driveability	Increase in cranking time and stumble on acceleration	Stretchiness on hot start	Increase in hesitation and stumble
0 - 60 MPH ACCELERATION TIME (SECONDS)	Increased from 12.3 to 15.5	Increased from 11.7 to 17.7	Increased from 12.9 to 13.6	Increased from 10.2 to 11.0	Increased from 9.7 to 10.2	Increased from 12.3 to 12.6
60 - 40 MPH DECELERATION TIME (SECONDS)	Increased from 22.9 to 23.3	Increased from 20.7 to 21.6	Increased from 21.8 to 23.2	Increased from 21.1 to 24.7	Increased from 21.0 to 22.2	Increased from 25.0 to 28.1
GAS MILEAGE PER GALLON	Average decrease of 9.7 percent (Reference Table 5-7)					

(1) Device 175 was not tested on this vehicle.

Table 5-9. DEVICE 175 INSTALLATION PROCEDURE

MINIMUM AVERAGE SKILL LEVEL: AUTOMOTIVE MECHANIC		
INSTALLATION AND ADJUSTMENT PROCEDURE	TOOLS, EQUIPMENT AND FACILITIES	TIME (MIN.)
1. Using engine analyzer, verify that engine is operating within manufacturer specifications, adjust as required.	Engine analyzer	15
2. Install control unit on fender wall or other readily accessible location in engine compartment using two sheet metal screws.	a. Electric drill b. Hand tools c. Sheet metal screws d. Control unit	10
3. Remove distributor point signal wire from distributor terminal on coil and connect to control unit red wire.	Wire	2
4. Connect control unit green wire to distributor terminal on coil.	Wire	2
5. Connect control unit block wire to battery terminal on coil.	Wire	1
6. Connect control unit red vacuum hose to carburetor vacuum.	Vacuum hose	2
7. Connect control unit blue vacuum hose to distributor vacuum advance.	Vacuum hose	1
8. Remove control unit cover plate.	Hand tools	1
9. Adjust switches per adjustment table located on inside of cover plate.	Hand tools	10
10. Reinstall cover plate.	Hand tools	1
11. Adjust idle speed to 50-75 rpm over manufacturer's specifications.	Engine analyzer	3
12. Adjust idle mixture for best lean idle conditions (approximately 1.5 percent CO)	Engine analyzer	12
	Total Time	1 hr

Table 5-10. DEVICE 175 INITIAL AND RECURRING COSTS

ITEM	DESCRIPTION	LABOR HOURS OR ITEM QUANTITY	COST (DOLLARS)
Initial Cost:			
Material			
1. Device	Control unit		32.00
2. Miscellaneous	a. Sheet metal screws b. Electric wire c. Vacuum hose		(Included in above)
Labor			
1. Installation	Table 5-9	0.5 hr	6.25
2. Test and adjust	Table 5-9	0.5 hr	6.25
		Total Initial Cost	44.50
50,000-Mile Recurring Cost:			
Material			
1. Fuel	10 average increase in fuel consumption (refer to Table 5-8)	400-gallon fuel increase x $0.35 per gallon over 50,000 miles (1)	140.00
		Total Recurring Cost	140.00
		TOTAL COSTS	154.50
(1) Based on an assumed national average of 10,000 miles per year at 12.5 mpg			

5.1.2.9 Feasibility Summary

Device 175 should serve adequately in the retrofit device class of ignition timing modifications. The study results indicate that the device is effective in controlling CO and NOx emissions, with relatively less effectiveness in controlling HC. This device has demonstrated overall technical and economic feasibility by meeting the standards for used car certification in California. The developer reported that manufacture of the device has been initiated on a mass-production basis.

The developer also reported that lower cost versions of the device are being developed for special control applications to selected pollutants.

5.2 IGNITION SPARK MODIFICATION - RETROFIT SUBTYPE 1.3.2

This group of devices attempts to reduce emissions by modifying the strength of the ignition spark. Based on information reviewed during the retrofit study, there is no apparent relationship between the spark strength and resulting emissions.

One device reviewed in this section incorporates a capacitive discharge ignition with no modification of spark timing. The capacitive ignition provides an extraordinarily high secondary voltage for a duration which is somewhat shorter than that obtained with a conventional ignition.

Another device reviewed in this section uses a photocell-controlled ignition system that is claimed to increase the duration of the spark at the spark plug, thereby reducing emissions.

A capacitive discharge system in general requires electronic circuits which perform the following functions:

1. A high voltage current generator to charge the capacitor

2. A transistorized switching element

3. A synchronizing circuit which triggers the switching. (This function is provided by the distributor points.)

In general, capacitive discharge ignition provides a much more rapid and much higher voltage ignition spark than can be obtained with a conventional ignition system. Good ignition spark is obtained even when distributor points and spark plugs are in a degraded condition that would cause excessive misfires; however, no relationship between spark strength and emissions is known to exist.

Capacitive discharge ignition is obtained by inducing a high voltage in the coil secondary winding by discharging a capacitor charged to approximately 200 volts through the coil primary. The capacitor is discharged through a transistor switch for which control voltage is applied by the normal primary signal from the distributor. When the primary points open, control voltage is removed from the transistor switch which causes it to flip closed, permitting the charged capacitor to discharge through the coil primary windings. A short duration, 200-volt spike is delivered to the coil primary, inducing a short high-voltage secondary voltage. The capacitor is recharged during the period the distributor points are closed.

5.2.1 Device 23: Electronic Ignition Unit

Although the manufacturer of this device did not respond to the retrofit data survey questionnaire, limited evaluation was possible on the basis of a HEW/NAPCA exhaust emission test report (Reference 81). The HEW/NAPCA tests were performed to evaluate the device for its retrofit potential.

The device attaches to both sides of the ignition coil, as specified by the device manufacturer. The test vehicle was apparently already equipped with a Ford retrofit kit. The device was tested in accordance with the 1970 and 1972 Federal Test Procedures (References 15 and 3). The results obtained with the 1972 procedure are summarized in Table 5-11.

Table 5-11. DEVICE 23 ELECTRONIC IGNITION UNIT EMISSION TEST RESULTS REPORTED BY HEW/NAPCA (REFERENCE 81) (1)

VEHICLE CONFIGURATION	POLLUTANT (GM/MI)		
	HC	CO	NOx
Without Device	6.51	93.81	2.14
With Device	6.32	109.08	3.33
Percent Reduction	2.9	-16.3	-56.0

(1) One 1972 Federal Test Procedure with and without Device 23 installed on a 1963 Ford Galaxie 289-CID with automatic transmission.

5.2.2 Device 95: Ignition Spark Modification

This device is a commercial product that is marketed as a vehicle economy and performance improver. The device has been tested on two occasions by HEW/NAPCA, with results indicating that the device has no effectiveness for controlling exhaust emissions (References 82 and 83).

5.2.2.1 Physical Description

The device fits between the distributor cap and the spark plug wires and is claimed to "...precondition the gases in the nonfiring cylinders."

5.2.2.2 Functional Description

The device was described by the developer as follows (Reference 82):

> "Using the principle of electromagnetic induction, the circuits of the (device) tap electrostatic energy from the firing spark. This energy is directed to the nonfiring cylinders, where it bombards the fuel molecules with radiation, preparing the mixture for more complete combustion."

5.2.2.3 Performance Characteristics

The emission reduction characteristics of this device are summarized in Tables 5-12 and 5-13, based on emission data obtained from the referenced reports.

Table 5-12. DEVICE 95 IGNITION SPARK MODIFICATION EMISSION TEST RESULTS (REFERENCE 83) (1)

VEHICLE CONFIGURATION (2)	POLLUTANT (GM/MI)		
	HC	CO	NOx
Without Device	1.30	16.0	4.80
With Device	1.38	17.5	4.55
Percent Reduction	-6	-9	6

(1) Average of two cold-start and two hot-start tests using the 1970 Federal Test Procedures (Reference 15). The cold-start tests were run before and after accumulation of 250 miles with the device installed.

(2) EPA 1971 Ford with 351-CID engine, air conditioning and automatic transmission.

Table 5-13. DEVICE 95 EMISSION TEST RESULTS (REFERENCE 82) (1)

VEHICLE CONFIGURATION (2)	POLLUTANT (GM/MI)		
	HC	CO	NOx
Without Device	6.0	92	1.6
With Device	7.6	108	2.1
Percent Reduction	-26.7	-17.4	-31.3

(1) Results of one test with and without device, using 1972 Federal Test Procedure (Reference 3).

(2) 1963 Chevrolet Impala with 283-CID engine.

5.2.2.4 Feasibility Summary

The developer did not provide information on which to base an evaluation of the device's reliability, maintainability, driveability, safety, installation, or costs. Based on the HEW/NAPCA test data it appears that this device would not be effective in reducing HC, CO, or NOx exhaust emissions. The device therefore appears to be infeasible for emission control application.

5.2.3 Device 259: Photocell-Controlled Ignition System

Device 259 is an ignition spark modification retrofit method that increases the duration of the ignition spark at the spark plug. The concept appears to be that a longer spark duration may increase combustion efficiency, with attendant emission reduction.

A photocell system is used in Device 259 to enable the spark to be prolonged. The photocell replaces the conventional mechanically actuated breaker points.

Device 259 is in a prototype developmental status. Fifteen prototype units have been made, and 10 installed on vehicles. Approximately 300,000 miles of operation have been accumulated, but no testing has been performed to determine if emissions are reduced.

5.2.3.1 Physical Description

The principal components of Device 259 for a four-cylinder ignition system are shown in Figure 5-4. The system consists basically of an amplifier, a photocell and light source, and a shadow disk. The shadow disk, bulb, and photocell are installed in the conventional distributor in place of the standard breaker point assembly. The shadow disk is a circular metal plate, sized to the distributor and with cutout sections which allow the photocell to be energized.

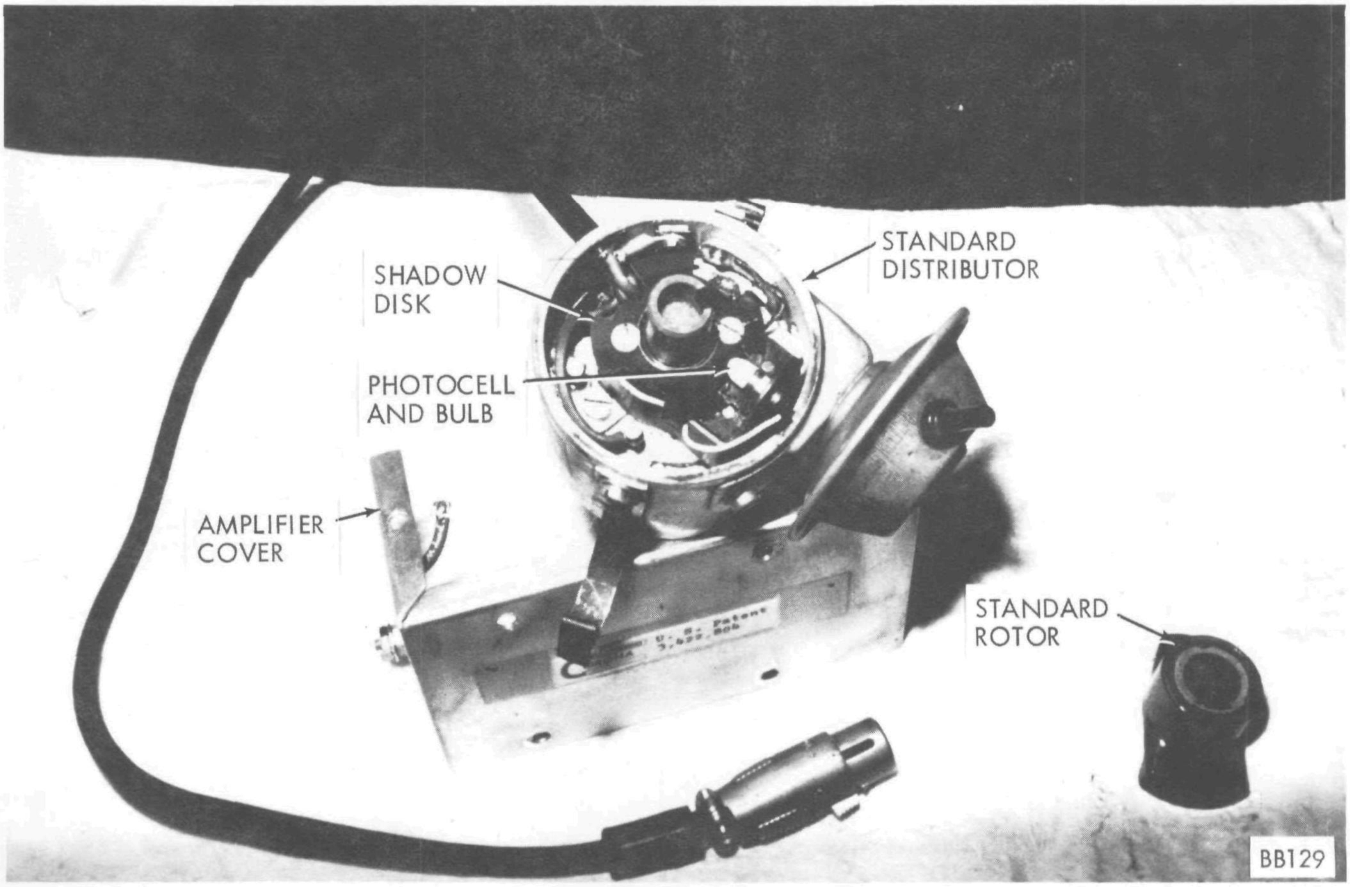


Figure 5-4. DEVICE 259 PHOTOCELL-CONTROLLED IGNITION SYSTEM COMPONENTS (4-CYLINDER IGNITION SYSTEM)

The photocell and bulb are standard commercial components. The amplifier is a prototype designed specifically for the requirements of this system by the developer. It incorporates printed circuit boards.

5.2.3.2 Functional Description

The system provides longer spark duration by replacing the standard breaker points of the conventional distributor with a photocell and shadow disk. The function of the breaker points is performed by the photocell, under control of the shadow disk.

As shown in Figure 5-4, the shadow disk attaches to the distributor rotor with the photocell on one side and the light source on the other. As the disk rotates, light to the photocell is pulsed in accordance with the cutout pattern in the disk. The duration of each pulse, and hence the spark duration, is determined by the arc length of the cutouts.

The electrical schematic of the Device 259 system is shown in Figure 5-5. The following excerpt from the developer's test report (Reference 85) defines the basic functional relationships:

> "The optimum spark duration can only be achieved when the spark gap in the distribution cap is replaced by a sliding contact (to lengthen the contact time and hence spark duration). It will have to be determined if this optimum spark duration is actually required. Once the now remaining unburned gases are burned by an extended spark, a further spark extension is superfluous. It may be pointed out that the development of a sliding contact in the distributor cap (would) be somewhat costly. Contact wear may reduce the dependability.
>
> "The spark duration times of a conventional ignition system . . . are considerably below the optimum time. The (Device 259) ignition system provides a maximum spark duration time of 3.8 msec which, at higher rpm, is only limited by the optimum time.
>
> "(With Device 259), the points of the distributor have been replaced by a shadow disk. A 5-volt bulb, rated 60,000 hours - the average life of an automobile engine when driven for 100,000 miles at 35 miles per hour would require an operating time of 2,857 hours - is connected to the 12-volt battery over a voltage drop resistor. To protect the bulb from overvoltage, a zener diode is connected in parallel to the bulb.
>
> "When the ignition switch is turned on, the 5-volt bulb burns continuously, shining on a highly sensitive photocell, which has a 50-microsecond switching time.
>
> "The shadow disk, mounted on the distributor shaft, moves between the bulb and the photocell. The photocell resistance changes from 2,000 ohms (light) to infinite (dark) and provides the bias for a transistorized amplifier. The output current of the amplifier flows over a resistor into the primary winding of the ignition coil. When connected to resistive load, the amplifier produces a square current wave.

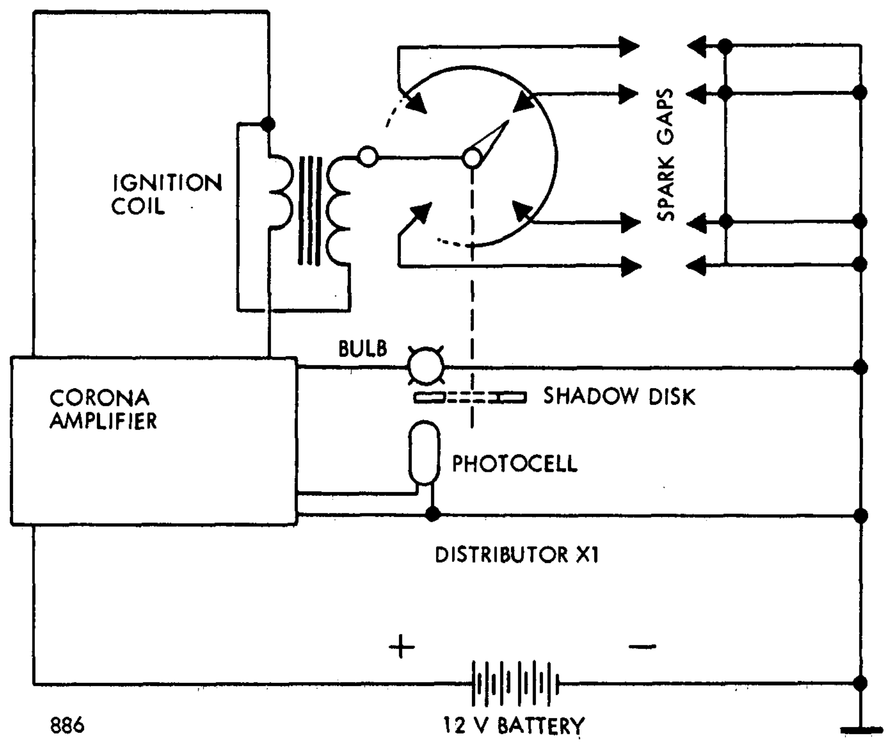


Figure 5-5. DEVICE 259 PHOTOCELL-CONTROLLED IGNITION SYSTEM ELECTRICAL SCHEMATIC (DEVELOPER SKETCH)

> "The spark is initiated when light hits the photocell and continues until the spark energy is used up. The current demand under operating conditions is approximately 4 A average."

5.2.3.3 Performance Characteristics

No emission test data was provided for this device by the developer. The developer's test report provided the following performance summary with respect to potential emission reduction:

> "A test car equipped with the (Device 259) ignition system was driven 30,000 miles. When the engine heads were removed, no carbon deposit could be detected. We therefore conclude that the combustion, when using our ignition system, is somewhat improved.
>
> "The point equipped ignition systems have distinct disadvantages, one of which is a short spark duration. It stands to reason that the unburned gases, which are contained in the exhaust smog, have a better chance of burning when the spark duration is extended."

5.2.3.4 Reliability

The developer claimed in his test report that the elimination of the point system and the application of a rotating shadow disk should provide the ultimate in dependability, because the system has no mechanical wear.

Data were not obtainable by which to determine a specific mean-miles-before-total-failure (MMBTF). With a reliable amplifier, the service life of the system could far exceed 75,000 miles. For the amplifier, components would have to be selected for the use environment. For example, use of silicon semiconductors rated to 125°C would be essential to meet reliability requirements, if the amplifier is mounted in the engine compartment.

Particularly critical to reliability is the selection of the light source and the photocell detector, because the failure of either could render the system totally inoperative in potentially hazardous driving modes. Acceptable reliability of photocells and light bulbs have not been verified for an automotive ignition use environment; however, acceptable reliabilities for silicon solid-state devices have been verified for:

(1) Light emitting diodes for the light source

(2) Photo field effect transistors for the detector

These devices are readily available in production quantities.

5.2.3.5 Maintainability

In the event of system failure, the average motorist or an automotive repair shop could remove and replace the system. It is expected that routine maintenance would be performed on the distributor, such as inspection, cleaning, and lubrication, in accordance with standard procedures and at the intervals prescribed by the vehicle manufacturer (25,000 MMBM). No additional maintenance peculiar to the Device 259 ignition modification appears to be required. Elimination of the breaker points, as the system would enable, would preclude the need for normal breaker point tuneup maintenance. Thus, some money would be saved by use of the device.

5.2.3.6 Driveability and Safety

The developer has tested the device on several vehicles as part of his development effort. He reported that no apparent driveability problems were observed in these tests. Catastrophic failures of the amplifier, photocell, and light could render the vehicle inoperative under hazardous circumstances; therefore, the final design and selection of components and methods of manufacture are critical to safety.

5.2.3.7 Installation Description

Installation of this device consists in installing an amplifier and coil in the ignition system and replacing the rotor, points, and condenser in the distributor with a photocell unit and shadow disc. The adjustment required after installation is to set the ignition timing. Figure 5-6 shows a typical installation.

The developer stated that the complete installation can be accomplished by the average mechanically inclined car owner. The required material would be supplied in a kit with installation instructions included. It would be necessary to buy this kit to fit a specific model automobile and a specific ignition distributor. An alternate method of accomplishing the installation would be to provide a modified distributor in exchange for the distributor from the car.

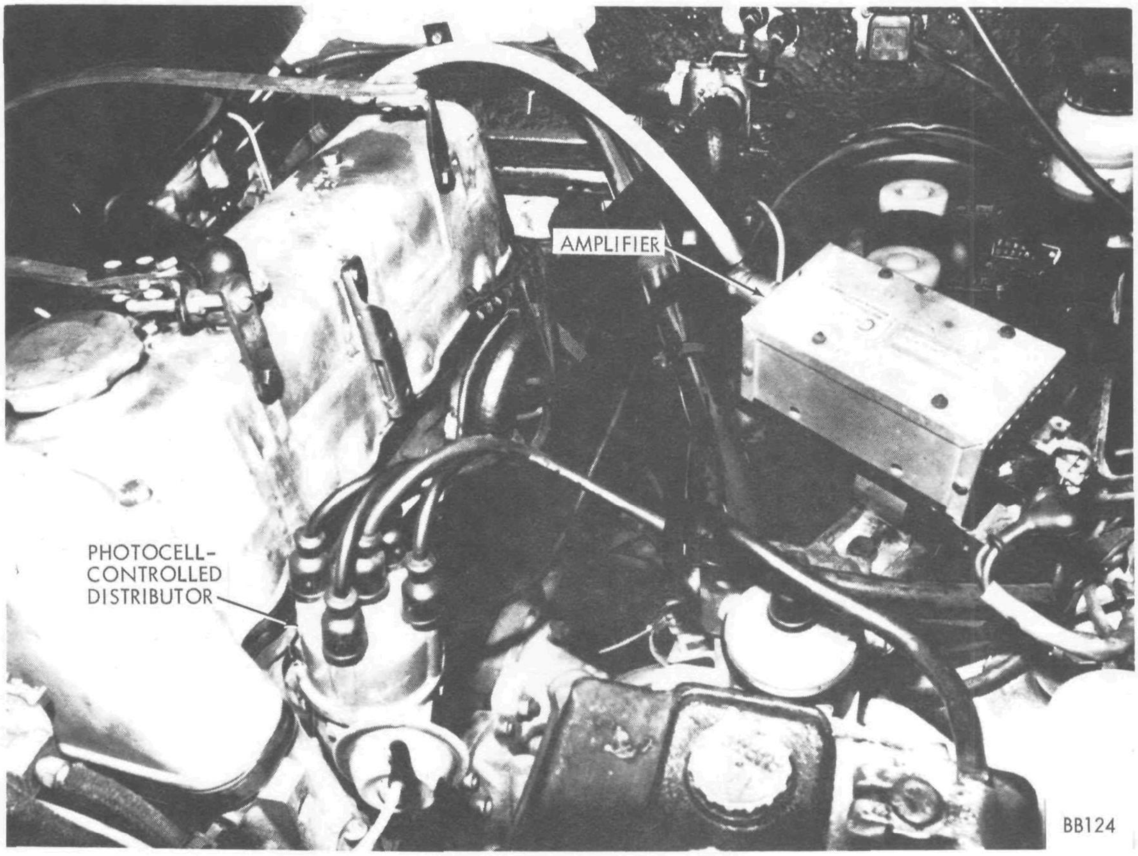


Figure 5-6. DEVICE 259 PHOTOCELL CONTROLLED IGNITION SYSTEM TYPICAL INSTALLATION

The developer estimated one-half hour labor for installation and the cost of material at approximately $50. This installation can be performed at the average service station provided that the kit contains the proper sized parts for the specific ignition distributor installed on the car. No special tools or test equipment are required. Table 5-14 describes the installation procedure.

5.2.3.8 Initial and Recurring Costs

Table 5-15 shows the costs associated with this device. Some recurring cost savings would be obtained, due to the maintenance free operation of the device.

5.2.3.9 Feasibility Summary

Since no test data to substantiate the device's emission reduction capability have been developed, the device's feasibility for emission control purposes is unknown.

Table 5-14. DEVICE 259 PHOTOCELL-CONTROLLED IGNITION SYSTEM INSTALLATION PROCEDURE

MINIMUM AVERAGE SKILL LEVEL: AUTOMOTIVE MECHANIC/STATION ATTENDANT		
INSTALLATION AND ADJUSTMENT PROCEDURE	TOOLS, EQUIPMENT AND FACILITIES	TIME (MIN.)
1. Remove distributor cap, leaving spark plug wires in place.	Hand tools	2
2. Observe position of rotor and remove distributor.	Hand tools	5
3. Replace points and condensor by adapter.	a. Hand tools b. Adapter	5
4. Replace rotor by rotor shadow disc combination.	a. Hand tools b. Rotor shadow disc	2
5. Reinstall distributor observing the same rotor position.	Hand tools	5
6. Replace distributor cap on distributor.	Hand tools	2
7. Fasten the amplifier coil combination in the engine compartment using two sheet metal screws.	a. Hand tools b. Electric drill c. Amplifier and coil combination	3
8. Move spark plug wire from old coil to new coil.		2
9. Connect cable from distributor into amplifier.	Hand tools	2
10. Move plug wire from old coil to amplifier.		2
11. Readjust ignition timing	a. Timing light b. Hand tools	15
	Total Time	0.75 hr

Table 5-15. DEVICE 259 PHOTOCELL-CONTROLLED IGNITION SYSTEM INITIAL AND RECURRING COSTS

ITEM	DESCRIPTION	LABOR HOURS OR ITEM QUANTITY	COST (DOLLARS)
Initial Cost:			
Material 1. Device	a. Amplifier b. Coil c. Adapter d. Shadow disc		50.00
2. Miscellaneous	Sheet metal screws		
Labor 1. Installation	Table 5-14	0.5 hr	6.25
2. Test and adjust	Table 5-14	0.25 hr	3.12
Total Initial Cost			59.37
50,000-Mile Recurring Cost (Savings):(1)			
Material 1. Ignition	Breaker Points (1)	4 pair of ignition breaker points saved by Device 259 @ $3.50/pair	-14.00
Labor 2. Ignition parts	Replace and adjust points (1)	0.5 hr x 4 replacements @ $12.50/hr	-25.00
Total Recurring Cost			-39.00
Total Costs			-20.37

(1) Indicates recurring cost savings due to material/labor no longer required.

5.2.4 Device 268: Capacitive Discharge Ignition

The operational concept of this device, as claimed by the developer, is to provide a higher-than-normal voltage spark so as to improve engine combustion, with resulting benefits in engine power, fuel economy, and lower emissions.

Over 200,000 units of the device have been manufactured for production and retrofit applications.

5.2.4.1 Physical Description

As shown in Figure 5-7, this device consists of an electronic assembly packaged in a 3- by 3- by 6-inch aluminum housing, and a power booster assembly of approximately half that size. The electronic unit weighs approximately 1/2 pound. A pushbutton switch on the side permits selection of either capacitive discharge or conventional ignition.

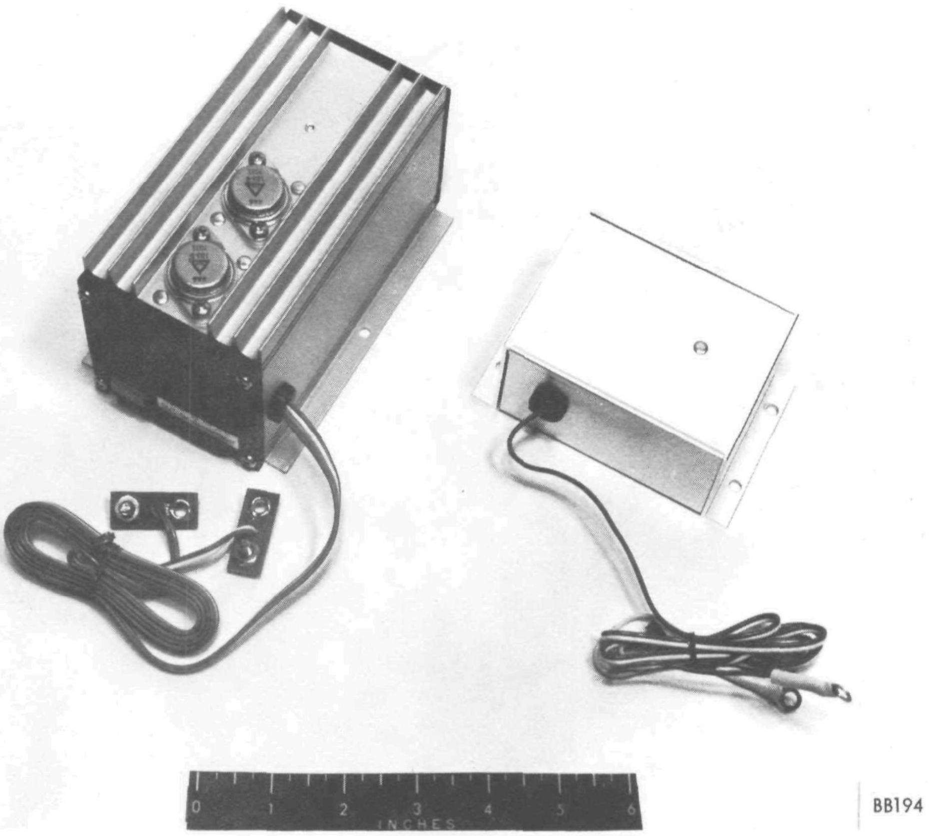


Figure 5-7. DEVICE 268 CAPACITIVE DISCHARGE IGNITION

5.2.4.2 Functional Description

Figure 5-8 shows a basic schematic of the device. Capacitive discharge ignition is obtained by inducing a high voltage in the coil secondary winding by means of a capacitor charged to approximately 200 volts through the coil primary. The capacitor is discharged through a transistor switch whose control voltage is applied by the normal primary signal from the distributor. When the primary points open, control voltage is removed from the transistor switch which causes it to flip closed,

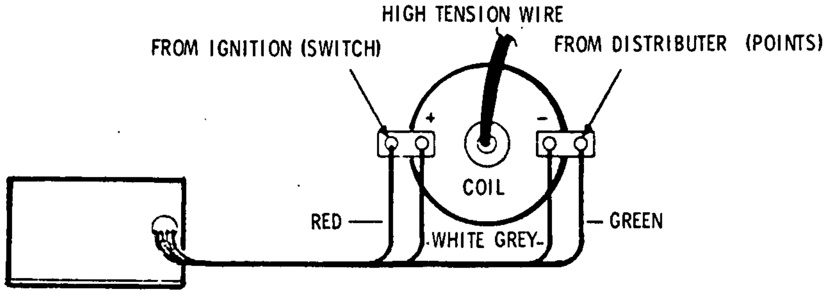


Figure 5-8. DEVICE 268 CAPACITIVE DISCHARGE IGNITION SCHEMATIC (DEVELOPER SKETCH)

permitting the charged capacitor to discharge through the coil primary windings. A short duration, 200-volt spike is delivered to the coil primary, inducing a short high-voltage secondary voltage. The capacitor is recharged during the period the distributor points are closed.

5.2.4.3 Performance Characteristics

This device has been used mainly to improve ignition system operation in higher performance engines. The manufacturer apparently has not determined whether the device is effective for emission control. No data were reported on emission characteristics, driveability, or fuel consumption. Based on electrical principles, a capacitive discharge could provide a more rapid, higher voltage spark than a conventional system.

5.2.4.4 Reliability

The manufacturer estimated minimum device reliability at 250,000 miles failure. The estimate was predicated upon field data and the manufacture and distribution of over 200,000 units. Examination of the device indicated that it contains about 40 standard electronic components and two specifically manufactured for the device: the high voltage transformer and a wire-wound resistor. Provided all components are selected for the use environment, particularly temperature, a 150,000-MMBTF should be achieved with high confidence level.

5.2.4.5 Maintainability

No routine maintenance appears to be required. In the event of system failure, the average motorist or automobile repair shop could remove and replace the system. It is estimated that the removal and replacement could be accomplished in less than 45 minutes. The system has an integral switch to enable the use of the standard ignition if required.

5.2.4.6 Driveability and Safety

Since 200,000 units of the device are in use on automobiles, this device apparently has no adverse driveability effect that is unacceptable. It is not known whether formal driveability tests have been performed. Failure of the system could result in engine failure under potentially hazardous circumstances. It might be considered desirable to install the system bypass switch in or under the dashboard for driver accessibility. No other potential hazards have been identified provided the usual precautions required when working around high voltages are observed during vehicle maintenance.

5.2.4.7 Installation Description

The installation of this device consists in installing the unit on the fender well in the engine compartment away from hot sections of the engine, and connecting four wires. Adjustment of the engine consists in increasing the spark plug gap and re-adjusting the ignition timing at the distributor.

The developer estimated that one-half hour of labor would be required for installation. Table 5-16 itemizes the installation requirements, including tools and special equipment. Installation can be accomplished in a normally equipped repair shop, by the average mechanic or by the vehicle owner.

5.2.4.8 Initial and Recurring Cost

The developer reported that his device is sold through dealers at a retail cost of $59.95. Table 5-17 summarizes the installation costs for this device. From the information available, it is estimated that the cost for installing this device, including material would be $69.32. Since no maintenance is required, the device would have no recurring cost.

5.2.4.9 Feasibility Summary

The ability of this device to reduce HC, CO, or NOx emissions would have to be demonstrated before it could be considered for retrofit use to control vehicle emissions. Except for reducing misfires as distributor points and plugs deteriorate, no mechanism is known by which a stronger spark reduces emissions.

Table 5-16. DEVICE 268 CAPACITIVE DISCHARGE IGNITION INSTALLATION PROCEDURE

MINIMUM AVERAGE SKILL LEVEL: AUTOMOTIVE MECHANIC		
INSTALLATION AND ADJUSTMENT PROCEDURE	TOOLS, EQUIPMENT AND FACILITIES	TIME (MIN.)
1. Install unit in engine compartment on fender wall or other readily accessible location using sheet metal screws, away from hot sections or engine.	a. Electric drill b. Sheet metal screws c. Device assembly d. Hand tools	15
2. Connect four wires	a. Hand tools b. Wire	10
3. Increase spark plug gap for maximum effectiveness, or install new plugs	Hand tools	5
4. Readjust timing at distributor.	Engine analyzer	15
	Total Time	0.75 hr.

Table 5-17. DEVICE 268 CAPACITIVE DISCHARGE IGNITION INITIAL AND RECURRING COSTS (1)

ITEM	DESCRIPTION	LABOR HOURS OR ITEM QUANTITY	COST (DOLLARS)
Initial Cost:			
Material			
1. Device			59.95
2. Miscellaneous	a. Sheet metal screws b. Electric wire		
Labor			
1. Installation	Table 5-16	0.50 hr	6.25
2. Test and adjust	Table 5-16	0.25 hr	3.12
(1) According to the developer this device has no recurring cost.		Total Initial Cost	$69.32

5.2.5 Device 296: Ignition Timing and Spark Modification

According to the developer's data, this device combines longer spark duration with retarded spark timing during acceleration. The retarded timing, which should have the same effect as disconnecting the vacuum advance, allows the use of lower grade gasoline with high compression engines.

5.2.5.1 Physical Description

As shown in Figure 5-9, Device 296 consists of two elements. The solid-state elements mount in the engine compartment away from engine heat. The circuitry is packaged in a plastic case about 2 inches in diameter and 4 inches long. It connects to the ignition system through a four-wire connector which is wired to the distributor, the coil primary circuit, and the battery. The device is wired to intercept the ignition signal from the distributor.

5.2.5.2 Functional Description

Device 296 is a solid-state ignition control which provides a longer than normal pulse to the automobile ignition coil at intervals controlled by the device, and that also controls spark timing in relation to engine rpm. At idle, the pulse to the coil is supplied at the normal time. As rpm increases, the timing pulse is delayed, in effect retarding the spark. The spark timing is then linearly advanced by the device until some point in the mid-rpm range, where the timing becomes the same as it would be without the device.

The system contains a flip-flop circuit with special timing and sensing elements for computing rpm. The circuit calculates the time for maximum combustion timing and delivers a spark of longer duration than the conventional system.

5.2.5.3 Performance Characteristics

Table 5-18 summarizes the results of tests performed on the device by the California Air Resources Board (Reference 86).

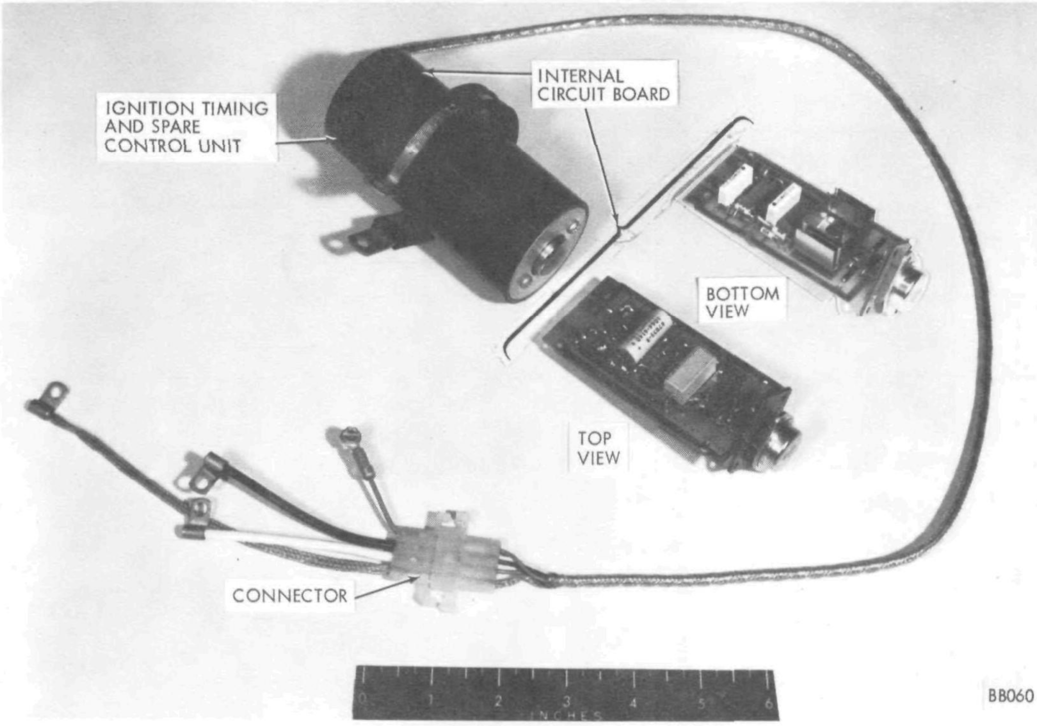
The results indicate that the device has no significant effectiveness in reducing exhaust emissions. The difference in emission values is within the range of normal variation for test results.

5.2.5.4 Reliability

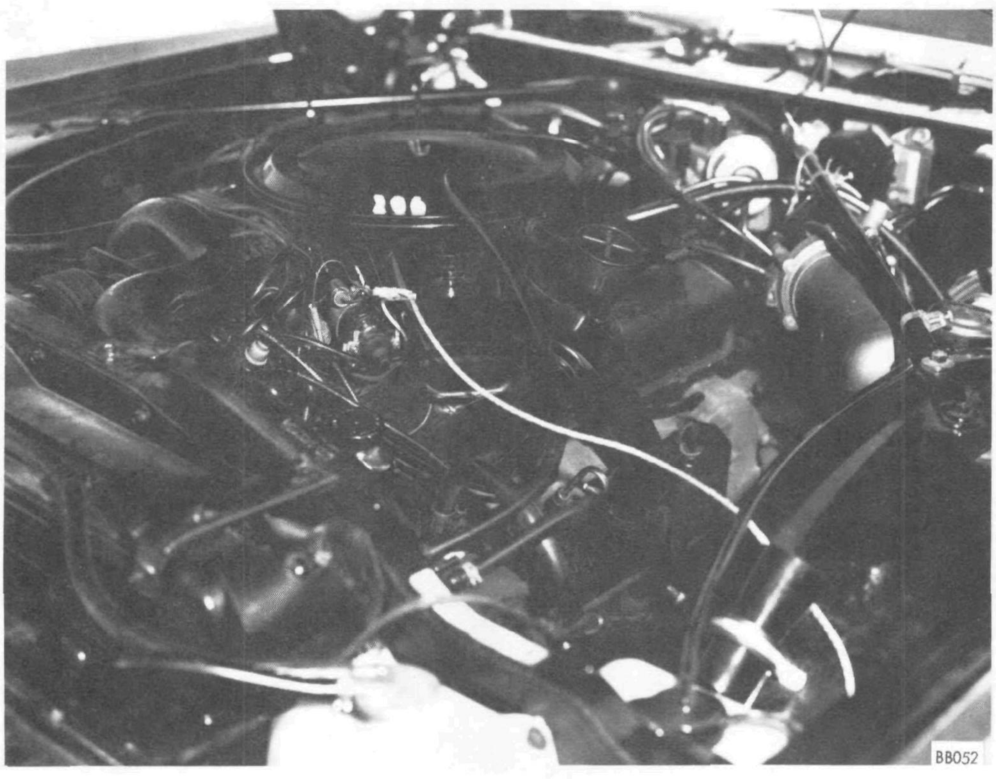
The device appears to contain about 18 standard electronic components, including a semiconductor integrated circuit. Provided all components have been selected for the use environment, particularly temperature, and properly rated in their circuit use, the equivalent mean-miles-before-total-failure would exceed 75,000.

5.2.5.5 Maintainability

No routine maintenance, attributable to the device, is indicated. In the event of device failure, the average motorist or automotive repair shop could remove and replace the device.



(a) Device 296 Components



(b) Device 296 Installation

Figure 5-9. DEVICE 259 IGNITION TIMING AND SPARK MODIFICATION

TABLE 5-18. DEVICE 296 IGNITION TIMING AND SPARK MODIFICATION EMISSION TEST RESULTS REPORTED BY DEVELOPER (REFERENCE 86) (1)

VEHICLE CONFIGURATION (2)	POLLUTANT		
	HC ppm	CO %	NOx ppm
Without Device	196	3.42	279
With Device	180	3.27	290
Percent Reduction	8	4	-4

(1) One hot start, four-cycle California 7-mode test (Reference 41) for each condition.

(2) 1965 Cadillac two-door hardtop, using standard Indolene test fuel, with 429-CID engine.

5.2.5.6 Driveability and Safety

Since the device is being marketed for use on automobiles, it would appear that there are no unacceptable driveability characteristics. The developer reported that the device has no adverse effect on vehicle driveability, but no formal driveability test data were provided. Failure of the device could result in engine failure under hazardous circumstances. It might be considered desirable to install a bypass switch in or under the dashboard for driver accessibility. Fuel costs could be reduced if a change to regular or low-lead gas is made possible by use of the device.

5.2.5.7 Installation Description

The installation of Device 296 consists in mounting the ignition control unit on the fender well in the engine compartment, and connecting the wiring to the coil, battery, points, and ground. It is estimated that installation of the complete system should take about 15 minutes. Table 5-19 shows the installation requirements. Installation can be accomplished in a normally equipped repair shop by the average mechanic.

5.2.5.8 Initial and Recurring Costs

The developer estimated that the cost of the device would be $20. Table 5-20 summarizes the overall costs for this device. From the information available, it is estimated that the cost for installation, including material, would be $23.12. There are apparently no recurring costs.

5.2.5.9 Feasibility Summary

Based on the emission test data results of Table 5-18, it would appear that this device would not be feasible for retrofit control of exhaust emissions; however, more tests would be required to make a conclusive determination as to the effectiveness of the device for a variety of used cars with the device in the optimum emission control configuration.

Table 5-19. DEVICE 296 IGNITION TIMING AND SPARK MODIFICATION INSTALLATION PROCEDURE

MINIMUM AVERAGE SKILL LEVEL: AUTOMOTIVE MECHANIC		
INSTALLATION AND ADJUSTMENT PROCEDURE	TOOLS, EQUIPMENT AND FACILITIES	TIME (MIN.)
1. Install unit in engine compartment on fender wall or other readily accessible location using sheet metal screws, away from hot sections of engine.	a. Electric drill b. Sheet metal screws c. Device d. Hand tools	5
2. Connect wire from unit to battery.	Hand tools	3
3. Connect wire from unit to ground.	Hand tools	2
4. Connect wire from unit to coil.	Hand tools	2
5. Connect wire from unit to points.	Hand tools	3
	Total Time	0.25 hr

Table 5-20. DEVICE 296 IGNITION TIMING AND SPARK MODIFICATION INITIAL AND RECURRING COSTS (1)

ITEM	DESCRIPTION	LABOR HOURS OR ITEM QUANTITY	COST (DOLLARS)
Initial Cost:			
<u>Material</u> 1. Device	Transistor ignition		20.00
2. Miscellaneous	Sheet metal screws		(Included in above)
<u>Labor</u> 1. Installation		0.25	3.12
(1) There are no recurring costs indicated for this device.		Total Initial Cost	23.12

SECTION 6

GROUP 1 RETROFIT METHOD DESCRIPTIONS: TYPE 1.4 - FUEL MODIFICATION

In Sections 3 through 5, descriptions are presented of retrofit exhaust-emission control systems which either act upon the pollutant byproducts of combustion to change their chemical composition to a nonpolluting form, or which modify the combustion process to inhibit the formation of pollutants. Related to the latter is the class of retrofit approaches described in this section. These approaches each use the fuel as the means of controlling exhaust emissions. The intent in each case is to inhibit the formation of pollutants during the combustion event in the engine cylinder and, in some cases, to generate only pollutants of lesser reactivity and hence of lesser photochemical smog potential.

These preventive or inhibitive approaches to exhaust emission control are implemented in the fuel modification retrofit methods studied in one of three ways:

a. By changing the fuel type from gasoline to one which produces fewer, less reactive pollutants.

b. By mixing additives with the gasoline normally used, so as to inhibit pollutant formation.

c. By subjecting the gasoline normally used to an electromagnetic field, with the intent of improving its combustibility and of generating fewer pollutants. This method does not appear to be substantiated; however, it is included to group some devices which refer to it specifically.

These approaches are reflected in the 12 retrofit devices listed in Table 6-1. Each approach defined above constitutes a fuel modification subtype.

6.1 GAS CONVERSION - RETROFIT SUBTYPE 1.4.1

Half of the retrofit approaches studied in the fuel modification category were of the gas conversion type. All but one of these gas conversions were of the gaseous fuel type. The sole liquid fuel conversion was from gasoline to methanol (Device 464).

As discussed in Section 2, two gaseous fuels are being given consideration and study by many agencies as feasible alternatives to gasoline. These fuels are liquified or compressed natural gas (LNG and CNG) and liquified petroleum gas (LPG). These fuels have an inherent advantage over gasoline for reduced emissions, because their chemical composition contains less of the olefinic and aromatic compounds which are key reactivity agents in the formation of smog. They also are capable of being operated at higher air-fuel ratios than gasoline; and, because they are gaseous at normal ambient temperatures, do not produce the high emissions characteristic of gasoline during cold start engine operations (refer to Section 2, paragraph 2.4).

Table 6-1. TYPE 1.4 FUEL MODIFICATION RETROFIT DEVICES

DEVICE NO.	NOMENCLATURE
ALTERNATIVE GAS CONVERSION - SUBTYPE 1.4.1	
52	LPG Conversion
459	LPG Conversion with Deceleration Unit
460	Compressed Natural Gas Dual-Fuel Conversion
461	LPG Conversion with Exhaust Reactor Pulse Air Injection and Exhaust Gas Recirculation
464	Methanol Fuel Conversion with Catalytic Converter
466	LPG-Gasoline Dual Fuel Conversion
FUEL ADDITIVE - SUBTYPE 1.4.2	
182	Fuel and Oil Additives
282	LPG Gas Injection
457	Water Injection
465	Fuel Additive
FUEL CONDITIONER - SUBTYPE 1.4.3	
36	Fuel Conditioning by Exposure to Electromagnetic Field
279	Fuel Conditioner

Thus gaseous fuels, by their chemical composition and physical properties, inherently have combustion byproducts which are less polluting than gasoline. These same characteristics enable the low-emission engine tuneup principles of high air-fuel ratio and spark retard to be used with greater effectiveness in decreasing exhaust gas CO, HC, and NOx. For example, emission tests reported in Reference 26 for CNG and LPG, with the vehicle engine tuned to an air-fuel equivalence ratio of 1.12 (lean) and with no vacuum advance, resulted in CO, HC, and NOx emissions that were less than the limits specified for 1973-74 new model vehicles in Reference 27 (1).

(1) Air-fuel equivalence ratio is equal to the air-fuel ratio of the mixture divided by the stoichiometric air-fuel ratio of the mixture.

While the retrofit approaches previously described used the engine as a means of attaining emission decreases, gaseous fuels enable the other principal component of the fuel-engine emission system - the fuel itself - to be used as a control. As indicated by the retrofit devices described in this section, the combination of both approaches offers lower emission reduction effectiveness, for the reciprocating engine as presently designed, than if used separately.

Besides their emission reduction potential, gaseous fuels appear to have other advantages over gasoline. Both gaseous fuels generally cost less, and their potential for economy of operation has attracted many people to their use, particularly industrial firms with large vehicle fleets, independent of emission reduction consideration. The low cost of natural gas is attributable to the regulation of its well-head price by the Federal Power Commission (Reference 30). Natural gas requires relative little processing for use and one of the products of such processing is propane, the principal constituent of LPG. Besides being a by-product of natural gas refining, propane is also a byproduct of crude oil refining. In California, natural gas sells for 16-19¢ per 100 cubic feet, including road tax, and LPG sells for approximately 25¢ per gallon including State and Federal taxes (Reference 28). (1) In other parts of the country, the price varies.

Further economies resulting from use of gaseous fuels have been claimed both in engine maintenance requirements and in the simplicity of the engine modifications for use of these fuels (Reference 29). Since the fuels are gaseous upon entering the carburetor, there is less possibility of the crankcase oil becoming diluted, as with liquid fuel. During cold start engine operations, liquid fuel is not readily vaporized; hence some of the raw fuel may run past the piston rings into the crankcase, with consequent dilution of the oil contained there. Gaseous fuel, being already vaporized, does not cause this problem. Lacking as many of the heavy hydrocarbons as gasoline, the gaseous fuels also tend to be basically cleaner burning, not causing as much buildup of deposits in the engine. In general, less engine wear is the claim of gaseous fuel advocates. Also, some of the mechanical components required for gasoline engine operation can be removed if a vehicle is converted to run solely on gaseous fuel. Components no longer needed would include the original equipment fuel pump, fuel tank, and carburetor. However, a new fuel tank and carburetor for gaseous fuel conversion must be installed.

These apparent benefits of gaseous fuels tend to be nullified by their objectionable features as retrofit methods. These objectionable features are attributable to a number of factors:

a. The lack of sufficient quantities of gaseous fuels to support their widespread use nationally on a retrofit basis within the near future.

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(1) In 1970, the California Legislature added Section 8657 to the California Revenue and Taxation Code to remove motor fuel tax on motor vehicles modified to use liquified petroleum gas or natural gas and approved by the Air Resources Board as meeting the emission standards set forth in the California Health and Safety Code. The retail costs for CNG and LPG, therefore, would be 9-12¢ per gallon and 19¢ per gallon respectively, based on State road taxes of 7.2¢ and 6¢ per gallon for the two fuels. Since no Federal tax is required on NG, its cost is lower than LPG, which has a 4¢ per gallon Federal tax.

b. The relatively high cost of implementing their use, particularly on a retrofit basis.

c. The requirements for special vehicle fuel tanks by which to contain sufficient quantities of the gases so that vehicles can be operated a reasonable distance without having to refuel.

d. The possibility of having to modify pre-1970 engines to prevent the excessive valve seat wear that could result from the lack of lead in gaseous fuels.

e. The possibility of performance degradation in older engines when converted to a gaseous fuel.

f. The requirement that, once the natural gas and petroleum industries have converted their processing facilities to support a higher demand for gaseous fuel, the automotive industry would have to design engines specifically for gaseous fuels, so as to provide for continued use of these fuels after their need for retrofit use have phased out.

g. Safety problems.

These factors are discussed in the descriptions of gaseous fuel devices which follow.

6.1.1 Device 52: LPG Conversion

Device 52 is in mass production for use on light- and heavy-duty vehicles. The device has been approved by the California Air Resources Board for use as an LPG and dual-fuel (LPG and gasoline) conversion system for light-duty vehicles since 1969 on 1966 and subsequent vehicles (Reference 31). In July 1971, the device was approved for natural gas conversions (Reference 32); and, concurrently, use was extended to include all light and heavy duty vehicles (Reference 33). It is estimated that approximately 350,000 conversions employing the device are in use in California and that 20 percent of these are light duty vehicles (Reference 33).

6.1.1.1 Physical Description

Device 52 is produced in two configurations, one for natural gas or liquified petroleum gas conversions and one for NG or LPG and gasoline conversions.(1) These are the two basic types of gaseous fuel systems. The former is referred to as the single-fuel system and the latter as the dual-fuel system. Incorporating the single-fuel system, a vehicle can run only on natural or liquified petroleum gas. Incorporating the dual-fuel system, a vehicle can run on either the gaseous fuel to which it has been converted, or on gasoline.

Conversions of the single gaseous fuel type incorporate basically the same system components. The physical characteristics of the principal components are described below:

6.1.1.1.1 Fuel Tank. The fuel tank, though its function is simply to store fuel for use by the engine, is the most expensive component of a gaseous fuel system, as shown in paragraph 6.1.1.8. The chief cause of this high cost is that both natural and petroleum gas have to be compressed before enough of either type can be stored on a vehicle to enable it to travel distances comparable to a gasoline fueled vehicle.

To store enough of either gas, it is necessary to compress them to the point where they are in the liquid state.

Storage of liquified petroleum gas is relatively simpler than liquified or compressed natural gas, which is discussed in paragraph 6.1.4. When pressurized, propane the principal constituant of LPG, can be stored as a liquid between -44F, its boiling point, and 206F, beyond which it cannot be liquified under any pressure. Under ambient temperature and at 160 psi, about 35 gallons of LPG can be stored in two tandem tanks, one 12 by 14 by 42 inches and the other 10 by 14 by 42 inches, in a passenger car trunk. This will provide enough LPG fuel to drive about 350 miles. The cost of a tank setup like this is about $165 (Reference 34).

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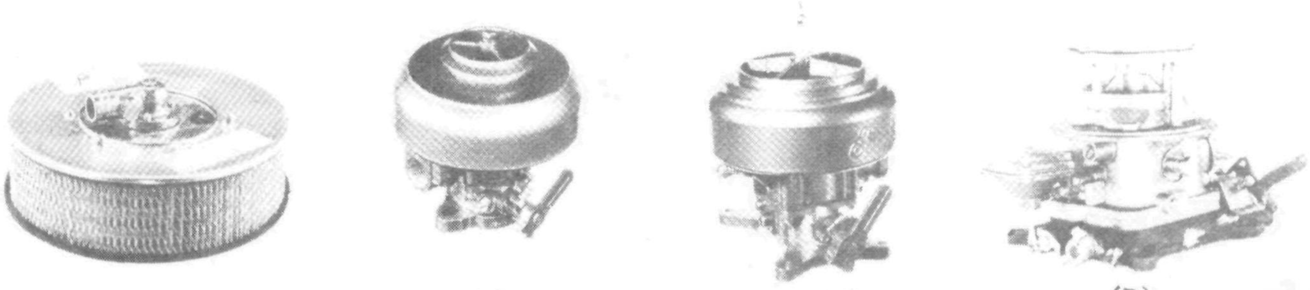
(1) The manufacturer of Device 52 produces all system components but gaseous fuel tanks and interconnecting lines. Gas fuel conversion systems are generally integrated by firms which specialize in system installation, using components from the various manufacturers in the gaseous fuel component field. Device 52 is described as an integrated system so as to examine the overall effectiveness and cost implications of gaseous fuel systems.

LPG tanks are generally constructed of heavy-gauge steel or aluminum. They weigh an average of 3.5-4.5 pounds per gallon capacity. A 35-gallon tank when 80 percent full may weigh 300 pounds even though LPG is lighter than gasoline (4.2 versus 6.5 lb/gal). The tanks incorporate an outage valve to limit filling to 80 percent of tank capacity so that there is room for the liquid to expand should the temperature rise.

6.1.1.1.2 Fuel Filter and Shutoff Valve. This is a combination valve that filters the fuel as it leaves the tank and that stops the flow of fuel when it is not needed.

6.1.1.1.3 Liquid-Gas Converter. This component converts liquified gas back to a gaseous state.

6.1.1.1.4 Carburetor. The carburetor is the principal functional component of a gaseous fuel system. Device 52 incorporates one of four different types of carburetors depending on the type of gas conversion and the cubic inch displacement of the engine. These are shown in Figure 6-1.



(A) (B) (C) (D)

Figure 6-1. DEVICE 52 GASEOUS FUEL CARBURETOR TYPES

The applications of these carburetors are as follows:

a. Type A: Dual-fuel conversions for use of gasoline and LPG or gasoline and NG on engines of 250 CID and over.

b. Type B: LPG conversions on engines of 200-375 CID and under 140 CID.

c. Type C: LPG conversions on engines of 250 CID and over.

d. Type D: LPG conversions on engines of over 300 CID.

6.1.1.2 Functional Description

Figures 6-2 and 6-3 show the system integration of components for representative single- and dual-fuel natural gas or liquified petroleum gas conversions. Except

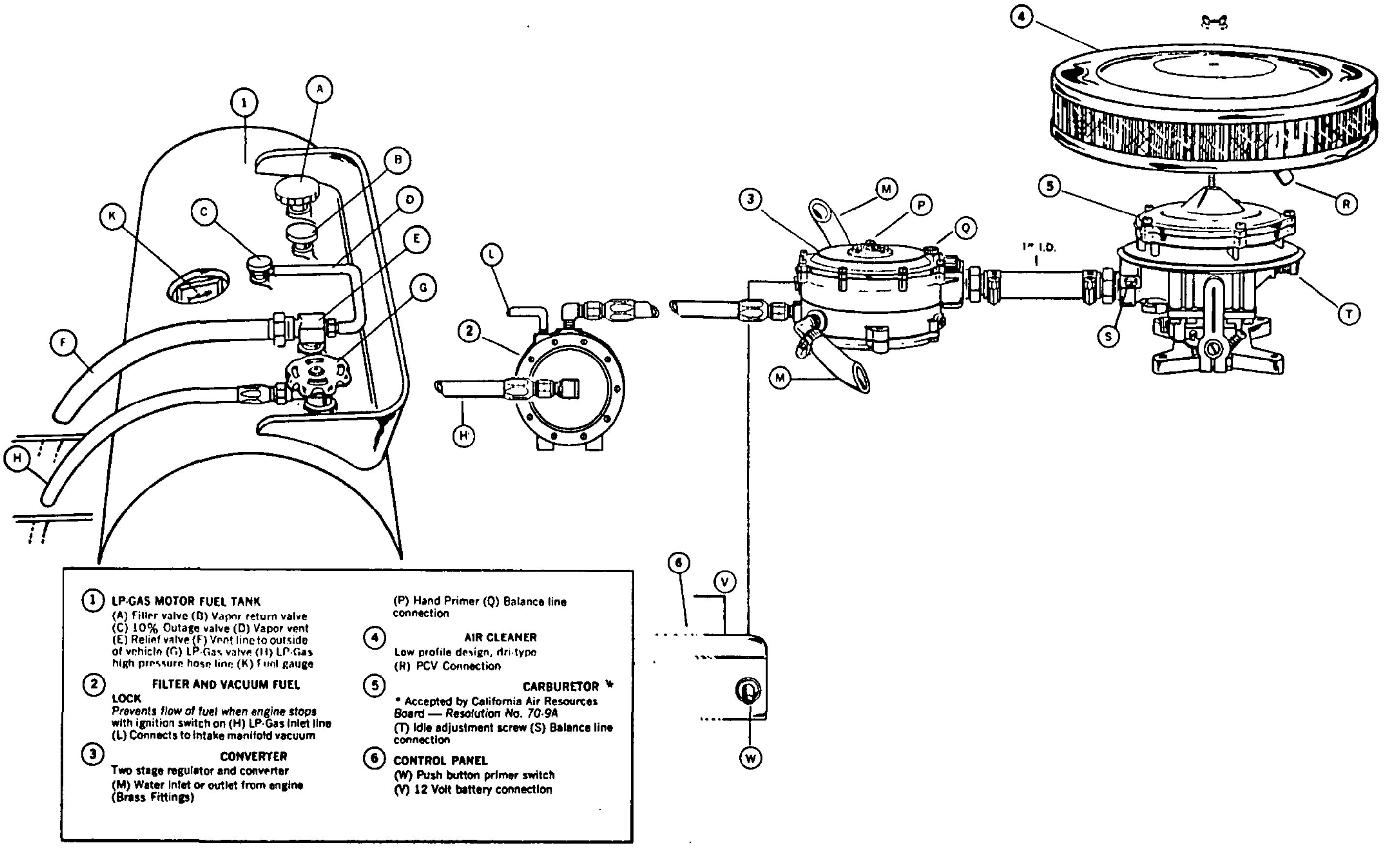


Figure 6-2. DEVICE 52 SINGLE-FUEL SYSTEM DIAGRAM (REFERENCE 35)

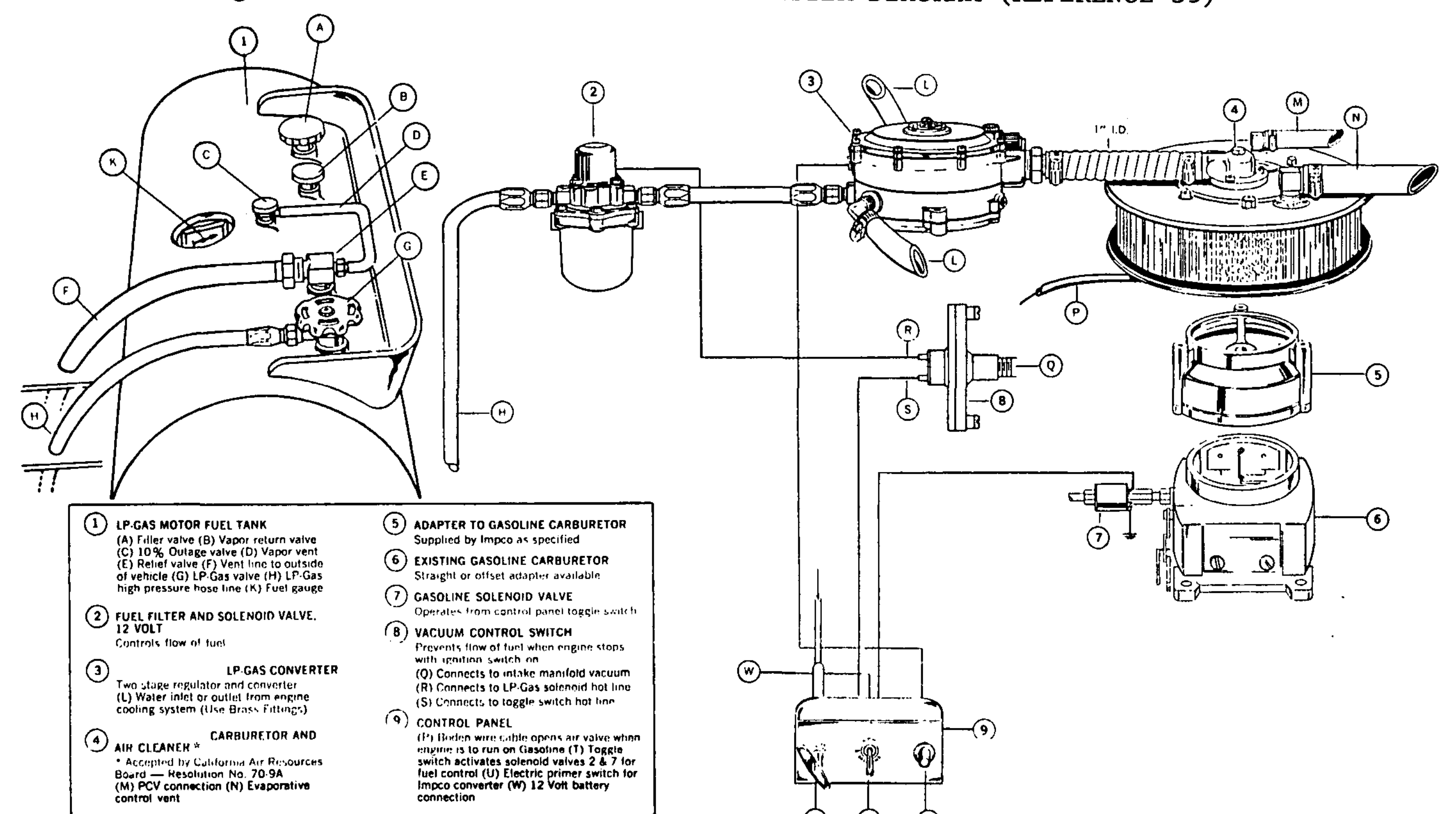


Figure 6-3. DEVICE 52 DUAL-FUEL SYSTEM DIAGRAM (REFERENCE 36)

for the fuel tank differences between the two gases, the systems operate much the same. The boiloff valve required for LNG vaporization due to cryogenic tank heat gain and the outage valve required to limit LPG tank filling are the principal tank differences, other than for physical construction and configuration.

In each case the gaseous fuel is under pressure in the tank. Under this pressure the LPG fuel flows in liquid form through the filter unit.(1) This unit combines two functions. Besides filtering the fuel to remove constaminants, it functions as a fuel lock to prevent fuel flow when the engine is off. In the single-fuel LPG system shown in Figure 6-2, this function is controlled by intake manifold vacuum, such that when there is no vacuum fuel flow is stopped. This prevents the possibility of fire should the ignition switch be left on with the engine stopped or stalled. In the dual-fuel system shown in Figure 6-3, the fuel lock function is controlled by means of the electrically actuated solenoid. This form of fuel lock mechanization is used with the dual-fuel system to facilitate changeover from gaseous to gasoline fuel while the vehicle is in operation.

From the filter, the fuel, still in the compressed and cooled liquid state, flows to the converter in the engine compartment. The converter performs the function of a fuel pump, so on single-fuel conversions the fuel pump can be removed. The converter consists of two diaphragm-actuated valves which, for safety purposes, reduce the pressure of the liquid in stages. As the liquid pressure is reduced, the liquid expands, rapidly absorbing heat, and converts to gaseous form. The necessary heat is provided by circulating hot water through a water jacket in the converter-regulator from the engine cooling system.

As shown in Figure 6-4, fuel enters the high pressure valve at tank pressure as a liquid and is reduced to 1.5 psi in the expansion chambers. Conversion of the liquid fuel to gas occurs in the expansion chambers which are heated by the hot water from the engine. The now gaseous fuel passes through the secondary, or low-pressure valve of the converter where the pressure is reduced slightly below atmospheric. From the low-pressure valve the fuel is drawn off through the regulator gas outlet to the carburetor in proportion to the amount of intake manifold vacuum.

As shown in Figure 6-5, the dual-fuel system functions the same way as the single-fuel system, except that the carburetor for the dual-fuel system mounts on top of the existing gasoline carburetor. With compressed natural gas, the converter is not required, since the fuel is already in a gaseous state. For compressed natural gas, a regulator is used to control the gas supply pressure to the carburetor.

The Device 52 carburetors (Figure 6-1) control the flow of fuel from the converter to the combustion chamber on the basis of the amount of airflow through the carburetor. Figure 6-6 shows the principal parts of a representative carburetor (Figure 6-1, Type C). The only moving parts are the butterfly valve and the combined air measuring valve and air metering valve diaphragm system.

Actuation of the butterfly valve through the accelerator linkage causes air to be drawn into the carburetor under intake manifold vacuum. The air measuring valve is depressed in proportion to the amount of airflow. Since the gas metering valve

(1) Compressed natural gas would be in the gaseous state throughout system flow.

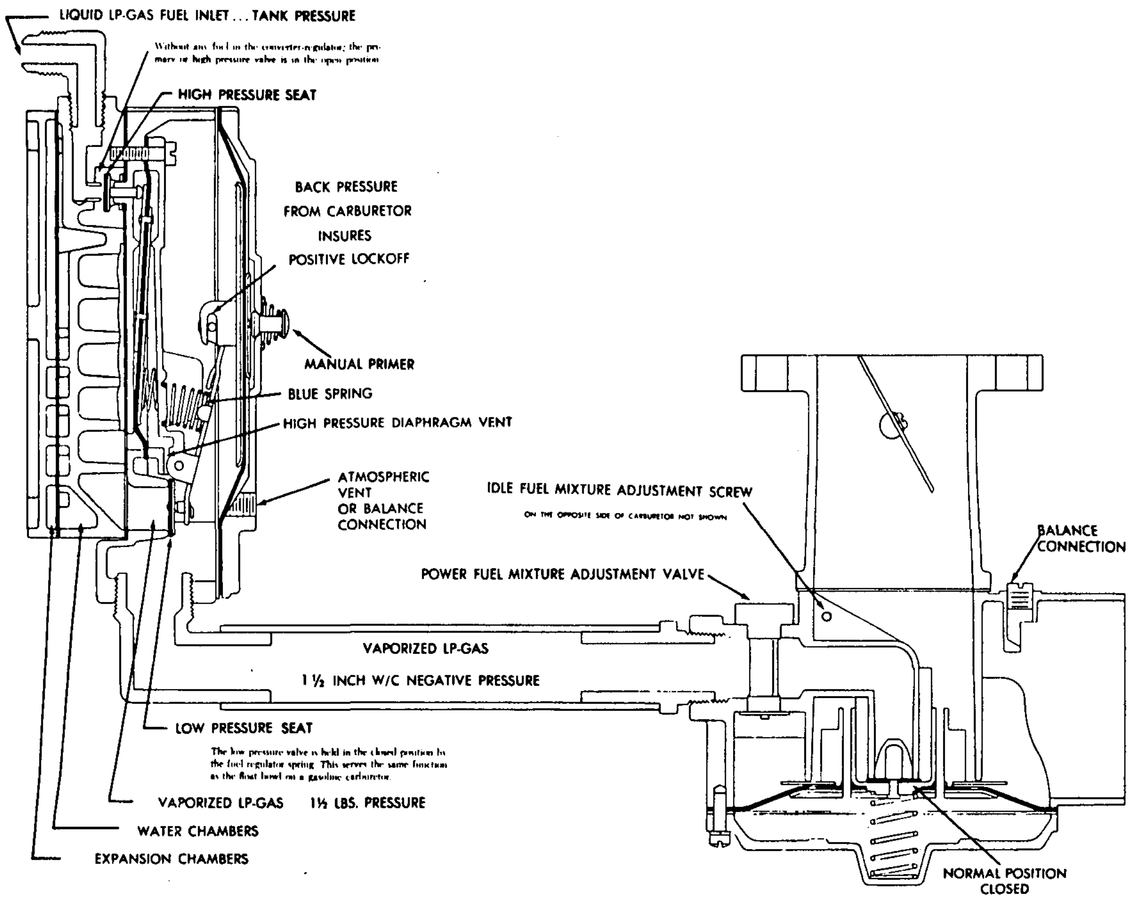


Figure 6-4. DEVICE 52 SINGLE-FUEL SYSTEM CONVERTER AND CARBURETOR DIAGRAM (REFERENCE 37)

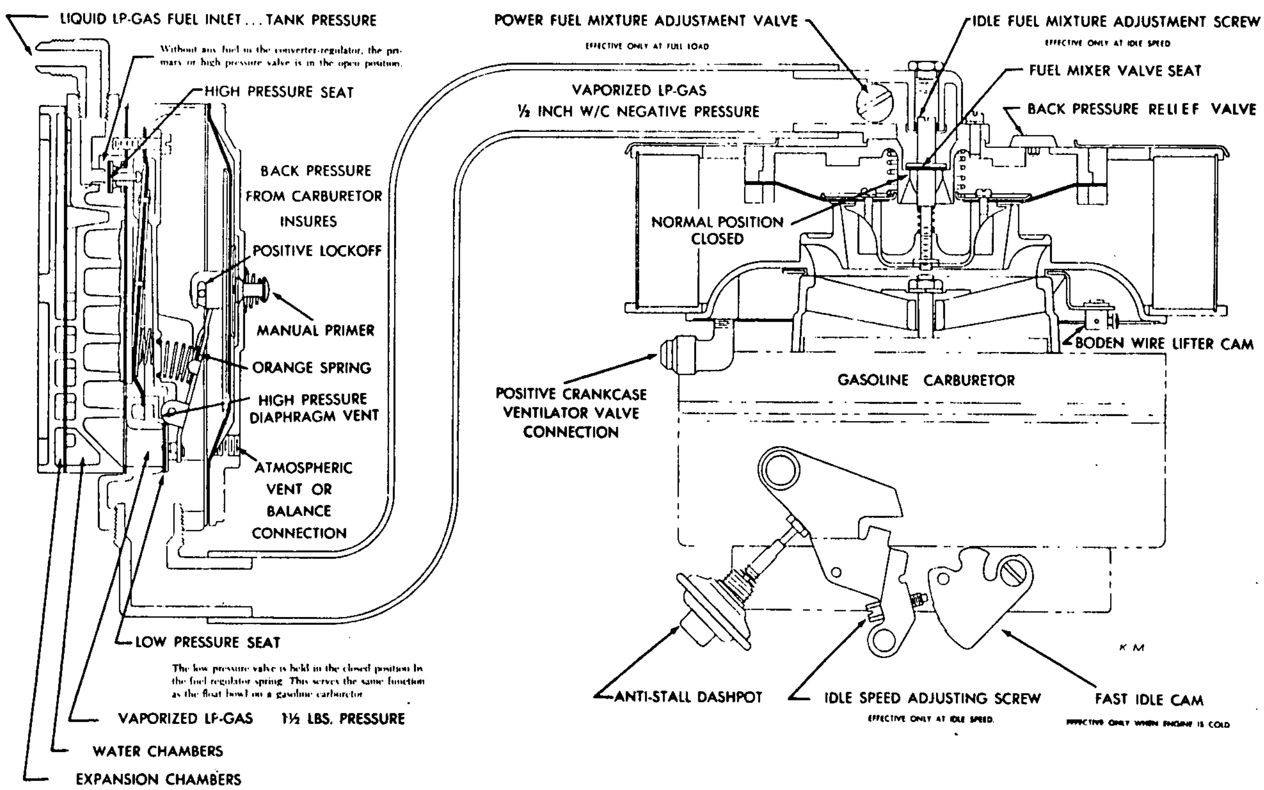


Figure 6-5. DEVICE 52 DUAL-FUEL SYSTEM CONVERTER AND CARBURETOR DIAGRAM (REFERENCE 38)

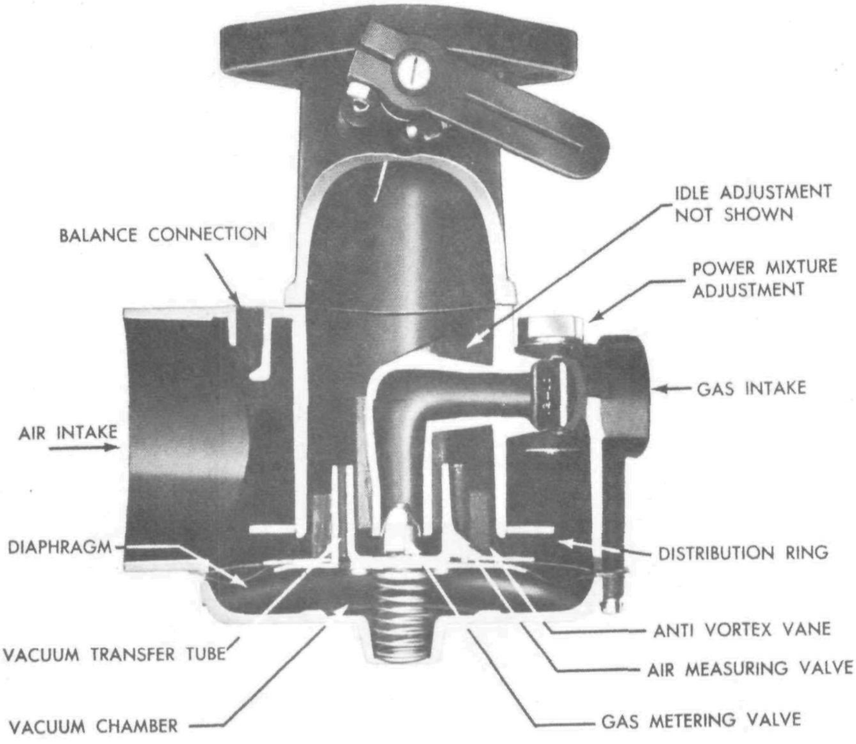


Figure 6-6. DEVICE 52 LPG CONVERSION REPRESENTATIVE CARBURETOR (REFERENCE 37)

is attached directly to the air valve, it opens as the air valve depresses. At maximum depression, the air valve forms a venturi and the air metering valve is completely off its seat in the gas intake circuit. The maximum amount of fuel that can enter this circuit is controlled by the power mixture adjustment, which can only be set at wide open throttle, when the gas metering valve is fully unseated. Adjustment of this valve sets the air-fuel ratio from off-idle through wide open throttle. Air-fuel ratio at idle is set separately through the idle adjustment. The idle adjustment is effective up to approximately 900 rpm, after which the air-fuel ratio determined by the power mixture adjustment becomes effective. In between idle and wide open throttle, the gas metering valve also affects air-fuel ratio, depending on its seating distance. Also the amount of fuel flow past the valve when it is partially restricting flow can be varied by controlling the fuel pressure. The air-fuel mixture can be leaned or richened in this way, particularly between 20 and 70 percent of wide open throttle (Figure 6-7).

One of the advantages of gaseous fuels is that they can be operated at higher air-fuel ratios than gasoline. (1) These higher ratios provide more oxygen for the combustion event, and thus enable more complete combustion, with less CO and HC byproduct. In recent tests of gaseous fuels, an air-fuel ratio of approximately 21:1 was found to be the limit for acceptable driveability (Reference 26). Figure 6-7 shows the air-fuel ratio variations that can be obtained by varying the fuel pressure at the carburetor inlet.

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(1) Lean misfire limits of over 1.5 air-fuel equivalence ratio have been measured for methane and propane, as compared with 1.3 for gasoline (Reference 30).

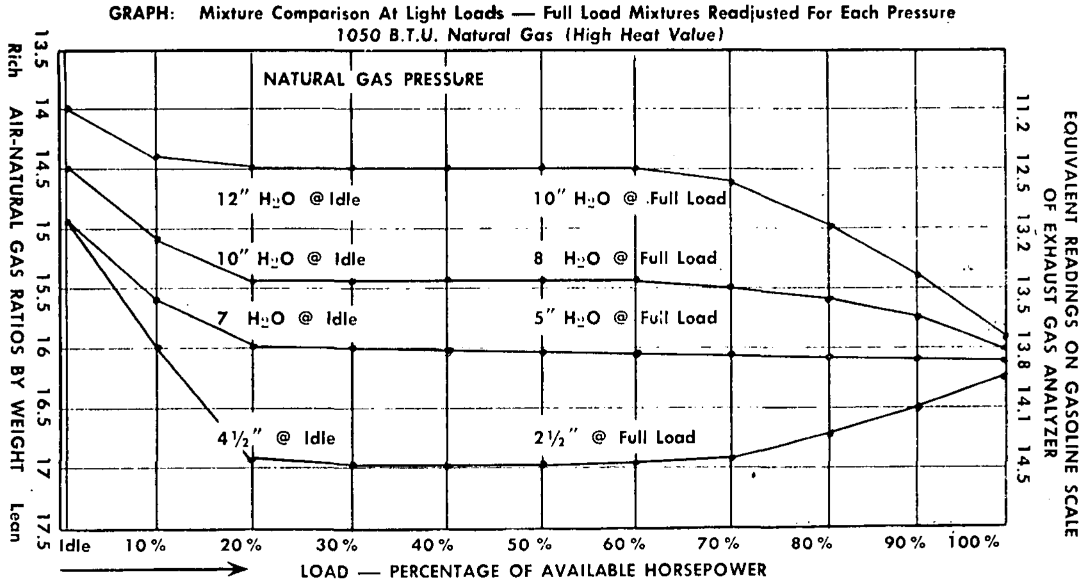


Figure 6-7. DEVICE 52 VARIATION OF AIR-FUEL RATIO WITH FUEL PRESSURE (ENGINE: FORD 352 CID WITH TYPE D - REFERENCE 37)

The carburetor functions of the single and dual-fuel systems shown in Figures 6-4 and 6-5 are basically the same. In the single-fuel carburetor, the air valve is seated by spring pressure when the engine is not operating, closing off the gas intake circuit. In the dual-fuel carburetor, the air valve is held shut by a lock ring (actuated by the Bowden Cable System) to prevent it from opening when the engine is operated off the gasoline carburetor.

Since the fuel enters the carburetor in a gaseous state, no carburetor choke system is required during cold start as with gasoline. The air valve and gas metering valve system admit the fuel mixture in direct proportion to engine demand.

6.1.1.3 Performance Characteristics

Device 52 was tested for emission reduction performance by HEW/NAPCA with single-fuel LPG systems installed on 10 Ford Falcons and 10 American Motors Rebels, all 1970 models, and on a 1968 Buick Skylark (Reference 38 and 39). The tests with the Buick were performed with the engine in its as-received condition. Since the LPG system was already installed on the Buick, it was not possible to obtain baseline emission data.

In addition to having the LPG system installed, the Falcons and Rebels had the distributor vacuum advance disconnected and the ignition timing set at top dead center (TDC) at 600 rpm in drive. The Falcons were further modified to incorporate hardened seat valves. (1) Table 6-3 presents the averages of the emission test results obtained for these vehicles with the 1972 Federal Test Procedure.

(1) As noted in paragraph 6.1.1.4, the reliability of the average engine may decrease when converted from gasoline to gaseous fuel. The valve seats could be affected adversely by this conversion because they are usually manufactured, for the gasoline-fueled engine, out of metal that requires the lead in gasoline as a lubricant to prevent recession of the seat during operation.

Table 6-2. DEVICE 52 LPG CONVERSION EMISSION TEST RESULTS WITH 1968 BUICK SKYLARK (REFERENCE 38) (1)

VEHICLE CONFIGURATION (2)	POLLUTANT (GM/MI)					
	HC		CO		NOx	
	COLD START	HOT START	COLD START	HOT START	COLD START	HOT START
Without Device	(3)	1.92	(3)	29.60	(3)	4.0
With Device	3.45	3.01	4.81	4.70	8.95	7.45

(1) Results obtained using the Federal 7-mode CVS Test Procedure (nine 7-mode cycles). (Reference 16).

(2) 1968 Buick Skylark with automatic transmission and 350-CID engine incorporating Device 52 Type A carburetor.

(3) No data; 1969 Surveillance Fleet Buick Skylark.

Table 6-3. DEVICE 52 LPG CONVERSION EMISSION TEST RESULTS WITH VACUUM ADVANCE DISCONNECT AND RETARDED TIMING ON 1970 FALCONS AND REBELS (REFERENCE 39) (1)

VEHICLE CONFIGURATION (2)	POLLUTANT (GM/MI)					
	HC		CO		NOx	
	FALCONS	REBELS	FALCONS	REBELS	FALCONS	REBELS
Without Device	3.70	2.67	15.99	22.13	9.43	6.85
Average Without	3.18		19.06		8.14	
With Device	0.69	0.51	1.76	3.89	2.59	3.13
Average With	0.60		2.83		2.86	
Percent Reduction	81.1		85.2		64.9	

(1) Averages of 18 tests using the 1972 Federal Test Procedure (Reference 3) and 9 of each vehicle type.

(2a) 1970 Falcon with automatic transmission and 250-CID engine incorporating Device 52 Type B single-fuel LPG carburetor and converter system. Engine timing set for TDC at 600 rpm in drive (from manufacturer's specification of 6 degrees BTDC at 550 rpm in drive) and vacuum advance disconnected.

(2b) 1970 Rebel with automatic transmission and 232-CID engine incorporating same LPG conversion, ignition timing and vacuum advance disconnect as the Falcon (manufacturer's specifications for Rebel ignition timing is 3 degrees BTDC at 550 rpm in drive).

Device 52 also has been tested by the California Air Resources Board, with the results shown in Table 6-4. Table 6-4 indicates that emission reductions with LPG conversions vary substantially from car to car, with no special emission controls other than production controls installed. Table 6-3 indicates that with the combination of LPG,vacuum advance disconnect, and retarded timing, emissions are substantially decreased. This would indicate that the emission reductions are more attributable to engine timing than to LPG. This indication accords with the results of similar tests reported in Reference 26. In the Reference 26 test program, emission levels of approximately 0.8 gm/mi HC, 3 gm/mi CO, and 1.3 gm/mi NOx were obtained with LPG conversions, when the vacuum advance was disconnected and an air-fuel ratio of approximately 17.5:1 was maintained.

Table 6-4. DEVICE 52 EMISSION TEST RESULTS WITH FORD FAIRLANE AND MUSTANG (REFERENCE 40) (1)

VEHICLE CONFIGURATION(2)	POLLUTANT					
	HC (PPM)		CO (%)		NOx (PPM)	
	FAIRLANE	MUSTANG(3)	FAIRLANE	MUSTANG(3)	FAIRLANE	MUSTANG(3)
Without Device	211(4)	256(5)	0.47(4)	0.55(5)	1,131.5(4)	1,565(5)
Average Without	233.5		0.51		1,348	
With Device	181	99	0.93	0.50	1,056.0	1,858
Average With	140		0.72		1,457	
Percent Reduction	40		-41		-7	

(1) Average of results obtained using four 7-mode hot-start cycles (Reference 41), except for Note (3).

(2) One 1968 Fairlane with Device 52. Type A dual-fuel LPG conversion and standard engine modification type exhaust control system; and one 1968 Mustang with Device 52 Type B single-fuel LPG conversion and standard engine modification exhaust control system.

(3) Average of two 7-mode hot-start cycles.

(4) Averages with Basin Mix and Premium gasoline.

(5) Averages with Premium gasoline.

The dependence of LPG emission performance on air-fuel ratio and spark advance is shown by Figure 6-8. This figure is based on emissions data obtained from tests on a 1970 Chevrolet with 350-CID engine, using three hot cycles of the California 7-cycle, 7-mode test procedure (Reference 41). CO is affected only by air-fuel ratio, decreasing as the increase in air enables more complete oxidation of carbon monoxide to carbon dioxide. NOx decreases in proportion to the amount of spark retard. HC tends to increase with leaner air-fuel ratio because of occasional misfire at the leaner fuel mixtures, with consequent dumping of unburned hydrocarbons into the exhaust; however, the magnitude of HC increase is less with less

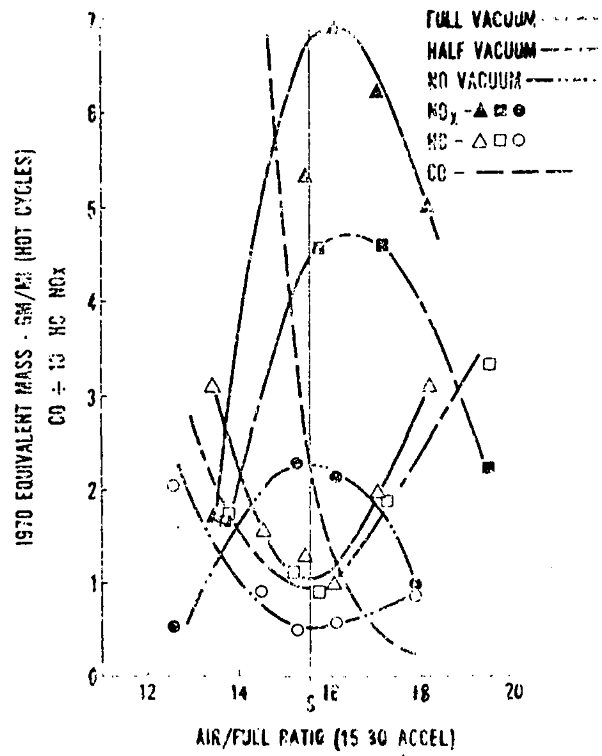


Figure 6-8. EFFECT OF AIR-FUEL RATIO AND SPARK ADVANCE ON LPG EMISSIONS (REFERENCE 41)

spark advance, which provides the higher exhaust temperature necessary to oxidize the unburned HC.

Table 6-2 indicates another performance characteristic of LPG, in the relatively little difference between the cold and hot start emissions. The overall variation between cold and hot start emissions for the three pollutants is approximately 10 percent. This is attributable to the gaseous state of LPG at the time it enters the carburetor. Unlike gasoline, no cold-start enrichment of the air-fuel mixture is required. Thus the mixture remains approximately constant for both cold and hot engine operations. Data obtained in the Reference 26 test program corroborates this indication that the LPG-converted vehicle has a low-emission advantage over a gasoline fueled vehicle during warmup, because no fuel enrichment is required.

The manufacturer of Device 52 has had numerous emission tests performed to qualify his gaseous fuel systems for the California exhaust emission standards. Since 1969, these tests have been performed in accordance with special California procedures for motor vehicles modified to use LPG or natural gas (Reference 45). These procedures are basically the same as the 1970 Federal Test Procedure for gasoline-fueled vehicles, except that for LPG (propane) the following factors are applied to the calculation of the exhaust emissions:

a. Because of the reduced reactivity of propane emissions over those of gasoline, a factor of 0.75 is applied to the measured NDIR hydrocarbon values. This factor is based on the fewer olefin and aromatic compounds present in propane than in gasoline. As noted in Section 2, LPG exhaust emissions are less reactive than those of gasoline because of this difference in chemical composition, and therefore cause less air pollution.

b. Because of the difference between propane and gasoline in their carbon to hydrogen ratios and in their heating values (BTU/lb.), a volume correction factor of 13 is used for propane in the exhaust dilution calculation instead of 14.5 as for gasoline.

c. A deterioration factor of 1.0 is applied.

Using these factors, the Device 52 manufacturer reported emission test data as shown in Table 6-5. The benefit of the revised test procedure by which these data were obtained is shown by comparing the ppm and percent calculations of the Note (3) vehicle with the actual NDIR readings listed in Table 6-4.

Table 6-5. DEVICE 52 LPG CONVERSION EMISSION DATA OBTAINED BY CALIFORNIA GASEOUS FUEL TEST PROCEDURE (REFERENCE 45) (1)

CARBURETOR TYPE	VEHICLE				POLLUTANT					
					HC		CO		NOx	
	YEAR	MAKE	MODEL	CID	GM/MI	PPM	GM/MI	%	GM/MI	PPM
A	1965	Chev	Impala	283	1.20	(2)	10.30	(2)	1.10	(2)
A(3)	1968	Ford	Fairlane	350	1.70	134	20.50	0.86	3.80	970
A	1971	Ford	Pinto	120	0.54	(2)	7.07	(2)	0.85	(2)
	(Same car with gasoline)				1.80		25.96		3.49	
A(4)	1971	Ford	Pinto	120	0.70	(2)	10.90	(2)	1.30	(2)
B	1965	Chev	Impala	283	1.40	(2)	2.30	(2)	0.80	(2)
B	1971	Ford	Pinto	120	0.49	(2)	3.49	(2)	0.79	(2)
C	1965	Chev	Impala	283	1.50	(2)	4.30	(2)	0.60	(2)
C	1965	Olds	88	425	0.90	61	1.50	0.05	1.20	282
C	1965	Olds	88	425	0.83	(2)	1.30	(2)	1.20	(2)
D	1965	Chev	Impala	283	1.50	(2)	7.60	(2)	0.80	(2)
D(5)	1965	Olds	88	425	0.25	(2)	12.60	(2)	1.10	(2)
D	1968	Pont	(2)	400	1.30	99	4.20	0.17	2.00	491
D	1968	Ply	(2)	383	0.80	50	2.50	0.11	1.30	392
D	1969	Chry	(2)	440	1.00	54	6.80	0.26	1.70	392
D	1970	Chev	(2)	350	1.80	148	1.30	0.05	2.10	554

(1) All vehicles were set to manufacturers specifications for spark advance and idle speed, except Note (5). All vehicles except Note (3) had the heat risers disconnected and a 160F thermostat installed. All data obtained by independent test laboratory.

(2) Data not provided by manufacturer.

(3) Same car as in Table 6-4; no special tuning.

(4) With turbocharger.

(5) Spark retarded and 160-degree thermostat installed with heat risers disconnected.

6.1.1.4 Reliability

The reliability of Device 52 depends mainly on the functional integrity of the filter and fuel lock, the converter, and the carburetor. These units (shown in Figures 6-2 and 6-3) have been in use for 15 years as integrated LPG systems, and have indicated high reliability. Under average vehicle use and maintenance, these components have demonstrated reliability of more than 100,000 miles (Reference 34). Device 52 systems have been used on police vehicles in 24-hour continuous patrol service with no failures attributable to the LPG system over a period of 46,681 miles (Reference 29). The vehicles, one 1969 Ford Custom 500 with 428-CID engine and one 1969 Dodge Coronet with 383-CID engine, are still in operation at this date with no failure of the Device 52 Type D single-fuel LPG system having been reported. Device 52 systems are currently in operation with 27,000 continuous hours of failure-free use (Reference 33).

Although the Device 52 system itself has high reliability, the reliability of engines converted to LPG use may be adversely affected if the engine is not in good condition to start with. The device manufacturer has found that a "poorly performing engine converted to propane will only magnify its poor performance" (Reference 42). Engines converted to LPG have been found to run cleaner because of the lack of the deposits which build up on the pistons, rings, valves, and cylinder heads of gasoline-fueled engines. When an older engine with heavy deposits is converted to LPG, it loses these deposits and, if the rings and valves are worn, may also degradate in performance because of an attendant decrease in power (Reference 34).

Engine reliability is also affected by the possible increased wear imposed on valve seats due to use of LPG. As noted in Reference 2, a number of studies have shown that exhaust valve seat wear increases with the removal of lead additives. Leaded fuels apparently provide high-temperature solid-film lubricants, in the form of lead chlorobromide deposits, which reduce this wear. LPG is analogous to unleaded fuel in this respect. With LPG there have been a number of cases in which the valve seats recessed into the engine block (Reference 42). This has occurred mainly on pre-1970 vehicles which were not designed to operate on unleaded fuel (Reference 34). Modification of engines to incorporate harder valve seats is offered as an option with LPG conversions, to prevent seat recession, as noted in paragraph 6.1.1.8.

6.1.1.5 Maintainability

The manufacturer of Device 52 reported that the only maintenance required on the LPG system is periodic inspection and cleaning of the fuel filter. If the propane used conforms to Specification HD-5 (Reference 43), this filter should not have to be replaced. Replacement cost reported by the developer is $2.00. Inspection and cleaning time is approximately 0.25 hour.

Maintenance histories reported by the users of LPG indicate that a substantial amount of money can be saved in vehicle maintenance costs by converting from gasoline to LPG (Reference 46). Because at ambient conditions it is naturally in a gaseous state, LPG is thought to not have the washing effect that gasoline has on the cylinder walls of an engine. If the lubricating oil on the cylinder wall is not continually washed off, then the piston rings, being well lubricated, would be expected to last longer. This is apparently the case with LPG. Furthermore, since the gaseous fuel does not run past the piston rings, as gasoline might, the crankcase oil should not become diluted. Also, since the fuel burns more completely, there is less residue in the form of carbon scale and gum in the combustion chamber to cause engine wear. Thus the combination of cleaner oil, cleaner combustion, and tighter engine should provide longer engine life and less performance degradation with mileage accumulation. Estimates as to how much engine life is increased range from zero to 300 percent (Reference 46).

The maintainability advantages of LPG are documented in a number of reports summarized by the Reference 30 study. In a trial fleet conversion of police vehicles using Device 52, spark plug life was found to be 30,000 miles or more with LPG, compared to an average of 8,000 miles with gasoline, and oil change mileage was upped to 10,000 miles from 3,000 miles (Reference 29). Table 6-6 summarizes the maintenance costs for the gasoline- and LPG-fueled vehicles used in this conversion program.

Table 6-6. DEVICE 52 LPG CONVERSION VEHICLE MAINTENANCE COST COMPARISON (REFERENCE 29)

VEHICLE CONFIGURATION(1)	MILEAGE ACCUMULATED	SERVICE AND REPAIR COSTS	MAINTENANCE COST/MILE
LPG-Fueled	46,681	$63.80	0.136¢/mi
Gas-Fueled	42,980	$221.81	0.516¢/mi

(1) Two 1969 Ford Custom 500's with 428-CID engines and two 1969 Dodge Coronets with 383-CID engines were compared, with one of each type converted to LPG using Device 52 Type D carburetors (shown in Figure 6-1). Each car had a standard police package and automatic transmission, and were run in the same 24-hour patrol service.

These maintainability benefits are corroborated by reports from other LPG fleet operators documented in Reference 46.

6.1.1.6 Driveability and Safety

6.1.1.6.1 Driveability. Driveability tests were performed in both of the HEW/NAPCA tests of Device 52 (References 38 and 39). These two test programs enable a comparison between the driveability of an LPG-converted vehicle that is not tuned for low emissions and converted vehicles that are tuned for low emissions. In the Reference 38 program, the 1968 Buick Skylark tested was representative of the emission levels resulting from a single-fuel conversion from gasoline to LPG. In qualitative tests, the test personnel generally agreed that the driveability of the vehicle was good. In cold-start driveaway tests, the car was considered to be superior to a conventional vehicle. Power loss was insignificant and in cold starts at ambient temperatures below 20F, the car started as well as gasoline-fueled vehicles, even though it was not known whether the engine was in the optimum state of tune for LPG.

The Falcons and Rebels tested in the Reference 39 program had been tuned for low emissions by having the distributor vacuum advance disconnected and the timing set at top dead center. The driveability of these vehicles was substantially degraded. Heavy tip-in and stretchiness problems occurred during acceleration. Some of the vehicles were so sluggish that entrance to expressways could be hazardous. With the spark advanced to 3 degrees BTDC on one Rebel for comparison, substantial improvement in acceleration resulted. Table 6-7 shows the averages obtained in acceleration tests of these vehicles.

Table 6-7. DEVICE 52 LPG CONVERSION ACCELERATION TEST RESULTS WITH SPARK RETARD AND VACUUM ADVANCE DISCONNECTED (REFERENCE 39)

VEHICLE	ACCELERATION (SEC)		
	20-50 MPH	0-60 MPH	50-80 MPH
Falcon (1)	11.4	20.1	31.6
Rebel (1)	11.4	20.0	31.0
Rebel with 3-degree BTDC advance	8.9	17.0	22.9
Gasoline-Fueled Vehicle (2)	9.6	17.9	(3)

(1) Four vehicles tested with LPG conversion and engine tuning as noted in Table 6-3.

(2) This was a 1969 gasoline-fueled Ambassador with 232-CID engine and odometer reading 31,000 miles.

(3) Ignition problem caused car to malfunction.

The 1969 gasoline-fueled Ambassador was tested to obtain acceleration data for comparison. This car was heavier than the Rebel, but it had basically the same 232-CID engine. Even though it had faulty ignition, it performed better than the Rebels. As the results for the Rebel with 3-degree BTDC advance indicate, the driveability problem appears to be attributable to the retarded timing and lack of spark advance rather than to the LPG. This indication was corroborated by driveability tests of a Falcon with the timing advanced to 6 degrees. Advancing the timing helped the overall driveability of the vehicle, but increased HC by 22 percent, CO by 13 percent, and NOx by 35 percent.

One of each type vehicle used in the Reference 39 program was driven under ordinary driving conditions as part of the test organization's vehicle fleet. This was done to check emission reduction, fuel consumption, and comparative performance with mileage accumulation. During 700 miles of operation the Rebel showed no substantial change in emission levels. The Falcon was driven with 6-degree BTDC timing. Fuel consumption results are shown in Table 6-8, compared to gasoline-fueled vehicles of the same type.

Table 6-8. DEVICE 52 LPG CONVERSION FUEL CONSUMPTION COMPARISON

VEHICLE	MILES PER GALLON		PERCENT DECREASE
	LPG	GAS(3)	
Rebel (1)	8.8	20-21	56
Falcon (2)	11.2	19-20	41

(1) With TDC timing and distributor vacuum advance disconnected.

(2) With 6-degree BTDC timing and distributor vacuum advance disconnected.

(3) Manufacturer's advertized mileage per gallon for the same model-year vehicle operating on gasoline (Reference 43).

The amount of fuel mileage decrease shown in Table 6-8 is excessive compared with data from other studies (Reference 29). Since propane has about 27 percent less Btu per gallon than gasoline (83,200 versus 114,500), a propane-fueled vehicle could be expected to consume more propane on a volume basis than it would on gasoline, assuming that the same number of Btu is required. Comparisons of four 1969 light-duty vehicles in the Reference 29 program under the same 24-hour continuous patrol service over more than 42,000 miles resulted in an average fuel consumption of 7.9 miles per gallon for propane and 9.3 miles per gallon for gasoline. This 15 percent loss of gas mileage was offset by an overall 32 percent savings on the fuel costs for propane.

The unusally high LPG fuel consumption reflected in Table 6-8 may be attributable to the retarded spark and vacuum advance disconnect, which degradated vehicle performance. Propane fuel consumption increase over gasoline of approxmately 30 percent was obtained when using retarded spark in the Reference 26 program. Other studies also have indicated that the fuel consumption of a propane fueled engine increases as air-fuel ratio is increased concurrent with retarding of the spark beyond the best fuel and power settings (Reference 30).

6.1.1.6.2 Safety. Device 52, being typical of LPG systems, is subject to the same same concern as to the safety of LPG as any similar device would be. This concern is placed mainly on the possibility of the LPG tank exploding, either from excess pressure buildup or accidental rupture from external cause, and on the threat of gas leakage with the consequent possibility of fire. Propane is odorless as manufactured and is required by safety regulations to be odorized, so as to be traceable in the event of leakage (Reference 47). Since it weighs 50 percent more than air, it settles to low areas or depressions.

The Interstate Commerce Commission has noted that LPG equipment is practically never involved in a fire accident because of failure or rupture of the fuel system (Reference 46). The American Society of Mechanical Engineers' safety code for LPG tanks is 250 psi working pressure and a 5 to 1 burst pressure (Reference 48). Thus a tank would be capable of sustaining 1,250 psi without rupturing. The average LPG tank for a light-duty vehicle, when 80 percent full, operates at approximately 130 psi when the ambient temperature is 80F and at 240 psi when the temperature is 120F (Reference 51).

Although there is no loss of LPG vapor in normal operation, the National Fire Prevention Association requires that tanks located in vehicle trunks be equipped with relief valves and that the passenger area be sealed off from the trunk (Reference 49). Under proposed California regulations, remote filling of the tank from outside the vehicle, with the trunk lid closed, will be required (Reference 50), eliminating the requirement for a sealed trunk.

The usual precautions are necessary when filling the tank, such as adequate ventilation, engine shut off, and no smoking. The vehicle driver should be knowledgeable in the characteristics of propane, refueling steps, and steps to be followed in case of leak or other emergency situations.

6.1.1.7 Installation Description

Conversion of light-duty vehicles for use of LPG is performed as standard practice by a number of companies. Within California such conversions are given the incentive of a 6¢ per gallon road tax refund, if the conversion incorporates a carburetor that is certified to meet the emission standards for the model year vehicle being converted. The plan for future standardization and control of such installations is to place them under the California Highway Patrol, which also is chartered to regulate installation and inspection of vehicle emission control devices (Reference 25).

The installation procedure described in this paragraph is based on the type of installation required for use of LPG to meet emission standards (Reference 34). The installation utilizes Device 52 single-fuel LPG components and complies with LPG conversion emission requirements as specified by California (Reference 50), and the safety requirements of the National Fire Prevention Association (Reference 49).

The basic single-fuel LPG installation procedure for a typical passenger vehicle in the 250-CID and over engine class is itemized in Table 6-9. The principal components identified in this procedure are shown in Figure 6-2. The installation procedure divides broadly into four phases:

a. Pre-conversion engine inspection during which the cylinder pressures are checked to verify that rings and valves are in satisfactory condition.

b. Engine installation of converter and carburetor.

c. Tank installation and hookup.

d. Emission standards compliance test.

Table 6-9. DEVICE 52 LPG CONVERSION INSTALLATION PROCEDURE

MINIMUM AVERAGE SKILL LEVEL: AUTOMOTIVE MECHANIC		
INSTALLATION AND ADJUSTMENT PROCEDURE	TOOLS, EQUIPMENT AND FACILITIES	TIME (MIN.)
1. Remove spark plugs and compression check each cylinder. Note: Vehicle is rejected for conversion if compression of any one cylinder is less than 20 percent from manufacturer's specified compression. To qualify for conversion the engine would have to be reworked as necessary to pass the compression check. If engine is reworked, and is a pre-1970 model, valve seats should be replaced with hardened seats. If engine has exhaust valve rotators on top of valve spring, deactivate.	Pressure gage	20
2. Install new spark plugs, points, and condensor. Check spark plug leads for dielectric breakdown and replace as required.	Hand tools	30
3. Install mounting bracket for converter and fuel filter plus vacuum fuel lock unit on fender well nearest engine cooling lines.	a. Electric drill b. Hand tools	5
4. Install converter and fuel filter plus vacuum fuel lock unit on mounting bracket (tighten all component screws first).	Hand tools	5
5. Install T-fittings in the heater inlet and outlet lines as close to the engine as possible. If unused engine and water pump openings are available, use them.	Hose cutter	5
6. Connect heater water inlet T to the converter's lowest water connection, and connect heater water return T to other converter water connection, using standard heater water hose.	Hose cutter and hand tools	5

Table 6-9. DEVICE 52 LPG CONVERSION INSTALLATION PROCEDURE (CONT)

MINIMUM AVERAGE SKILL LEVEL: AUTOMOTIVE MECHANIC		
INSTALLATION AND ADJUSTMENT PROCEDURE	TOOLS, EQUIPMENT AND FACILITIES	TIME (MIN.)
7. Connect vacuum fuel lock to intake manifold vacuum fitting. Drill and tap hole if necessary.	Hand tools	15
8. Remove existing gasoline carburetor, fuel pump, fuel tank and interconnecting fuel lines. Install cover plate over fuel pump opening.	Hand tools	30
9. Install Type C carburetor adapter on intake manifold, mount carburetor, and hook up throttle linkage.	Hand tools	10
10. Disconnect heat riser and plug automatic choke outlet in exhaust manifold.	Hand tools	5
11. Install 160F thermostat in engine cooling system.		5
12. Remove rear seat and install LPG 35-gallon tandem tank set.	Electric drill and hand tools	60
13. Install LPG fuel gage on instrument panel and interconnect electrical wiring to tank	Hand tools	15
14. Install fiberglass sheeting to seal opening between passenger compartment and trunk. If vehicle is equipped with rear window defrosters or radio speakers, seal these off with fiberglass.	Fiberglass, resin, and brush	45
15. Install stainless-steel wire braid liquid hose between LPG tank gas valve outlet and converter in engine compartment.	Hand tools	15
16. Install vent line between tank relief valve and trunk deck floor.	Electric drill and hand tools	5

Table 6-9. DEVICE 52 LPG CONVERSION INSTALLATION PROCEDURE (CONCL)

MINIMUM AVERAGE SKILL LEVEL: AUTOMOTIVE MECHANIC			
INSTALLATION AND ADJUSTMENT PROCEDURE		TOOLS, EQUIPMENT AND FACILITIES	TIME (MIN.)
17.	Install remote fill line.	Hand tools and drill	30
18.	Install vapor hose between converter low pressure outlet and Type C LPG carburetor.	Hand tools	3
19.	Fill LPG tank with commercial propane to 80 percent gage level and inspect all fittings and lines for leakage.	None required	7
20.	Prime carburetor at converter and start engine. Inspect carburetor, converter and fuel lines for leaks.	None required	5
21.	Set engine timing and idle rpm to manufacturer's specifications.	a. Hand tools b. Engine analyzer	5
22.	Set air-fuel ratio at idle and wide open throttle for lowest emissions.	Engine analyzer	5
23.	Test emissions with vehicle on dynamometer, using one 7-mode cycle in accordance with Reference 45.	a. Chassis dynamometer equipped with power absorption unit and flywheels b. Engine cooling fan c. Exhaust sampling and analytical system.	30
		Total	12 hrs. (6 hr/man)

Figure 6-9 shows a typical Device 52 single-fuel engine conversion and LPG tank installation. This installation would require an automotive mechanic specially trained in LPG carburetors and a mechanic assistant. Average installation time is 12 hours.

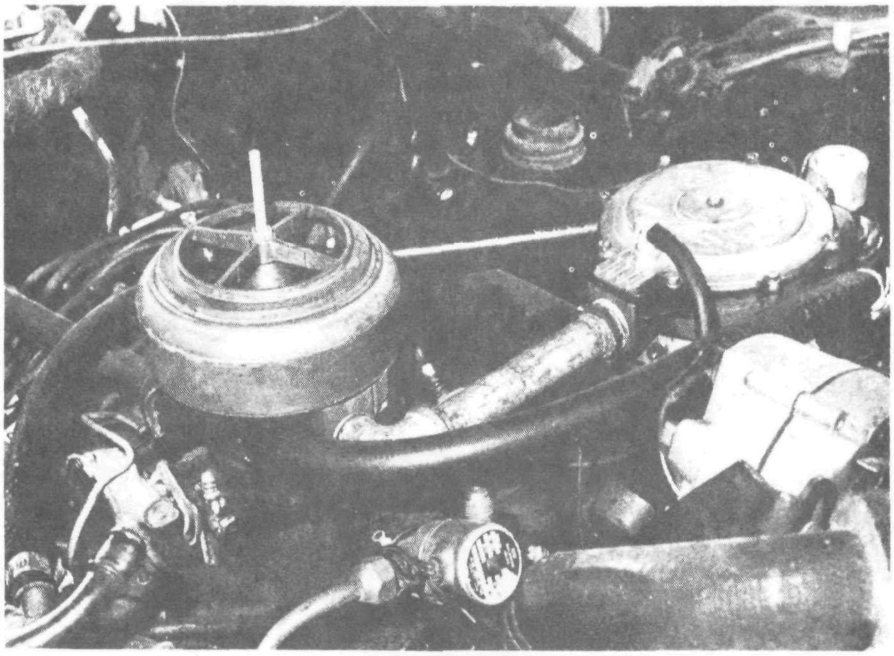
6.1.1.8 Initial and Recurring Costs

Estimates as to the cost of installing a Device 52 LPG system in place of an existing gasoline system range from $300 to over $600 (References 26, 30, and 34). The principal cost factors are the size of the fuel tank and whether the installation is designed to meet safety and emission standards. Other cost variables are the options, such as instrument panel fuel gage and auxiliary fuel outlet valve, that the vehicle owner may desire. The cost of the components and tank making up the most basic LPG conversion kit of minimally reasonable driving range (150 miles) would be more than $300, based on component prices provided by the Device 52 manufacturer and tank prices shown in Reference 46. Labor to install such a kit would cost approximately $150, not including tuneup or any of the special vehicle modifications required for safety.

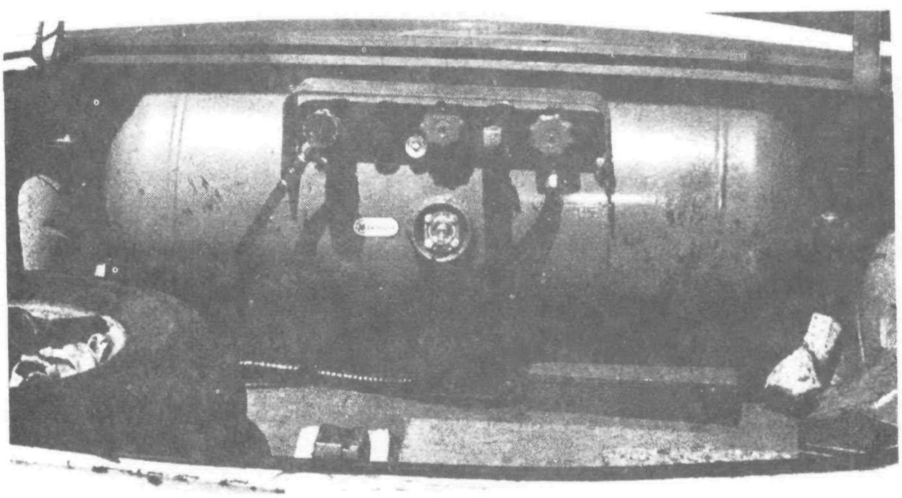
The initial and recurring costs for a complete light-duty vehicle conversion to LPG are shown in Table 6-10. The initial cost of $607.95 is based on the type of installation that would be required to meet the proposed California regulations for gaseous fuel conversions (refer to Table 6-9). That installation is specifically designed to meet the safety requirements of the National Fire Prevention Association and the emission standards for the vehicle model year being converted (References 49, 50, and 51).

The initial cost for such an installation assumes that the engine of the vehicle being converted is in good condition. As with any retrofit method for controlling vehicle emissions, the effectiveness of the retrofit depends on whether the engine's condition is reasonably close to the manufacturer's specification. If the engine required rings and a valve job to qualify for conversion, the initial cost might increase by 50 percent. A minimum requirement for most vehicles would be a tuneup to manufacturer's specifications. This would eliminate the engine as the cause of operating problems immediately after the conversion. For the initial cost estimate shown in Table 6-9, the vehicle engine is assumed to be in the 300- to 375-CID class and the carburetor is assumed to be a Device 52, Type C (Figure 6-1).

Although the initial costs are high, the savings indicated by the reduced fuel and maintenance costs could possibly pay for the initial costs almost 100 percent over 50,000 miles of operation. As shown in the recurring cost estimate of Table 6-10, the savings in operational and maintenance costs over a 50,000 mile period would be $605.26, assuming that a vehicle is maintained to manufacturer's specifications. This would reduce the net initial cost to $5.82.



(a) Engine Compartment with Carburetor (Left) and Converter (Right)



(b) Fuel Tank Installed in Vehicle Trunk

Figure 6-9. DEVICE 52 SINGLE-FUEL LPG INSTALLATION (REFERENCE 52)

Table 6-10. DEVICE 52 LPG CONVERSION INITIAL AND RECURRING COSTS FOR TYPICAL CONVERSION TO MEET EMISSION STANDARDS

ITEM	DESCRIPTION	LABOR HOURS OR ITEM QUANTITY	COST (DOLLARS)
Initial Costs:			
Material			
1. LPG Fuel tank	35-gallon tandem set	1 set	$165.00
2. Fuel filter and lock		1 each	24.95
3. Converter and regulator		1 each	75.00
4. Carburetor and adapter	Type C (Figure 6-1)	1 each	65.00
5. Dash panel fuel gage		1 each	14.00
6. Trunk vent and remote fill line		1 each	40.00
7. Fiberglass	To seal trunk		20.00
8. Hoses, fittings, and brackets	To connect tank, converter, and carburetor		40.00
9. Points and spark plugs		a. 1 set points with condensor b. 8 plugs	3.50 8.00
10. Thermostat	160F		2.50
Labor			
Total labor to install Items 1-10 above and to perform tune-up and emissions test (reference Table 6-9)	Two mechanics,	12 man-hrs at $12.50 per hour	150.00
		Total Initial Costs	607.95

Table 6-10. DEVICE 52 LPG CONVERSION INITIAL AND RECURRING COSTS FOR TYPICAL CONVERSION TO MEET EMISSION STANDARDS (CONT)

ITEM	DESCRIPTION	LABOR HOURS OR ITEM QUANTITY	COST (DOLLARS)
50,000-Mile Recurring Costs: (Estimated savings by converting to LPG)			
Material/Labor Savings (1)			
1. Fuel Savings per 50,000 miles			
Vehicle	MPG Gal/50,000 Mi	$/Gal. Fuel Cost	
Gasoline	12.5 4,000 X	0.35 = 1,400.00	
LPG	10.6 4,717 X	0.22 = 1,037.74	
	Fuel Savings	$362.26	362.26
2. Oil Change Savings Per 50,000 Miles			
Vehicle	MMBM Oil/Filter $/Change (2)	No Changes Cost	
Gasoline	3,000 10.25 X	16 = 164.00	
LPG	10,000 10.25 X	4 = 41.00	
	Oil Change Savings	$123.00	123.00
3. Tuneup Savings Per 50,000 Miles			
Vehicle	MMBM $/Tuneup	No. Tuneups Cost	
Gasoline	8,000 30.00 X	6 = 180.00	
LPG	20,000 30.00 X	2 = 60.00	
		$120.00	120.00
		Estimated Savings	605.26
Labor Expenditure			
1. Fuel Filter	Clean once at 25,000 miles	0.25 hr @ $12.50 per hr	3.13
	ESTIMATED NET SAVINGS		602.13
	Total Initial Costs	607.95	
	Less Net Savings	6-2.13	
		TOTAL COSTS	5.82

(1) Based on the comparison of LPG- and gasoline-fueled light-duty vehicle maintenance requirements reported by the Chandler, Arizona, Police Department (Reference 29).

(2) Eight quarts of oil at 85¢ a quart and one oil filter at $3.50.

The Table 6-10 estimate of recurring cost savings is based on operations and maintenance data reported to the Device 52 manufacturer by the Chandler Arizona Police Department in 1970 (Reference 29). At that time, after approximately 50,000 miles of operation, the LPG-fueled police vehicles had been operating at a 44 percent less dollar-per-mile cost than the gasoline-fueled vehicles ($0.0295 per mile for the gasoline vehicles compared to $0.0165 per mile for the LPG vehicles). The Chandler Police Department reportedly is operating and maintaining a 12-car LPG patrol fleet with the same cost savings (Reference 33).

6.1.1.9 Feasibility Summary

As reported by the National LPG Association, Chicago, Illinois, LPG has been used as a fuel for the internal combustion engine for over 50 years (Reference 53). The Device 52 manufacturer has produced LPG system components for about 15 years, and since 1969 has met California exhaust emission standards for light-duty motor vehicles. Thus the technical feasibility of Device 52 as a means of achieving used vehicle exhaust emission control by retrofitting LPG systems appears adequate. Since it is possible to eliminate the original equipment fuel pump, fuel tank, and emission control accessories such as air pumps and air injection manifolds when converting to a single-fuel LPG system, it is apparent that the basic technical feasibility of Device 52 is considerably enhanced by the simplicity of operation that it could provide. Also there are the indicated benefits of longer engine life,reduced engine maintenance and lower operating costs to be considered. In addition, there is the fact that an LPG system provides control over evaporative emissions, since it is a sealed system, except for the LPG tank relief valve which normally should never operate. Thus the 20 percent of total vehicle hydrocarbon attributable to fuel evaporation is eliminated with an LPG single-fuel system. Furthermore, the emissions that come from the exhaust when using LPG are not as reactive in their capability to produce photochemical smog; hence LPG is inherently less polluting than gasoline.

The obvious technical feasibility of the Device 52 approach to vehicle emissions control does not dismiss equally important economic factors. One is the high initial cost of an LPG conversion and another is whether there would be sufficient LPG fuel available for a major retrofit effort.

The high initial cost of converting a vehicle to LPG, with the objective of reducing emissions, would be a prohibitive expense for the average vehicle owner. The indicated initial cost of a conversion is about one-sixth the price of the average new car, and is about equal to the Blue Book value of pre-1967 vehicles. Even though the recurring cost savings that LPG appears to provide over gasoline could pay back the initial cost, this would be possible only if the converted vehicle is good for another 50,000 miles of operation. Should an older vehicle require major overhaul to qualify for conversion, the initial cost would be that much higher and the payback period would extend correspondingly past 50,000 miles.

To be considered for conversion under any regulated retrofit program it would appear that a vehicle should have been operated less than 50,000 miles. Assuming that such a vehicle had been maintained satisfactorily, it could possibly be converted without major overhaul and operated for another 50,000 miles or, because of the reported LPG benefits, longer. Considering the odometer mileages recorded in the EPA Short Test Cycle Effectiveness Study Program (Reference 17), pre-1968 cars would be ineligible for LPG conversion on this basis. With this model-year as the cutoff point for conversion eligibility, approximately two-thirds of the used car population would be excluded from control by LPG (Reference 54).

Since exhaust emission controls were incorporated on vehicles nationally beginning with the 1968 model year, the use of LPG as a retrofit control becomes a matter of whether LPG is significantly more effective than the factory installed controls. From the emission test data of Tables 6-2, 6-3, and 6-4, it would appear that some retarding of engine timing, along with distributor vacuum advance disconnect, would have to be used in combination with LPG if the exhaust emissions of the controlled baseline vehicle are to be significantly reduced. The specific compromise to be made between emission control and vehicle performance would have to be established for each model year vehicle.

Assuming that all post-1967 vehicles were to be converted to LPG, the availability of fuel would be a factor to consider. Based on LPG carburetor sales over the past 10 years, automobile engines represent about 7 percent of the internal combustion engines equipped to run an LPG (Reference 55). Since engine fuel use of LPG is 7.6 percent of total LPG sales (Reference 30) automobile engines represent about 0.5 percent of the total propane usage. In automobiles, this represents the total of 81,140 which have been converted since 1960 to run on LPG. With propane production predicted to increase 2.5 percent a year through 1980 (Reference 56), approximately 405,700 automobiles could be converted to propane in 1972, if the total production increase of propane for that year were used as automobile fuel. If the 2.5 percent increase in propane were to be continued to be used to supply automobile fuel, an average of approximately 450,000 more converted vehicles could be supplied.each year through 1980. Cumulatively, by 1980 about 4 percent of the total light-duty vehicle population could be operating on propane. As other studies have indicated, propane II-650 would have to become a principal rather than a byproduct of the oil and natural gas industries if all motor vehicles were to be converted (References 30 and 47).

As noted in Reference 50, the supply of LPG may increase as the requirements for leaded gasoline decrease and also as the use of LPG as a chemical feedstock fluctuates with the market price (the higher the price, the more LPG is diverted to the commercial market). With no lead in gasoline the production of propane could be increased approximately 60 percent by 1980; however, this would require $5-10 billion of capital outlay by the oil and natural gas industry, and would increase refinery investment by 40 percent (Reference 30). This would be equivalent to making propane the primary product of the industry, rather than a byproduct. If this were done, the refinery price of propane would almost double (Reference 30), and its present economic benefits would be lost. Based on these considerations, it would appear that a major shift to the use of LPG as a motor vehicle fuel would require an equivalent move in the oil and natural gas industry to increase LPG supply.

Because of its high initial cost and the relatively inadequate LPG fuel supply, it appears that the Device 52 LPG conversion would be more applicable to use on fleet vehicles rather than privately owned cars. Fleet vehicles are generally the ones for which the maximum recurring cost savings could be obtained by conversion to LPG, since they are usually later model vehicles that are maintained and serviced on a controlled schedule. Fleets could be selected for conversion on the basis of climatological conditions affecting air quality, geographical density of vehicle population, number of vehicles and mileage rate of vehicle usage. This would enable the use of LPG either to stay within the predicted 2.5 percent supply growth, or to increase in accordance with planned production growth. Should LPG fuel systems and engines be incorporated in new model vehicles, requiring propane to be produced as a primary product, retrofit applications could then be expanded beyond fleet vehicles.

6.1.2 Device 466: LPG-Gasoline Dual-Fuel Conversion

This device is a production LPG conversion system that is typically used for dual-fuel applications (Reference 58). The carburetor of the system has been accepted by the California Air Resources Board as meeting California emission standards (Reference 65). System information was obtained from HEW/NAPCA emission test reports and by telephone contact with the manufacturer (References 38, 57, and 58).

6.1.2.1 Physical Description

Although a detailed system description was not obtainable within the time frame of the retrofit study program, coordination with the manufacturer indicated that the system configuration is similar to Device 52 (paragraph 6.1.1). The manufacturer produces the system carburetor, converter, and the filter/fuel-lock unit. These components are combined with an LPG fuel tank, fuel lines, and vent valves to form a complete system.

Figure 6-3 is representative of a dual-fuel installation. The Device 466 carburetor mounts on top of the existing gasoline carburetor, as shown for the Device 52 dual-fuel configuration. As with Device 52, Device 466 also can be used in a single-fuel configuration. In this configuration it mounts directly to the intake manifold by means of an adapter.

6.1.2.2 Functional Description

The Device 466 carburetor is controlled under the same patent as Device 52, and operates on the same air valve principle as described in paragraph 6.1.1.2. All other system components function as described in that paragraph.

6.1.2.3 Performance Characteristics

The results of emission tests performed by HEW/NAPCA with Device 466 installed on a 1969 Ford Galaxie are shown in Table 6-11. This vehicle was equipped to run on gasoline, as well as LPG; thus it was possible to obtain comparative emission data, using gasoline as the engine fuel, from the same vehicle. The high CO reduction obtained when using LPG was 85% and the HC reduction was 37% NOx increase. Exhaust hydrocarbon composition by subtractive column analysis showed that the olefin content of the LPG fuel was approximately 30 percent less than that of the gasoline used, whereas the aromatic content was about 50 percent less. The paraffins, however, were 54 percent greater in the LPG fuel. These results accord with the fact that LPG contains less of the highly reactive olefin and aromatic hydrocarbons. The results obtained for the subtractive column analysis of exhaust hydrocarbon composition are presented in Table 6-12.

Table 6-13 presents the results of additional exhaust emission tests performed on Device 466. In these tests seven vehicles were equipped with LPG systems incorporating Device 466 carburetion. The test report (Reference 57) indicates that a Device 466 representative was present to make fuel mixture adjustments. According to the test report, these data indicate the chief advantages of LPG-fueled cars: good control of carbon monoxide, average HC reduction, and average NOx reduction.

Table 6-11. DEVICE 466 LPG GASOLINE DUAL-FUEL CONVERSION EMISSION TEST RESULTS (REFERENCE 38) (1)

VEHICLE CONFIGURATIONS (2)	POLLUTANT (GM/MI)		
	HC	CO	NO_x
Without Device	7.36	37.77	5.2
With Device	2.70	5.59	8.6
Percent Reduction	37	85	-65

(1) Results of one test using CVS 9-cycle, 7-mode test procedure (Reference 16).
(2) 1969 Ford Galaxie with 351-CID engine and automatic transmission.

Table 6-12. DEVICE 466 EXHAUST HYDROCARBON COMPOSITION BY SUBTRACTIVE COLUMN ANALYSIS (REFERENCE 38)

VEHICLE CONFIGURATION	PERCENT OF TOTAL HYDROCARBONS		
	PARAFINS & BENZENES	OLEFINS	AROMATICS
LPG Ford (1)	61.7	26.1	12.2
Gasoline Ford	40.0	36.4	23.6

(1) Averages of data recorded during exhaust emission tests of Table 6-11.

6.1.2.4 Driveability and Safety

Qualitative driveability tests were performed in both the Reference 38 and 57 test programs of Device 466. In the first test program, using a 1969 Ford Galaxie, the test staff generally agreed that driveability was good. Power loss was insignificant. This driveability test was performed without knowing whether the vehicle was tuned for the best performance with LPG.

In the second test program, the vehicles apparently had been tuned for best emission performance. The test report notes that driveability "...was typical of lean operation, with slight hesitation on tip-in, stretchiness on accelerations, and surging during cruise."

Table 6-13. DEVICE 466 EMISSION TEST RESULTS (REFERENCE 57) (1)

VEHICLE CONFIGURATION (5)	POLLUTANT (GM/MI)					
	HC		CO		NOx	
	WITH DEVICE	WITHOUT DEVICE	WITH DEVICE	WITHOUT DEVICE	WITH DEVICE	WITHOUT DEVICE
Ford (2)	2.41	3.12	4.23	28.46	1.78	3.58
Plymouth/Dodge (3)	2.36	3.39	7.20	30.45	2.88	3.63
Rambler Rebel (4)	2.98	3.04	15.36	31.47	2.62	3.08
Average	2.58	3.18	8.93	30.13	2.43	3.43
Percent Reduction	19		70		29	

(1) Results are from 6 tests using 1972 Federal Test Procedure (Reference 3).
(2) One 1968 Ford Ranch Wagon station wagon with 302-CID engine.
(3) Three 1969 Dodge Coronets with 318-CID engine.
(4) Two 1969 Rebel station wagons with 343-CID engines.
(5) All vehicles tested were 4-door and had automatic transmissions. Emission data for gasoline-fueled vehicles of equivalent model year and engine size were used from the existing NAPCA file for comparison.

The device manufacturer stated that driveability of a vehicle equipped with the system is equivalent to the driveability of any vehicle that incorporates exhaust controls capable of meeting emission standards (Reference 58).

The device should have no safety problems if installation procedures similar to those described in paragraph 6.1.1.4 are followed. The manufacturer stated that the safety requirements of the National Fire Prevention Association (Reference 49) are met in all system installations.

6.1.2.5 Reliability

The manufacturer stated that the device has a reliability of several vehicle life times. It is standard practice for vehicle owners to transfer system components from one vehicle to the next as older model vehicles are replaced by newer models.

6.1.2.6 Maintainability

The manufacturer stated that periodic maintenance would be required only on the fuel filter. If HD-5 propane is used, the filter should not have to be cleaned more than once every 25,000 miles.

6.1.2.7 Installation Description

The installation procedure described in paragraph 6.1.1.7 for Device 52 is representative of the Device 466 installation.

6.1.2.8 Initial and Recurring Costs

The manufacturer reported that component costs for a typical installation are basically the same as competing systems. It is assumed therefore that a vehicle conversion using Device 466 to meet California emission standards and installation requirements (References 45 and 50) would have approximately the same initial and recurring costs as summarized in Table 6-10.

6.1.2.9 Feasibility Summary

Device 466 indicates an overall emission reduction of all three pollutants. If the emission data were corrected for exhaust dilution and reactivity factors as provided for in the California gaseous fuel test procedure (Reference 50), the relative effectiveness would be higher. The device is readily obtainable in a production model, and is in use on privately owned and fleet operated vehicles.

As for Device 52, the device appears to be a feasible candidate for retrofit to late-model vehicles, particularly fleet operated vehicles. In this way, the high initial costs of the device would be repaid through the savings in operational and maintenance expenses over the vehicle's service life.

6.1.3 Device 459: LPG Conversion with Deceleration Unit (1)

This device incorporates one of the three LPG carburetors (refer also to Devices 52 and 466) which have been accepted by the California Air Resources Board as meeting California emission standards. The device is in production and the carburetors are obtainable in two accepted models for control of exhaust emissions from light-duty vehicle engines of 300 and over cubic inch displacements.

Evaluation of the device was based on information obtained from the manufacturer and from a HEW/NAPCA exhaust emission test report (References 59, 60 and 66).

6.1.3.1 Physical Description

A typical Device 459 system is shown in Figure 6-10. The carburetor is a single-fuel LPG mixer that mounts on the engine intake manifold in place of the conventional gasoline carburetor. As shown in Figure 6-10, the carburetor operates as part of an overall LPG fuel system much like Device 52 (Figure 6-2). The system components produced by the manufacturer include the converter and the filter/fuel-lock unit. The deceleration device tested by HEW/NAPCA with Device 459 was an auxiliary component not provided by the Device 459 developer (Reference 59).

6.1.3.2 Functional Description

As described in Reference 66, the liquid gas, stored under pressure in an approved tank, flows through high pressure hoses and fittings, a fuel filter and an electric solenoid safety valve, to a vaporizer-regulator heat converter, where the liquid is converted to a vapor in two stages of regulation. From the converter, the vaporized LPG is metered through the carburetor to the engine in accordance with the engine's requirements. When the high pressure liquid is changed to a low pressure vapor the refrigerating action that takes place within the regulator is counteracted by circulating hot water from the engine coolant system through a cavity in the heat exchanger.

As in any LPG system, the carburetor is the key component with respect to emission control. The Device 459 carburetor, shown in Figure 6-11, is of the metering valve type (Reference 47). The carburetor feeds the gaseous fuel into the incoming airflow through a spray bar or ring. The spray bar or ring is located transversely across the carburetor, approximately midway between the intake manifold end of the carburetor and the airflow-control butterfly valve. The amount of fuel flowing through the bar or ring is controlled by a valve located in the fuel inlet line. This fuel-flow valve and the airflow-control butterfly valve within the carburetor are interconnected by means of a drag link. By varying the adjustment on each valve, idle rpm and mid-through-high-range air-fuel ratio are adjusted. Idle air-fuel ratio is adjustable separately, by means of a variable orifice fuel circuit that bypasses the main fuel flow valve.

(1) Device 459 represents an LPG conversion of a vehicle already equipped with a deceleration unit. The developer shown for Device 459 in Volume V, Appendix V-1, is the manufacturer of the LPG system. The details of the deceleration unit are not known.

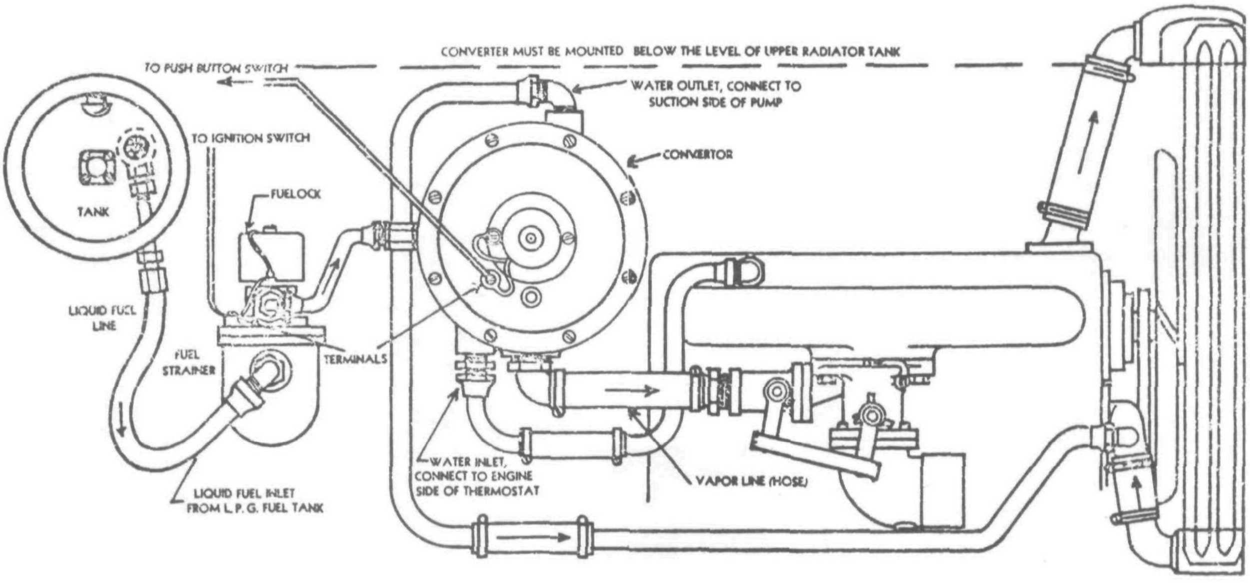


Figure 6-10. DEVICE 459 LPG CONVERSION SYSTEM ILLUSTRATION (REFERENCE 66)

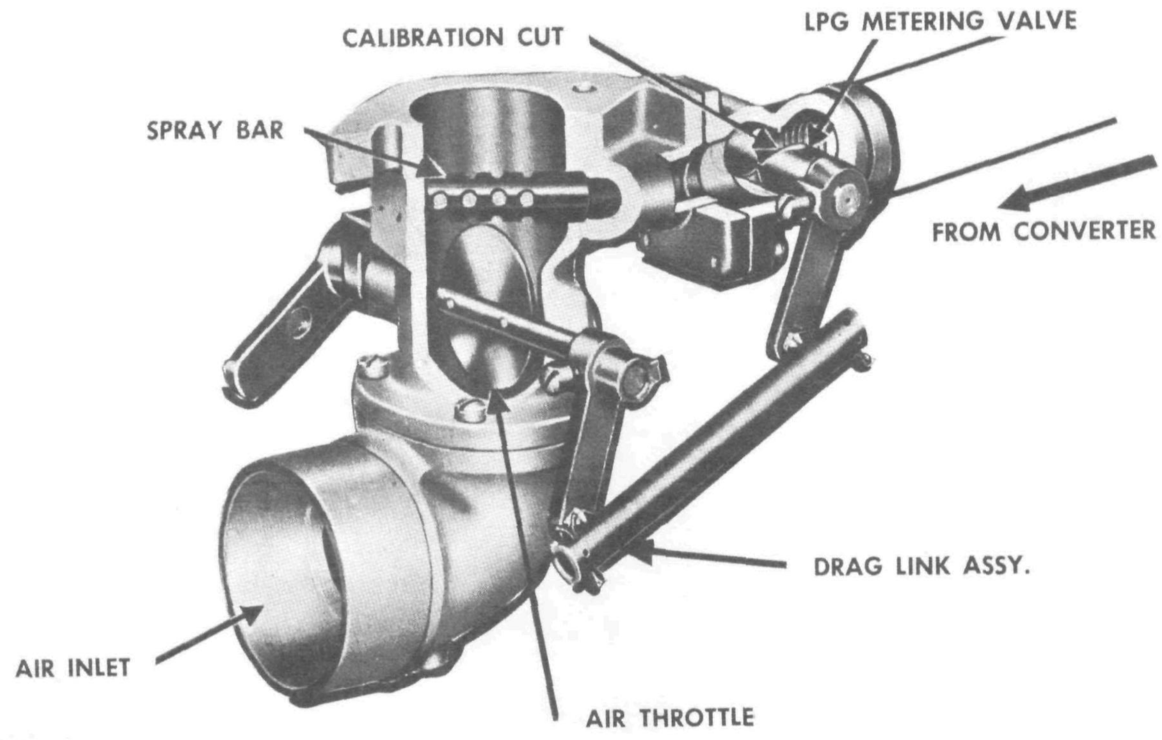


Figure 6-11. DEVICE 459 SINGLE-FUEL AIR VALVE CARBURETOR (REFERENCE 66)

6.1.3.3 Performance Characteristics

The results of NAPCA emission tests on Device 459 are summarized in Table 6-14.

As noted in the NAPCA report, the vehicle tested with Device 459 installed met the 1972 Federal exhaust emission standards for light-duty vehicles (2.9 gm/mi HC, 37.0 gm/mi CO, and 3.0 gm/mi NO_x). The deceleration device was credited with decreasing HC by 20 percent and CO by 6 percent more than the percentage reduction achieved with Device 459 alone.

Table 6-14. DEVICE 459 LPG CONVERSION WITH DECELERATION UNIT EMISSION TEST RESULTS (REFERENCE 60) (1)

VEHICLE CONFIGURATION	POLLUTANT (GM/MI)					
	HC		CO		NOx	
	WITH DECEL	WITHOUT DECEL	WITH DECEL	WITHOUT DECEL	WITH DECEL	WITHOUT DECEL
Test Vehicle (2)	1.04	1.29	3.77	3.99	1.95	1.94

(1) Results based on 1 test using 1972 Federal Test Procedure (Reference 3). No baseline test performed.

(2) 1969 Ford LTD with 429-CID engine and automatic transmission.

6.1.3.4 Reliability

The manufacturer stated that the device's reliability is such that the same components can be used from one model year vehicle to the next. A Device 459 system has been driven 197,000 miles on a 1967 Pontiac with no change in emission reduction effectiveness. Tested in January 1971, under the 1972 Federal Test Procedure, this vehicle had the following grams per mile emission levels:

HC	CO	NOx
1.0	4.8	1.2

6.1.3.5 Maintainability

During the 197,000 miles accumulated on the 1967 Pontiac, the only maintenance performed was periodic tuneup of the engine. It is assumed that an LPG system incorporating Device 459 would require no maintenance other than that described for the typical LPG conversion in paragraph 6.1.1.6. Under this maintenance requirement, the fuel filter would be cleaned at 25,000 miles.

6.1.3.6 Driveability and Safety

The manufacturer stated that driveability of a vehicle is not noticeably degradated when operated with the device. Safety characteristics are equivalent to those of any LPG system (refer to paragraph 6.1.1.4).

6.1.3.7 Installation Description

With installation requirements for the deceleration unit added, the installation described in paragraph 6.1.1.7 is representative of that required for Device 459. The specific installation details of the deceleration unit are not known. The manufacturer reports in Reference 66 that in converting engines from gasoline to LPG, cooling the intake manifold can reduce NOx. Cooling of the intake manifold is accomplished by closing off the manifold heat control valve and wherever possible by placing an insulated plate between the exhaust and intake manifolds. On some manifolds, heating is provided by cast fins which conduct the heat from the exhaust manifold to the intake manifold. By removing or cutting through these fins, cold manifolding is accomplished.

As in the typical installation shown in Figure 6-10, the converter usually is mounted in an upright position below the level of the water in the radiator so as to promote circulation of water. To assure complete circulation at all times, water is taken either from a boss on the cylinder head or the heater hose connection, heat indicator unit, or bypass connection, circulated through the vaporizer regulator water casting, and returned to the suction side of engine coolant pump.

Preferably, the converter is mounted on a vibration-free member such as the fire wall, fender panel or frame. The solenoid valve and filter may be mounted on the regulator or on the fire wall or fender, with connecting hoses. The various components should be mounted so they do not interfere with the normal service items of the vehicle, such as the oil dip stick, battery cell caps, generator and coil.

6.1.3.8 Initial and Recurring Costs

Based on the $70-80 list price reported for the carburetor by the manufacturer the initial purchase price and installation cost of Device 459 would be approximately the same as that shown in Table 6-10 for Device 52. Cost data for the deceleration unit were not reported. It is assumed that the initial costs would be repaid after 50,000 miles of use.

6.1.3.9 Feasibility Summary

By use of Device 459, a 1969 vehicle was controlled to 1972 emission standards. This indicates that the device is an effective emission control method. Its high initial cost however, as appears to be typical of LPG systems, removes it from serious consideration for large scale retrofit to vehicles older than 1968, because the initial investment probably would not be recoverable.

Since the device is marketed in production quantities, it is readily obtainable and appears to be a feasible candidate for retrofit to late-model fleet vehicles. The auxiliary deceleration unit appears to enhance the HC emission reduction capability without degradation of the CO and NOx reduction capability. The extent to which this enhanced emission reduction capability may be canceled by cost would have to be determined before including the deceleration unit as a part of the Device 459 system.

6.1.4 Device 461: LPG Conversion with Exhaust Reactor Pulse Air Injection and Exhaust Gas Recirculation

This device shows the emission reduction attainable when the benefits of LPG are combined with those of exhaust gas oxidation and recirculation.

6.1.4.1 Physical Description

The overall configuration details of this device are not known. It has been tested for emission reduction effectiveness by EPA, installed on a 1971 Oldsmobile Delta 88 (Reference 61). Since the LPG conversion kit was made by the manufacturer of Device 459, the LPG system configuration may be similar that described in paragraph 6.1.3.1.

6.1.4.2 Functional Description

Based on its known performance characteristics, the LPG phase of this emission reduction system, besides providing cleaner burning fuel, would enable higher air-fuel ratios to be achieved with attendantly fewer HC and CO emission byproducts of combustion. The exhaust reactor phase of the system would enable the HC and CO produced during combustion to undergo oxidation to carbon dioxide and water. The exhaust gas recirculation phase would lower the combustion temperature and thereby inhibit NOx formation.

6.1.4.3 Performance Characteristics

The emission test results obtained by EPA are summarized in Table 6-15. As the EPA report notes, if exhaust dilution and reactivity factors for LPG were used in the emission calculations in place of those for gasoline, the HC emission would probably be less. Also the report notes that at the emission levels being measured, the background hydrocarbon levels were quite high on some tests and this may have influenced the levels recorded. The composition of the LPG fuel was not known.

Table 6-15. DEVICE 461 EMISSION TEST RESULTS (REFERENCE 61) (1)

VEHICLE CONFIGURATION	POLLUTANT (GM/MI)		
	HC	CO	NOx
Test Vehicle (2) Baseline Vehicle	0.87 (3)	3.07 (3)	0.30 (3)
% Reduction			

(1) Results from a single test using 1972 Federal Test Procedure (Reference 3)
(2) 1971 Oldsmobile Delta 88
(3) No baseline test performed

6.1.4.4 Reliability

Because of the lack of detailed design data, it was not possible to evaluate the reliability of this device. It is assumed, however, that the reliability would not be less than the reactor reliability. If the reactor is a thermal type, reliability could be expected to exceed 50,000 miles, based on data reported in paragraph 3.2.1.5. Equivalent reliability with a catalytic converter should require clean engine operation (refer to paragraph 3.1.1.5).

6.1.4.5 Maintainability

Assuming that the device incorporates a thermal reactor, the only planned maintenance would be the cleaning of the LPG filter at 25,000 miles, as noted for the typical LPG system described in paragraph 6.1.1.6.

6.1.4.6 Driveability and Safety

The high air-fuel ratios attainable with LPG combined with exhaust gas recirculation could produce driveability characteristics similar to excessively lean fuel carburetion. These characteristics include combustion misfire and stretchiness on accelerating. The EPA report states that after the first test the carburetor was adjusted to improve driveability. Since CO increased on subsequent tests, the adjustment may have been made to reduce a too lean air-fuel mixture. After this adjustment, CO increased 50 percent over the initial reading, although the final average was still only 3.1 gm/mi.

No information on safety was reported.

6.1.4.7 Installation Procedure

Detailed installation procedures for this device are not known. An indication of the installation requirements is provided, however, by the separate installation descriptions provided for reactors in paragraph 3.1.1.7, for LPG in paragraph 6.1.1.7, and for exhaust gas recirculation in paragraph 4.1.2.7. Total installation time is estimated to be approximately 18 hours, using experienced automotive mechanics.

6.1.4.8 Initial and Recurring Costs

Although this device indicates very high emission reduction effectiveness, its cost could be excessive for retrofit use. This excessive cost would be attributable to the combination of LPG, which may cost over $600 (refer to paragraph 6.1.1.8), with a reactor which may cost over $175 (refer to paragraph 3.1.1.8). When the cost of exhaust gas recirculation is added, the benefits accruing from the reduced recurring costs associated with LPG systems would not offset the initial cost enough to make this device acceptable for retrofit use. The initial costs could be over $800.

6.1.4.9 Feasibility Summary

Because of the unusually high initial cost indicated for Device 461, it would appear to be economically infeasible for retrofit applications. These costs are a result of the multiple approaches integrated by the device to achieve high emission reduction effectiveness.

An integrated approach of this type would appear to be more reasonably applied to new motor vehicles, on which the device could be incorporated as a part of the original production configuration.

6.1.5 Device 464: Methanol Fuel Conversion with Catalytic Converter

This device consists of an American Motors Corporation Gremlin modified to run on methanol fuel and with a Device 292 catalytic converter installed. The existence of this device was discovered too late in the retrofit study to make a complete cost and effectiveness evaluation. The following summarizes data obtained from EPA emission tests and from coordination with the Amsco Division of Union Oil Company, a producer of methanol (References 62 and 63).

6.1.5.1 Physical Description

The methanol-fueled vehicle had a 232-CID six-cylinder engine and standard three-speed transmission. The carburetor jets were modified so that the vehicle could operate on methanol. The intake manifold was modified to supply additional heat to the air-fuel mixture. A Device 292 catalytic converter (described in paragraph 3.1.2) was installed in the exhaust system about six inches from the exhaust manifold. (1).

6.1.5.2 Functional Description

The use of methanol as fuel was the fundamental approach used in this method for controlling exhaust emissions. Since methanol is a paraffin hydrocarbon of the methane series, it would inherently be less reactive and therefore less polluting than gasoline. Because it boils at a relatively low temperature (146^{o}F), it would also provide better air-fuel mixing qualities and be more easily convertible to the gaseous state necessary to achieve combustion efficiency. Air-fuel mixing and conversion of the methanol to a gaseous state would be enhanced by the intake manifold modification. The catalytic converter would further oxidize these pollutants downstream of the combustion event.

6.1.5.3 Performance Characteristics

Device 464 was tested by EPA for emission reduction effectiveness using the 1972 Federal Test Procedure and the 7-mode procedure. Additional tests were performed to characterize the chemical composition of the exhaust emissions. Tests were performed with gasoline to establish a baseline with the reactor installed. Tests with methanol as fuel were performed with the catalyst removed, to establish the emission level with methanol only. The emission test results for the 1972 Federal Test Procedure are summarized in Table 6-16.

These results indicate that methanol has better emission reduction effectiveness with the reactor than without, but that gasoline with the reactor is better for HC and CO but not for NOx. Overall, the methanol fuel with reactor comes closer to meeting the 1976 Federal standards of 0.46 gm/mi HC, 47 gm/mi CO, and 0.4 gm/mi NOx. Methanol indicates much better NOx control than gasoline.

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(1) This vehicle was also equipped with an EGR system, which was not operated during the emission tests.

Table 6-16. DEVICE 464 EMISSION TEST RESULTS
(REFERENCE 62)

VEHICLE CONFIGURATION(2)	POLLUTANT (GM/MI)		
	HC	CO	NOx
1. Gasoline Fuel with Reactor (3)	0.34	5.44	4.74
2. Methanol Fuel with Reactor (1)	0.45	6.82	0.24
Percent Reduction over Item 1	-32	-25	95
3. Methanol Fuel without Reactor	1.33	10.8	0.45
Percent Reduction of Item 2	66	37	47
Percent Reduction of Item 1	74	50	-91
Percent Reduction of Item 2	50	16	97

(1) Average of six standard 1972 Federal Tests (Reference 3)
(2) American Motors Corporation Gremlin
(3) One 1972 Federal Test
(4) Calculated by assuming that the percentage reductions of Item 2 over 1 represent the basic percentage differences between gasoline and methanol emissions for the vehicle tested.

The exhaust composition tests (reference 62) indicated that methanol constitutes 95 percent of the pollutants being emitted from the exhaust with methanol as fuel. This indicates that with methanol as fuel, photochemical smog attributable to vehicle exhaust emissions would be practically eliminated. The composition tests also indicated that the catalytic reactor mainly decreases exhaust emissions of methanol (90 percent) and CO (70 percent), but has relatively no effect on NOx. Therefore, the large reduction of NOx shown for Item 2 of Table 6-16 appears to be attributable to the methanol itself.

6.1.5.4 Reliability

The effects of methanol on engine life were not noted in Reference 62. Since methanol contains no lead, it would eliminate the problem of converter catalyst degradation which occurs with leaded gasoline.

6.1.5.5 Maintainability

Assuming that methanol does not adversely affect engine components, or catalyst life, there should be no special maintenance required for Device 464.

6.1.5.6 Driveability and Safety

Since the test vehicle, as modified, was the winner of the Liquid Fuel Division of the 1970 Clean Air Race, methanol apparently has satisfactory driveability characteristics. Being a poisonous chemical, however, methanol in widespread use might present safety problems. The toxic effects of methanol inhalation by humans and animals were not investigated.

6.1.5.7 Installation Description

The installation of Device 464 requires a carburetor modification and catalytic converter installation. The latter is described in paragraph 3.1.2.7 for the Device 292 converter used in the test vehicle. The carburetor modification could be accomplished in accordance with standard carburetor overhaul kit procedures. The total installation time is estimated to be 3.5 hours, adding the converter time of 1 hour (Table 3-12) to the carburetor modification and tuning time of 2.5 hours.

The specific modification made to increase intake manifold heat is not known, and therefore is not included in the installation time estimate.

6.1.5.8 Initial and Recurring Costs

Initial and recurring costs for the Device 292 catalytic converter were estimated to be between $75 and $85 (see Table 3-13 for assumptions). If only one converter were required then costs would be approximately $40. (1)

The lower cost per gallon of methanol over gasoline could reduce the recurring costs assuming that fuel consumption with methanol would be equivalent to gasoline. In bulk quantities of over 6,000 gallons, methanol can be bought for 18.5¢ a gallon (Reference 63). If State and Federal taxes were added, the cost per gallon would be approximately 28.5¢.

(1) The specific cost of converting an engine to run on methanol is not known.

6.1.5.9 Feasibility Summary

Methanol as vehicle fuel indicates effective NOx reduction and, when combined with a catalytic converter, is also effective for HC control along with relatively smaller decrease of CO. Methanol would eliminate the lead contamination problem associated with the gasoline-and-catalytic-converter emission control combination. The effect of methanol on engine life, particularly that of older engines, would have to be determined first. For some limited application, the existing supply of methanol may be adequate, although this was not verified as part of the retrofit study.

The overall determination of the feasibility of methanol as a motor vehicle fuel would have to include consideration of its toxic effects on human and animal life.

6.1.6 Device 460: Compressed Natural Gas Dual-Fuel Conversion

This device is in production, and is the natural gas version of Device 52, which was described for LPG applications in paragraph 6.1.1. The device has been accepted by the California Air Resources Board as meeting California emissions standards, and is eligible for State road tax refund on natural gas of 7¢ per gallon (Reference 32). The following summary description of the device is based on data obtained from the Device 52 manufacturer and from an EPA test report (Reference 67).

6.1.6.1 Physical Description

A typical compressed natural gas (CNG) dual fuel system consists of the following components (Reference 46):

a. Carburetor

b. Adapter for gasoline carburetor

c. Regulator - low pressure

d. Regulator - high pressure

e. Gasoline solenoid valve

f. CNG solenoid valve

g. Check valve (excess flow valve)

h. Hoses and fittings

The CNG fuel is stored in Department of Transportation Specification 3AA approved tanks of the same type used for welding or oxygen supply (Reference 68). Fuel pressure is usually about 2,250 psi. The fuel line connects the cylinders to the gas regulators installed in the engine compartment. Shutoff solenoids are installed in the gaseous fuel line and in the gasoline line.

The carburetor is a gas-air mixer similar to Device 52 Type A (refer to Figure 6-1). The mixer unit mounts inside a standard dry-paper air cleaner, and is mated to the top of the existing gasoline carburetor by means of an adapter. The mixer can be turned off from the driver's position by means of a cable control that runs between the dash panel and the mixer.

A complete conversion kit includes all components, interconnecting hoses, brackets, and clamps. The main variation among installations is in the size and number of tanks and the adapter for the gasoline carburetor. The range of tanks available is shown in Table 6-17.

Table 6-17. COMPRESSED NATURAL GAS TANK CHARACTERISTICS (REFERENCE 46)

Capacity (standard cubic feet)	@	Fill Pressure (psi)	Size (less valve) Diam. x Length	Weight (lbs.)	Cost
375	@	2400	9½" x 55"	135	$83.27
325	@	2400	10" x 43"	108	111.58
312	@	2265	9¼" x 51"	120	75.57
85	@	2250	7" x 24"	27	42.92
303	@	2400	10" x 40"	?	less than 111.58
?	@	2400	10" x 37"	?	less than 111.58

6.1.6.2 Functional Description

The principal functional component of the CNG dual-fuel system is the mixer, which mounts on the gasoline carburetor intake as a replacement for the production air cleaner. The mixer can be supplied with natural gas through a system of regulators and valves from either pressure cylinders or liquefied natural gas tankage - in the latter case, a heat exchanger would be required to vaporize the natural gas (Reference 69). No internal engine modifications are required. Spark timing is usually readjusted slightly to obtain minimum exhaust emissions during both natural gas and gasoline operation.

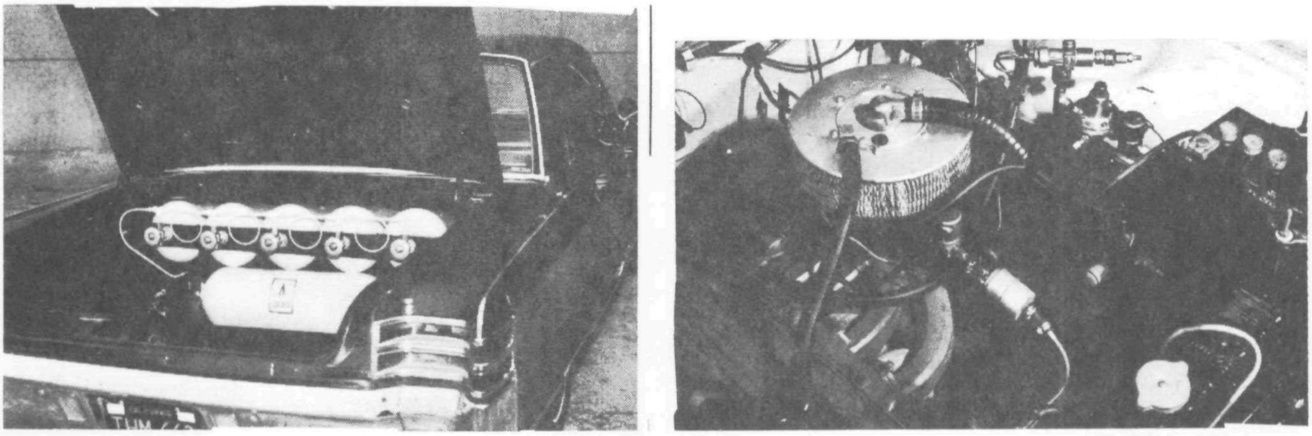
As for the Device 52 carburetor described in paragraph 6.1.1.2, the CNG carburetor operates on the diaphragm controlled, variable venturi principle. It meters the required quantity of natural gas into the carburetor air stream over the full range of engine airflow demands. The one Device 52 model covers the full range of engine sizes. The adjustment procedure is the same for all engine sizes and consists of two steps (Reference 69):

a. Adjust the final pressure regulator to deliver natural gas at a pressure between ± 0.5 inch of water when the engine is operating under a light load.

b. Adjust the mixer idle screw to the lean drop-off point.

At these settings, the carburetor maintains a lean mixture with approximately 25 percent excess air.

The gasoline carburetor functions when the mixer is placed in the "gasoline" configuration. This is accomplished by pulling the Bowden cable control on the vehicle dash. Electrical selection of the proper fuel is coordinated with the mixer cable control, through the solenoids in the CNG and gasoline fuel lines.



(a) CNG Tank Set (b) CNG Carburetor

Figure 6-12. DEVICE 460 COMPRESSED NATURAL GAS DUAL FUEL CONVERSION SYSTEM INSTALLED ON A CHRYSLER NEW YORKER (REFERENCE 68)

A photograph of the operator controls is shown in Figure 6-13. A gauge monitors fuel tank pressure and a pilot lamp flashes on when switching modes of operation. Operations such as starting, stopping, and accelerating, are the same whether operating on gasoline or CNG. Filling of the CNG tanks is accomplished from a gas-storage facility. The CNG fill-valve is located in the vehicle's engine compartment for handling ease and safety reasons (Reference 103).

Figure 6-14 shows the functional flow of a typical CNG-gasoline dual-fuel system. The CNG flows from the tanks through the regulators and the gas-air mixer into the carburetor. The two stages of regulation reduce fuel pressure to 55 psig and finally to 0.7 psig before the gas is admitted to the mixer.

Since enough CNG cannot be compressed to operate a vehicle over extended distances, the dual-fuel system is frequently used so that the vehicle can proceed on gasoline when the CNG is expended. Under the extremely low temperatures and vacuums obtainable with cryogenic techniques, natural gas can be liquified. In this state, enough natural gas can be stored in a 15-to-20 gallon tank to operate a vehicle for the distances possible with gasoline. The special vacuum wall tanks required to store liquified natural gas at the required low temperatures (between -258.8 and -116F) presently sell for about $400 (Reference 30).

Natural gas is more frequently stored in the compressed gaseous state, in high-pressure steel cylinders like those used for storing other compressed gases. In these bottles, natural gas can be stored at ambient temperatures; however, the amount of gas that can be compressed in one of these bottles, even at 2,200 psi, is only equivalent to about 3 gallons of gasoline. Thus more than one cylinder is required. Since each one weighs 130 pounds when full (about the same as a full gasoline tank), and occupies over 2 cubic feet of space, most of the trunk space of a passenger vehicle is required to store compressed gas to drive 100 miles.

Figure 6-12 shows a typical set of CNG tanks installed in a vehicle. The six tanks store enough fuel for about 100 miles. These cylinders cost about $60 each (Reference 30). Since this price is based on existing mass production of the cylinders it would not be likely to decrease much if more vehicles were equipped for use of natural gas.

6.1.6.3 Performance Characteristics

In the EPA program reported in Reference 67, two vehicles were tested (a 6-cylinder Chevrolet and a Ford pickup truck) with Device 460 installed. Table 6-18 summarizes exhaust emission results obtained using the 1972 Federal Test Procedure with the vehicles operating first on gasoline and then on CNG. Emission increases of CO and NOx were measured on the Ford Test Vehicle.

Table 6-18. DEVICE 460 COMPRESSED NATURAL GAS DUAL-FUEL CONVERSION EMISSION TEST RESULTS (REFERENCE 67) (1)

VEHICLE CONFIGURATION	POLLUTANT (GM/MI)					
	HC		CO		NOx	
	CNG	Gasoline	CNG	Gasoline	CNG	Gasoline
Chevrolet	2.1	(2)	3.8	(2)	2.0	(2)
Ford	3.0	3.0	25.0	21.0	4.6	2.8
Percent Reduction (3)	0		-19		-64	

(1) Results from 1 test using standard 1972 Federal Test Procedure (Ref 3)
(2) Not tested
(3) Percent reduction calculated on Ford only, as no baseline for the Chev

In 1969, an extensive test program was conducted by the Device 460 developer to qualify the dual-fuel system for California acceptance (Reference 69). Most of the testing was performed at the California Air Resources Board Emission Test Laboratory. Table 6-19 summarizes the results of this program.

The high percentage reductions shown in Table 6-19 for all three pollutants with CNG as fuel were obtained using the California 7-Mode test procedure (Reference 41). The test report indicates that sometimes it was necessary to retard the spark timing. Emissions recorded during the test indicated the emission levels with CNG are con-

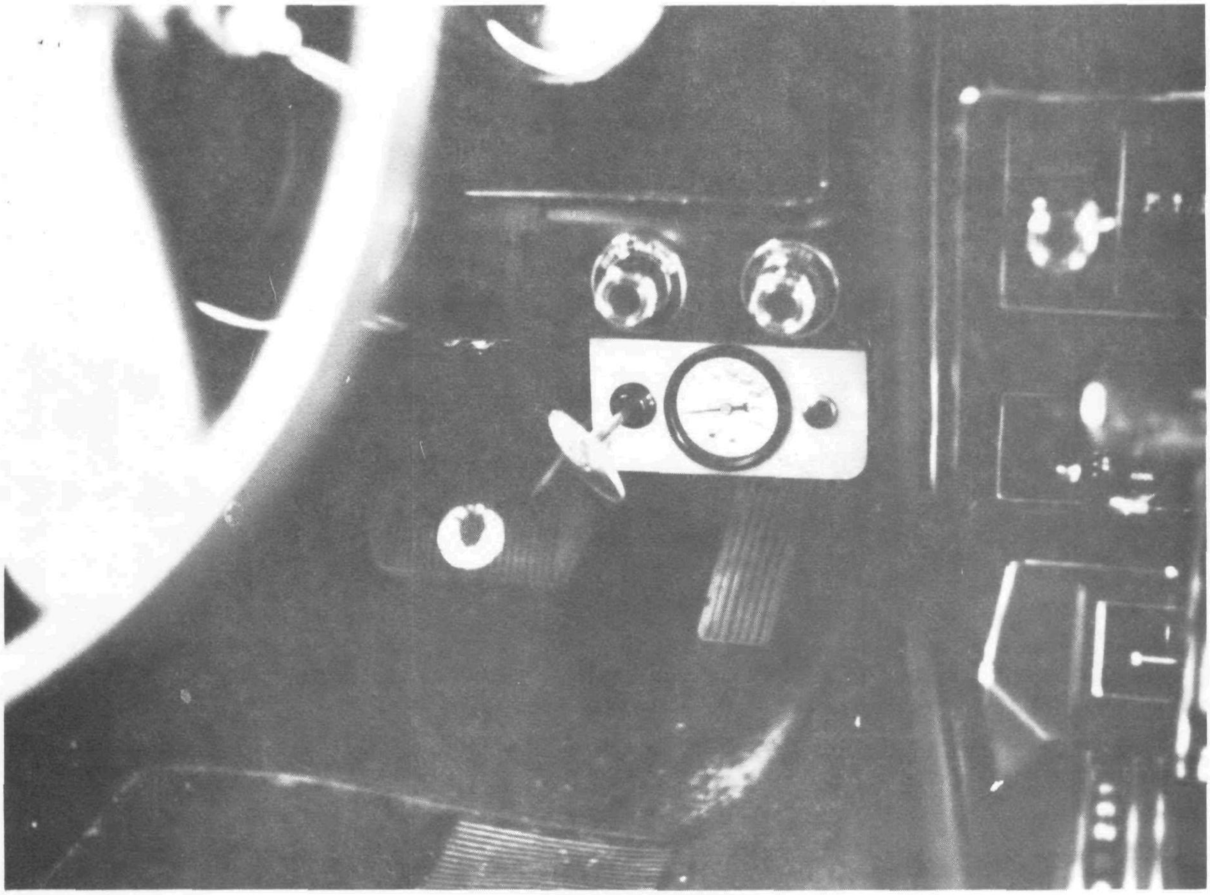


Figure 6-13. CNG INSTRUMENT PANEL CONTROLS (REFERENCE 103)

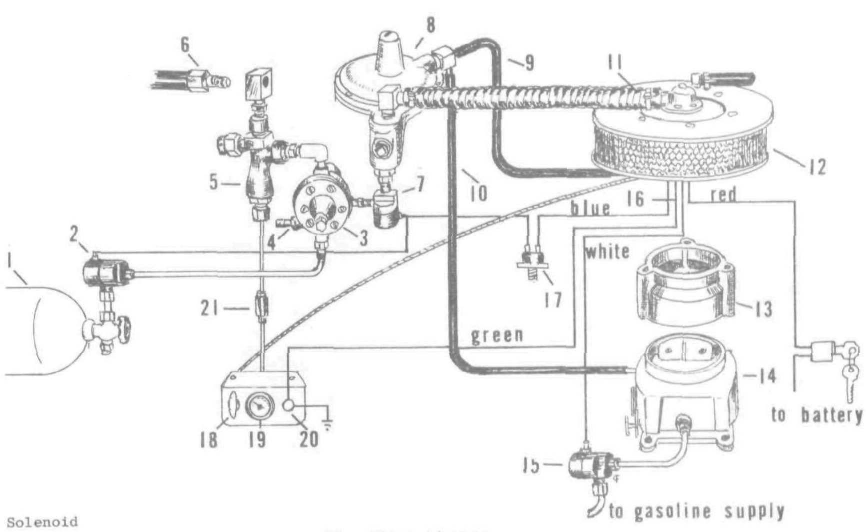


FIGURE 3

1. Fuel Cylinder
2. Positive Fuel Shut Off Solenoid
3. Primary Regulator
4. Primary Regulator Test Point
5. Natural Gas Fill Valve and Pressure Safety Valve
6. Cylinder Refill Line
7. Natural Gas Solenoid Valve
8. Secondary Regulator
9. Secondary Regulator Vent Line
10. Accelerator Vacuum Line
11. Vapor Hose
12. Dual Fuel Systems Gas Air Mixer
13. Mixer Adapter
14. Carburetor
15. Gasoline Solenoid Valve
16. Wiring Harness
17. Vacuum Switch
18. Fuel Selector
19. Natural Gas Gauge
20. Fuel Selector Indicator Light
21. Fuel Pressure Safety Restrictor Fitting

Figure 6-14. CNG DUAL-FUEL CONVERSION SYSTEM FUNCTIONAL SCHEMATIC (REFERENCE 46)

Table 6-19. DEVICE 460 CNG DUAL-FUEL CONVERSION EMISSION TEST RESULTS (REFERENCE 69)

Amended September 15, 1969

Engine Class Cubic inch	Yr/Make/Cyl Displacement Transmission	Test Conditions	Carbon Monoxide Concentration: Gasoline[1/] %	Carbon Monoxide Concentration: Nat. Gas[2/] %	Hydrocarbons Concentration: Gasoline[1/] ppm	Hydrocarbons Concentration: Nat. Gas[2/] ppm	Hydrocarbons Reactivity Units: Gasoline Units	Hydrocarbons Reactivity Units: Nat. Gas[3/] Units	Oxides of Nitrogen Concentration: Gasoline[1/] ppm	Oxides of Nitrogen Concentration: Nat. Gas[2/] ppm
a	1969 Jeep 4	Baseline	1.97	-	393	-	1590	-	1079	
0-140	134 cu. in.	At conversion	1.97	.15	321	158	1165	35	1100(5)	275
	Manual	After 4,000 Mi.	.59	.22	365	218	1320	270	1439	411
b	1969 Rambl. 6	Baseline	2.45	-	417	-	2420	-	1345	
140-200	199 cu. in.	At conversion	2.34	.09	348	106	2065	225	855	359
	Manual	After 4,000 Mi.	3.21	.12	378	74	1975	175	840	359
c	1968 Chev. 6	Baseline	1.07	-	709	-	1950	-	1279	-
200-250	250 cu. in.	At conversion	1.16	.15	418	168	2330	205	679	158
	Manual	After 4,000 Mi.	.96	.17	248	123	1345	160	522	146(5)
d	1968 Ford 8	Baseline	1.3	-	273	-	-	-	736	-
250-300	289 cu. in.	At Conversion	1.8(4)	.12	331(4)	118	-	-	1476(4)	570
	Automatic	After 9,000 Mi.	.54(4	.13	233(4)	97	1370	86	1581(4)	110(5)
e	1969 Ford 8	Baseline	1.11	-	471	-	2370	-	1051	-
300-375	302 cu. in.	At conversion	.86	.22	271	130	2940	285	491	122
	Automatic	After 4,000 Mi.	.56	.20	342	185	1855	190	600(5)	172
f	1967 Chrys. 8	Baseline	2.20	-	272	-	1455	-	1200(5)	-
375 +	440 cu. in.	At Conversion	1.66	.15	178	547	1815	270	484	410
	Automatic	After 4,000 Mi.	2.26	.13	158	79	1470	175	477	293(5)
	Percent Reduction		90		51				71	

NOTE: Data are continuous NDIR except Reactivity Units which are from F.I.D. tests on bag samples.

(1) Gasoline emissions are for cold start sequence, except as noted in footnote (4), corrected to 15 % CO_2.
(2) Natural gas emissions are from hot start cycles, corrected to 11 % CO_2. Previous test data show no difference between cold and hot starts, Table IV.
(3) Reactivity Units for natural gas
(4) Hot Start cycles.
(5) Oxides of nitrogen derived from bag samples.

Table 6-20. DEVICE 460 CNG HYDROCARBON REACTIVITY (REFERENCE 69)

Engine Class Cubic Inch	Yr/Make/Cyl Displacement Transmission	Test Conditions	Gasoline Concentrations Par. ppm	Gasoline Concentrations Ole. ppm	Gasoline Concentrations Aro. ppm	Gasoline 1-8-3 Reactivity Units	Natural Gas Concentrations Par. ppm	Natural Gas Concentrations Ole. ppm	Natural Gas Concentrations Aro. ppm	Natural Gas 1-8-3 Reactivity Units	Natural Gas 0-8-3 Reactivity Units
a	1969 Jeep 4	Baseline	230	110	160	1590	-	-	-	-	-
0-140	134 cu. in.	At conversion	185	70	140	1165	270	4	1	305	35
	Manual	After 4000 Mi.	160	100	120	1320	265	30	10	535	270
b	1969 Ramb. 6	Baseline	390	175	210	2420	-	-	-	-	-
140-200	199 cu. in.	At conversion	475	165	90	2065	380	27	3	599	225
	Manual	After 4000 Mi.	205	165	150	1975	185	22	0	361	176
c	1968 Chev. 6	Baseline	370	115	220	1950	-	-	-	-	-
200-250	250 cu. in.	At conversion	475	125	285	2330	470	20	15	675	205
	Manual	After 4000 Mi.	225	95	120	1345	250	17	8	410	160
d	1968 Ford 8	Baseline	-	-	-	-	-	-	-	-	-
250-300	289 cu. in.	At conversion	-	-	-	-	-	-	-	-	-
	Automatic	After 9000 Mi.	230	105	100	1370	260	20	0	420	160
e	1969 Ford 8	Baseline	330	195	160	2370	-	-	-	-	-
300-375	302 cu. in.	At conversion	340	250	200	2940	600	30	15	885	285
	Automatic	After 4000 Mi.	270	140	155	1855	440	23	2	630	190
f	1967 Chrys. 8	Baseline	125	140	70	1455	-	-	-	-	-
375 +	440 cu. in.	At conversion	155	155	140	1815	820	30	10	1130	270
	Automatic	After 4000 Mi.	110	140	80	1470	240	30	0	480	240

sistently low from cold to hot test cycles. This apparently is attributable to the even diffusion of the air-fuel mixture whether the intake manifold is hot or cold. This is characteristic of gaseous fuels. For this reason, a choke is not required during cold start, as with gasoline, which does not diffuse well during cold start because of its liquid state.

Because of the uniform mixture distribution of CNG and the excess of air provided by the carburetor, the low carbon monoxide emission level is an expected result.

The exhaust hydrocarbon concentrations shown in Table 6-19 indicate substantial reductions when converting from gasoline to natural gas, but do not reflect the change in nonreactive hydrocarbon compounds with natural gas fuel. As noted in the Reference 69 test report, methane is the primary constituent both of natural gas and the exhaust hydrocarbons resulting from natural gas combustion. Methane has indicated zero reactivity in measurements of photochemical smog production known to date. This pattern is consistent with methane's paraffinic stability. The gas chromotographic data obtained in the Reference 69 program indicated that the paraffinic component of natural gas is almost pure methane; and that when another paraffin is found, it is ethane, which is nearly as nonreactive as methane. Gasoline, in comparison, has a preponderance of olefin and aromatic compounds that are long chain with high photochemical reactivity.

A benefit of Device 460 (and of any gaseous fuel system) is that hydrocarbon emissions from carburetor and gas tank fuel evaporation are nearly zero because of the sealed gaseous fuel system. The gasoline carburetor is dry when operating on natural gas, and consequently gasoline hot soak emissions are zero.

According to the Reference 69 report, the low NOx emission levels with CNG are attributable to the high air-fuel ratios achievable with CNG, which can operate at air-fuel equivalence ratios on the order of 20 percent higher (for given throttle settings) than gasoline (Reference 124).

6.1.6.4 Reliability

Device 460 CNG-gasoline dual-fuel systems are in widespread use nationally. The rate of usage is increasing. During 1970, it was estimated that CNG conversions increased from 100 to 3,000 (Reference 68). Most of these conversions have been made on fleet vehicles, including passenger cars, trucks, tractors, and sweepers. Some of these vehicles average 20,000 miles per year (Reference 46). Based on this fleet usage data, it would appear reasonable to assume that a Device 460 system would have several vehicle life times of reliability. For the performance analysis of Volume III, a 300,000-mile reliability was assumed.

6.1.6.5 Maintainability

Based on the system configuration shown in Figure 6-14 and available data, it was assumed that no periodic maintenance attributable solely to the Device 460 system would be required. As for LPG (paragraph 6.1.1.5), maintenance histories reported by CNG-gasoline dual-fuel system users indicate substantial savings in overall engine maintenance through this type of conversion.

Maintenance data reported by the General Services Administration (GSA), Washington, D.C. (as summarized in Reference 46) indicate recurring cost savings ranging from 10 to 60 percent in vehicle maintenance, due to reductions in oil changes, oil filters, and tuneups. Overall fleet maintenance cost was reduced by 36.6 percent.

6.1.6.6 Driveability and Safety

As noted in Reference 30, peak power output of a spark-ignition engine is reduced by approximately 10 percent when the fuel is changed from gasoline to methane (CNG). This power loss is attributed to the reduced volumetric efficiency of gaseous fuel. As for propane, the brake specific fuel consumption (pounds of fuel consumed per brake horsepower hour) is less than that for gasoline. Reference 30 reported that a 13 percent reduction in specific fuel consumption has been measured on CFR engines when the fuel is switched from gasoline to methane. This is attributable to methane's higher heat energy per pound than that of gasoline (23,900 Btu/lb. methane compared to 20,500 Btu/lb. gasoline).

It is generally accepted that 100 standard cubic feet (SCF) of CNG equals 1 gallon of gasoline in Btu/lb. (Reference 30). Since only about 325 SCF can be stored in the average CNG cylinder at 2,265-2,400 psi, the driving distance of a vehicle on a single CNG tank like this would be equivalent to that for about 3 gallons of gasoline; or, at 12.5 mpg for gasoline, 37.5 miles. Four of these large size tanks would provide enough fuel for only about 160 miles. Because of its lower specific gravity compared to gasoline's, twice as much methane would still be required in the liquid state to equal gasoline's Btu/gallon heat energy. The principal physical properties of gasoline and methane are as follows:

	Boiling Point (°F)	Btu/Lb.	Btu/Gal.	Specific Gravity
Gasoline	100	20,747	123,000	0.7
Methane	-259	23,861	61,000	0.3

An example of the slightly reduced vehicle performance resulting from CNG use is the acceleration test reported in Reference 103. Acceleration performance measurements were made on a quarter-mile drag strip using a 1971 Ford Mustang with a Device 460 dual-fuel conversion. After five runs were made on CNG, the vehicle was switched to conventional fuel operation and two runs were made on gasoline to obtain a comparison. The elapsed time and speed at the end of each run and the overall averages are shown in Table 6-21. Vehicle acceleration when operated on CNG showed a decrease in performance in comparison to gasoline with an 11 percent increase in elapsed time and a 7.6 percent decrease in speed. This slight loss of acceleration is the only reported driveability penalty found for CNG in the retrofit study.

Safety does not appear to be a problem with CNG, despite the high pressures at which it must be stored. The Department of Transportation Specifications DOT-3A and 3AA require testing of the gas cylinders at 5/3 times service pressure every five years (Reference 46). DOT also requires that each CNG cylinder be equipped with approved safety relief valves, if charged to 1,800 psi or higher at 70F.

The high ignition temperature of CNG (1,300°F compared to 600°F-700°F for gasoline) reduces the possibility of accidental fire should leakage occur. Since methane is lighter than air it would rise, further reducing safety problems. Reference 46 reported a crash test in which 25 fuel cylinders were dropped tested in many different but normal tiedown configurations on a vehicle from a height of 46 feet (equivalent to 30 mph head-on collision). Only three tanks shifted in their mountings and none ruptured. A CNG tank normally incorporates a safety burst disc that vents the tank if 3,200 psi is reached.

Table 6-21. DEVICE 460 ACCELERATION TEST RESULTS WITH A 1971 FORD MUSTANG (REFERENCE 103)

RUN NO.	FUEL	ELAPSED TIME (SECONDS)	SPEED (MPH)
1	CNG	19.26	70.75
2	CNG	19.09	71.20
3	CNG	20.18	70.47
4	CNG	19.30	70.75
5	CNG	19.01	70.97
Average	CNG	19.37	70.83
6	gasoline	17.45	76.40
7	gasoline	17.47	76.92
Average	gasoline	17.46	76.66
Percent Change		-11	7.6

6.1.6.7 Installation Description

It is assumed that a CNG-gasoline dual-fuel conversion made for retrofit purposes to control vehicle exhaust emissions would have to meet rigorous installation requirements such as those presently being considered in California (Reference 50). On this basis, the installation requirements for a Device 460 conversion would be similar to that described for the Device 52 LPG system in paragraph 6.1.1.7. The principal difference would be in the system components. For Device 460, these would consist of the CNG tanks, fuel line, two pressure regulators, the mixer, solenoid valves to control the flow of gaseous fuel or gasoline, and the Bowden control cable.

Detailed instructions for installing these components are presented in Reference 104. The CNG tanks are mounted on two wooden runners with steel straps and bolted through the trunk floor using 1/2-inch bolts and backup plates. Cylinder mounting brackets and clamps are used for a permanent installation.

The pressure regulators are mounted on the left front side of the engine compartment. Normally the mixer is installed directly onto the carburetor after removal of the standard air cleaner. In some installations, the lack of hood clearance may necessitate the use of an offset adapter to connect the gas-air mixer with the carburetor.

The remaining installation, engine tuneup and test requirements are analogous to the Device 52 installation. It is estimated that 12 hours would be required for this installation. Garages and mechanics certified for this type of installation should be used.

6.1.6.8 Initial and Recurring Costs

The basic components required for a Device 460 conversion would cost approximately $300, not including the fuel tanks (Reference 30). For a light-duty vehicle dual-fuel retrofit installation, it is assumed that at least two fuel cylinders would be used. This would provide enough fuel for a driving range of about 75 miles, after which the vehicle would be switched to gasoline. This should enable a vehicle to be operated on CNG most of the time in metropolitan areas, in which exhaust emission control requirements are generally most critical.

As shown in Table 6-17, a 312 cubic foot tank would cost about $75. Overall installation costs would therefore be approximately $600. Over a 50,000-mile service life, this initial investment would be recouped by recurring cost savings as indicated in Table 6-22. The major savings are in reduced fuel costs and engine oil changes and tune-ups. Fuel cost per 100 SCF (equivalent to one gallon of gasoline in Btu/hr.) was estimated to be 16¢, based on California rates (Reference 28), including 7¢ per 100 SCF State road tax refund.(1) Savings on oil changes and tuneups were based on the reduced requirements indicated for LPG (Table 6-10), since gaseous fuel benefits with respect to reduced engine maintenance appear to be about the same.

For the savings in fuel costs, it was assumed that the vehicle would be operated on CNG 50 percent of the time over a 50,000-mile service life. This assumption is based on the transient modes of operation reported in Reference 30 for the New Jersey Cycle pattern of vehicle operation, in which transient modes occur approximately 47 percent of the time. These modes contribute heaviest to vehicle exhaust emissions and are therefore the ones during which the CNG phase of a dual-fuel system would be most likely used.

6.1.6.9 Feasibility Summary

Although either natural gas and propane can be used in dual-fuel applications with gasoline, both dual-fuel systems have been found to compromise engine performance. The gasoline engine design is optimized for gasoline and even sole use of a gaseous fuel instead of gasoline does not provide the same level of performance as gasoline.(2) The performance penalty is not severe, however, compared to the benefits in reduced emissions. Natural gas produces about one-fourth as many harmful pollutants as gasoline (Table 6-20).

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(1) See Footnote, page 6-3.

(2) In tests reported in Reference 26 it was found that the gasoline engine produces 14.6 percent less power with CNG, although BSFC predicts essentially equal thermal efficiency for gasoline and CNG. The difference in power output was attributed to the difference in fuel density. The gaseous fuel replaces more air volume flow than gasoline and in effect lowers the engine's volumetric efficiency. The Reference 26 program also indicated the performance compromise inherent in a dual-fuel system, in that it was found that CNG requires about 5 degrees more spark advance than gasoline for a minimum-for-best-torque (mbt) spark advance. It can be seen that a dual-fuel car timed for gasoline would run with retarded timing when operated in CNG; or, conversely, if timed for CNG would be over-advanced for gasoline. The effective retard for CNG running at the mbt for gasoline would be perhaps 5 degrees more, since in the normal installation CNG operates at a much leaner air-fuel ratio (19:1) than the leanest-for-best-torque (lbt) ratio. Dynamometer tests performed on CNG in the referenced program showed that mbt spark advance at 19:1 air-fuel increases by another 5 degrees over lbt operation.

Table 6-22. DEVICE 460 CNG DUAL-FUEL CONVERSION INITIAL AND RECURRING COSTS

ITEM	DESCRIPTION	LABOR HOURS OR ITEM QUANTITY	COST (DOLLARS)
Initial Cost:			
Material			
1. Dual-fuel conversion kit	Refer to par. 6.1.6.7	Approximately $300.00	300.00
2. Fuel tanks	9.25 by 51 inches, 312-SCF capacity at 2,265 psi, and 120-pound weight each.	$75.57 each (Table 6-17)	151.14
			451.14
Labor			
1. Engine tuneup, kit installation, checkout, and test.	Refer to par. 6.1.6.7	12 hrs. @ $12.50 per hr.	150.00
		Total Initial Costs	601.14
50,000-Mile Recurring Costs: (Estimated savings by converting to CNG-gasoline dual-fuel system)			
Material Savings			
1. CNG Fuel Economy Versus Equivalent Gasoline Consumption (1)			
Fuel	Miles/Unit Volume	Vol./50,000 Mi. $/Unit Volume	
Gasoline	12.5 mpg	2,000 gal. X 0.35/gal. = = $700.00	
CNG	12.5 mi./100 SCF	200,000 SCF X 0.16/100 SCF = = 320.00	
	Fuel Savings	$380.00	- 380.00
2. Oil Change and Tuneup Savings	50 percent of savings for LPG in Table 6-10 (2)	Oil = .50 X $123.00	- 61.50
		Tuneup = .50 X $120.00	- 60.00
		Total Recurring Cost Savings	501.50
		TOTAL COSTS	99.64

(1) Based on the Btu/hr. equivalency of gasoline and CNG, one gallon of gasoline is assumed equivalent to 100 SCF CNG. Assuming that CNG would be used 50 percent of the time over a 50,000-mile period and that average miles per unit of equivalent volume is 12.5 for both fuels (based on an assumed national average of 12.5 mpg for gasoline), 2,000 gallons of gasoline and 200,000 SCF of CNG would be required for a vehicle to be operated 50,000 miles on a dual-fuel basis. The $/unit volume are based on averages assumed for the retrofit study.

(2) Assuming that CNG offers maintenance benefits equivalent to gasoline, but would be used only 50 percent of the time in a dual-fuel system.

The significant problem with use of CNG as a vehicle fuel is its lack of sufficient supply for that application. It has been estimated that a complete switch to CNG from gasoline, for all motor fuel requirements, would require the natural gas industry to triple its size by 1982 (Reference 47). As compared to the more than 100 million gasoline vehicles operating in the U.S. at the end of 1971, there were approximately 250,000 LPG and 3,000 NG vehicles (Reference 31). The use of natural gas as a vehicle fuel is insignificantly small compared to the total primary consumption of natural gas in the U.S. (23.3 trillion cubic feet forecast for 1971). The total supply of natural gas projected through 1990 would not be sufficient to meet future requirements presently estimated on the basis of no substantial variation in the percentage of vehicles using natural gas.

The supply deficiency is attributable to the fact that the price of natural gas being regulated Federally at the wellhead is too low to provide the economic incentive for the exploration and drilling necessary to produce additional supplies of gas (Reference 32). The proving out of additional supplies is an essential part of the natural gas supply situation, in that the Federal Power Commission requires a 20-year supply of gas from proved reserves as backup to any contract for the delivery of natural gas in interstate commerce. The reserves needed presently exist in the form of "future discoveries." Some price adjustment would be needed for natural gas if these reserves were to be brought into the "proved" category so that the supply of natural gas would be adequate for widespread use of natural gas as a vehicle fuel. An increase in wellhead price to stimulate increased natural gas production probably would not offset the current trend toward supply deficiency until 1975 (Reference 30).

Though a sufficient quantity of natural gas could be provided eventually, it is doubtful whether the required increase could be accomplished within the retrofit time frame of the next 10 years. The required growth to support a major CNG retrofit program would be far below the expected decline in natural gas production from the 1968 growth rate of 5.5 percent to 4 percent per year through 1975.

The following is a quotation from Reference 28 on the availability of natural gas for vehicle fuel conversions:

> "Powering all California motor vehicles with natural gas would necessitate a 42% increase in supply. Powering all fleet vehicles would require a more modest increase of 4%.
>
> "The natural gas available to California is currently unable to supply all power plant and other usage during the winter months. This is likely to continue for the next few years. Transportation of liquified natural gas by ship began about 1964 and is being expanded rapidly. Oversea transportation holds promise to meet future demands for natural gas."

Without economic incentives, the industry output may decline further after 1975 (Reference 30). Since all pre-1973 gasoline-fuel vehicles could be retrofitted with CNG it does not appear that such widespread use of CNG-fuel would be feasible, because of the inability of the natural gas industry to respond and still supply its firm residential and commercial users. Some compromise use of natural gas would have to be made if it were applied as a retrofit approach. The use of a dual-fuel conversion would be a possible compromise. Also use might be limited to certain fleets of vehicles or to vehicles within prescribed geographical areas where air quality standards cannot be met due to excessive vehicle emissions.

Though the initial cost of a dual-fuel conversion is high, a large economical advantage of gaseous fuel is the reduction in engine maintenance and lower fuel cost. The reduced dilution and contamination of oil could be expected to extend oil change intervals and reduce engine wear. CNG is clean burning and produces no lead, varnish, or carbon deposits. Thus spark plugs should stay cleaner much longer and the engine should not load up with sludge. With the anticipated maintenance and fuel reduction advantages, it is estimated that the initial costs of installation could be recovered in six years, or sooner, depending on the average mileage driven (Table 6-22). It would appear to be more advantageous to the vehicle owner to obtain the economy of maintenance of an LPG or CNG system while emissions are being reduced, rather than to have a gasoline engine which has been detuned to reduce emissions to the point where performance is marginal. The low maintenance factor also is important because the longer the engine stays clean and in tune, the longer the emissions are reduced to the acceptable level (Reference 103).

It should be noted that an increase in demand for CNG could cause an increase in cost; however, any such increase could be offset by legislation exempting converted vehicles from road use taxes.

The alternate fuels project reported in Reference 103 indicated that exhaust emissions may be lowered significantly by conversion to CNG without major engine adjustments. Further reductions in emissions may be obtained by the same methods used for gasoline operation, such as retarding the spark and leaning the fuel mixture. However, the same sacrifice must be made as on gasoline: a decrease in performance.

Because of the shortage of CNG for full scale retrofit applications, the best approach for utilization of the potentially available supply sould appear to be for the automobile manufacturers to offer the option of new car conversions to LPG and CNG systems and for fleet vehicles to be converted on a retrofit basis in slected air quality control regions. If done exclusively as a single-fuel conversion, this would allow the most efficient usage of carburetion and minor engine modifications. Because of convenience and vehicle owner acceptance problems of these fuels, the interim solution would be to offer dual-fuel LPG-gasoline or CNG-gasoline conversions. This compromise has the disadvantages of higher emissions and lower performance. In particular, on a dual-fuel conversion involving gasoline, the emissions during operation in the gasoline mode are indicated as being higher than if the engine had not been converted. This tends to nullify the emission reduction gained during the LPG or CNG mode of operation. An approach which may deserve more consideration in the future is the use of a dual fuel system consisting of combined CNG/LPG operation. The carburetion and engine modifications common to both fuels could be used without increasing emissions or decreasing performance, yet would still allow the convenience of a dual-fuel system.

Another problem associated with the shortage of CNG supply for full-scale vehicle conversions is the lack of general public retain distribution of CNG. Generally, each fleet operator has designed his own refueling station (Reference 46). As vehicle owner use expands, refueling stations would be required commensurately.

Thus far, most gaseous fuel conversions have been made because of the fuel and maintenance economy benefits, rather than for emission reduction (Reference 34). As noted in Reference 30, there are at least three factors which will influence the rate of conversion for emission reduction purposes:

a. Shifts in the relative prices of gasoline, compressed natural gas, LNG, and propane.

b. Additional tax incentives and other legislated inducements offered by government bodies.

c. Progress of the automotive industry in providing a "clean" car using gasoline fuel.

Without some implementation of these factors, the rate of conversion of at least commercial fleet vehicles would not be likely to tax the ability of gaseous fuel suppliers or equipment manufacturers to supply the market demand.

A recent development stimulating conversions is the leasing of the gaseous fuel equipment to the vehicle owner. Use of this approach would depend on individual cases. In some cases, leasing of the equipment for a monthly fee over a specified time period can provide the lessee a tax advantage not obtainable by purchasing the equipment outright. The same applies to acquisition of onsite storage facilities. If the lease arrangement is selected, the only investment cost to the lessee is the cost of labor involved in the conversion. The monthly cost may be as low as $8 per vehicle for the equipment used in the conversion, depending on the vehicle (Reference 30).

6.2 FUEL ADDITIVE - RETROFIT SUBTYPE 1.4.2

This category of fuel modification devices approaches exhaust emission reduction by adding compounds either directly to the gasoline fuel or to the air-fuel mixture in the intake manifold. The objective in general is to modify the fuel mixture for improved combustion and reduced emissions.

As shown in Table 6-1, four devices were studied in this category. For two of these devices (182 and 282), data were obtained from the developers. For the other two (457 and 465), the sole data source was EPA.

6.2.1 Device 182: Fuel and Oil Additives

These additives are marketed products that are claimed by the developer, with some test data substantiation, to decrease exhaust emissions of CO, HC, and NOx, and also to provide fuel economy through reduced consumption. Less engine maintenance was reported by the developer as an additional benefit. The developer guarantees a 5 percent fuel savings to any account, including the cost of the additives.

6.2.1.1 Physical Description

The developer described the additives as a "combination of hydrocarbon base fuel and oil additives," and a "complex homogeneous mixture of petro-chemicals." The chemical composition of the additives is apparently proprietary. They are sold in tube quantities. Typically one tube of fuel additive is used for each tank of gasoline, at a ratio of one part additive to 5,000 parts gasoline. Similarly, one tube of oil additive is used in the crankcase, at a ratio of one part additive to 130 parts oil.

6.2.1.2 Functional Description

The developer claims that the additives are "formulated to restructure the hydrocarbons in the fuel and oil. By restructuring the molecules so they burn more efficiently they achieve the normally noncompatible result of additonal power and increased fuel economy."

The principles of operation of the additives were not reported. One industrial user was of the opinion that the fuel additive promotes "more complete combustion in the quench zone near cold cylinder walls." He based this on the observation that varnish deposits on the cylinder walls were quickly removed with use of the additive. Another user reported that he found no carbon deposits on the heads or intake valve stems. A diesel user reported elimination of exhaust smoke, and indicated that the smoke depressant normally used could be eliminated. Fuel mileage increases, reduced oil consumption, and elimination of pinging with regular gasoline have also been reported by users.

6.2.1.3 Performance Characteristics

Emission test data were provided by the developer from two independent test agencies. Table 6-23 summarizes the results of tests performed by the City of Los Angeles. Table 6-24 summarizes test results obtained by Olson Laboratories in tests performed for the developer prior to the retrofit study.

Table 6-23. DEVICE 182 FUEL AND OIL ADDITIVES EMISSION TEST RESULTS REPORTED BY CITY OF LOS ANGELES (1)

VEHICLE CONFIGURATION (2)	POLLUTANT					
	HC (PPM)		CO (%)		NOx (PPM)	
	IDLE	2,500 RPM	IDLE	2,500 RPM	IDLE	2,500 RPM
Without Additive	143	52	1.43	0.25	(Not measured)	
With Additive	60	13	0.58	0.18		
Percent Reduction (3)	58	75	59	28		

(1) Results measured by Bureau of Transportation with a Sun Infrared Emission Tester under dynamoneter steady state conditions at idle and 2,500 rpm.

(2) Four Plymouth Valiants, one Buick Special, and one Buick Electra.

(3) Average of six tests with and without additive.

Table 6-24. DEVICE 182 FUEL AND OIL ADDITIVES EMISSION TEST RESULTS REPORTED BY OLSON LABORATORIES

ITEM	POLLUTANT		
	HC	CO	NOx
Percent Reduction	26.2 (1)	30.5 (1)	24.0 (2)

(1) Average of four tests using the 1970 Federal Test Procedure on two 1968 and two 1969 Ford Fairlanes, with and without additive.

(2) Result of one test using the 1970 Federal Test Procedure on a 1969 Ford Fairlane, with and without additive.

6.2.1.4 Reliability

The Device 182 additives were reported by the developer as having been used with numerous types of vehicles for thousands of miles of operation with no failure attributable to the additives. Corrosion tests performed for the developer by Admerco, Incorporated, Van Nuys, California, indicated that the additives are "essentially non-corrosive to the materials tested" (copper, epoxy fiberglass laminate, galvanized zinc, mild steel, and aluminum).

Additional testing was reported by the developer on a 4-cycle, single cylinder stationary engine driving an electrical generator. No engine damage was noted in 120 hours of operation both with and without the fuel additive. Cylinder wall deposits were comparable in magnitude to engines not using the additive but the color was white instead of black, which suggests the need for further testing.

6.2.1.5 Maintainability

As a fuel additive, Device 182 would appear to require no maintenance action. The developer provided a number of letters from users indicating improved engine performance and cleaner operation, which might decrease engine maintenance. The quantitative data provided were insufficient to verify these claims.

6.2.1.6 Driveability and Safety

Based on the aforementioned user reports, Device 182 improves engine performance and fuel economy. The developer reported that he has a one year contract to supply McDonnell Douglas Aircraft Division, Long Beach, California, to treat all fuel for its vehicle fleet. Fuel consumption data reported by McDonnell Douglas with and without use of the additive indicate that fuel consumed with the additive is, on the average, 18.4 percent less than untreated fuel. Table 6-25 lists the fuel consumption data.

Since the chemical composition of the additives was not reported by the developer, safety requirements with the device were not determinable.

6.2.1.7 Installation Description

The content of one tube of additive is added to each fuel tank of gasoline. The additive is put in the tank first, followed by the gasoline, so that the two will mix thoroughly. The oil additive is added through the engine oil spout.

Table 6-25. DEVICE 182 FUEL CONSUMPTION REDUCTION REPORTED BY McDONNELL DOUGLAS AIRCRAFT DIVISION (DEVELOPER SUPPLIED DATA)

	WITHOUT ADDITIVE				WITH ADDITIVE				
Vehicle	Test Period	Total Miles	Total Gals.	Avg. MPG	Test Period	Total Miles	Total Gals.	Avg. MPG	Percent Change in MPG
I-76 (Ford Truck)	1/2-1/22	1514	203.0	7.46	1/22-2/13	1787	216.8	8.24	10.5%
I-78 (Ford Truck)	1/2-1/22	927	169.0	5.49	1/22-2/13	1180	170.0	6.94	26.5%
L1-819 (Ford Van)	1/2-1/22	1410	123.6	11.41	1/22-2/21	1972	163.7	12.05	5.6%
L-202 (IHC Scout)	2/23-3/22	654	90.4	7.23	3/22-4/20	634	73.9	8.58	18.6%
L-203 (IHC Scout)	2/23-3/22	911	138.8	6.56	3/22-4/20	890	99.4	8.95	36.4%
L3-222 (Buick Sta.Wagon)	2/27-3/22	798	125.6	6.35	3/22-4/20	1920	265.4	7.23	13.9%
L3-223 (Buick Sta.Wagon)	2/23-3/22	2091	274.8	7.61	3/22-4/20	1665	189.4	8.79	15.5%
							Average		18.4%

(1) Summary of Test Results 1/2/70 - 4/20/70.

6.2.1.8 Initial and Recurring Costs

Table 6-26 itemizes initial and recurring costs for the Device 182 fuel additive. The only initial costs would be a vehicle tuneup for maximum emission reduction. As indicated, the fuel savings indicated by the developer would offset recurring costs by approximately $168 over a $50,000-mile vehicle service life.

Table 6-26. DEVICE 182 FUEL AND OIL ADDITIVES INITIAL AND RECURRING COSTS

ITEM	DESCRIPTION	LABOR HOURS OR ITEM QUANTITY	COST (DOLLARS)
Initial Costs:			
Material/Labor			
1. Additive	Device 182	$1.10 tube per 25 gallons	$1.10
Total Initial Costs			1.10
50,000-Mile Recurring Costs:			
Material			
1. Fuel additive	Device 182 additive	$1.10/tube per 25 gal gasoline X 4,000 gal. over 50,000 mile service life	176.00
2. Fuel savings	Assumed average 12 percent decrease in fuel consumption based on developer supplied data	480-gal. fuel reduction x $0.35 per gallon over 50,000 miles (1)	-168.00
Total Recurring Cost			$8.00
TOTAL COSTS			$ 9.10

6.2.1.9 Feasibility Summary

Since the additives represented by Device 182 have not been subjected to complete and formal emissions, driveability, and durability tests, the overall feasibility of the device as a retrofit approach for vehicle exhaust emission control is considered to require further substantiation. The data collected thus far indicate that additional study of the device should be made so that a definite determination of its feasibility can be made. The simplicity of the approach and the savings indicated by the developer in recurring costs could possibly make this device cost effective when used in combination with other controls for vehicle exhaust emission reduction.

6.2.2 Device 465: Fuel Additive

The sole source of information on this additive was obtained from an EPA exhaust emissions test report (Reference 105). The developer of this additive was not reported. Only limited evaluation of the additive's emission reduction effectiveness was possible based on the available data.

EPA tested a 1962 Chevrolet Impala with and without the additives used. The additives were mixed with Indolene 30 fuel as specified by the manufacturer. Table 6-27 summarizes the test results obtained by EPA using the 1972 Federal Test Procedure. Steady state emissions were also measured at 10-mph increments between 10 and 50 mph. The EPA report noted that the cyclic test results for the 1972 Federal Test Procedure differed considerably from that of steady state operation. Steady state showed a significant increase in emissions, whereas the cyclic test showed a reduction. Emissions measured under the 1970 Federal Test Procedure and the EPA 9-cycle CVS procedure were also inconsistent with the Table 6-27 results.

The EPA report concluded that extensive testing would be required to determine conclusively what the emission reduction effectiveness of the Device 465 additive would be for the total vehicle population.

Table 6-27. DEVICE 465 EMISSION TEST RESULTS (REFERENCE 105) (1)

VEHICLE CONFIGURATION	POLLUTANT (GM/MI)		
	HC	CO	NO_x
Without Additive	9.50	112.30	4.15
With Additive	8.33	101.19	3.81
Percent Reduction	12.3	9.9	8.2

(1) Result of one test using 1972 Federal Test Procedure (Reference 3) on 1962 Chevrolet Impala with 283-CID V-8 engine and automatic transmission, with and without additive.

6.2.3 Device 282: LP Gas Injector

This device is intended to enable use of low octane fuel with high compression engines without ensuing ignition spark knock (pinging). Propane is injected when the vehicle is accelerating, passing, or pulling hard, to increase fuel octane and eliminate ping. This approach would reduce lead requirements for gasoline, thereby limiting a source of pollutant byproducts. With this approach, the eventual use of catalytic mufflers (which require low-lead gas) when pollution standards are increased would not necessitate lower compression engines, which run less efficiently. The retrofit unit is in manufacture, and it has been installed on 85 vehicles. Approximately 600,000 miles of operation have been accumulated.

6.2.3.1 Physical Description

The principal components of this system are a regulator assembly, a manifold vacuum switch, and an LP gas solenoid. Not supplied with the retrofit kit is the LP gas bottle or the copper tubing to interconnect the system. System components are shown in Figure 6-15. A functional diagram of the system is shown in Figure 6-16. The components and accessories included in a Device 282 kit are:

a. Regulator with special spring, 1/8-inch pipe nipple, K-O hose nipple

b. Manifold vacuum switch

c. 12-volt LPG solenoid valve, cone-type strainer, half-union

d. I-3 gas adjusting block

The copper tubing recommended is 3/8-inch outside diameter, 12 to 14 feet, and electricians loom about 11 feet to protect the tubing. The LP bottle recommended is from 6 pounds to 20 pounds capacity depending on the space available to mount the unit. The tank would be mounted in the trunk or some other rear part of the vehicle.

6.2.3.2 Functional Description

This system is intended to replace the requirement for lead additives in gasoline by injecting propane (LPG) into the air inlet upon engine load demand. The device does this by sensing manifold pressure and opening the pressurized LP gas supply to the air intake stream.

6.2.3.3 Performance Characteristics

No emission data were supplied for the evaluation of this device. One advantage of this retrofit kit may be that regular gas rather than premium gasoline can be used with high compression engines. Data verifying this were not provided.

Reduction of pollutants may be indirectly affected by the reduction of lead in the fuel. Other possible benefits of leadless gasoline would be in the feasibility of a catalytic muffler installation on the car. Longer spark plug life, longer piston ring life, and longer muffler system life are some of the additional benefits claimed by the developer.

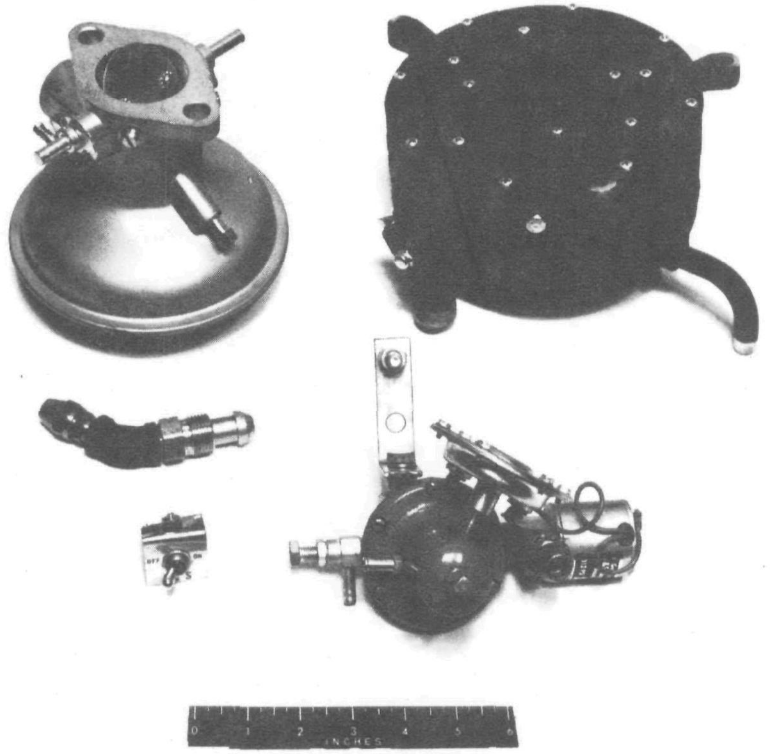


Figure 6-15. DEVICE 282 LP GAS INJECTION SYSTEM COMPONENTS

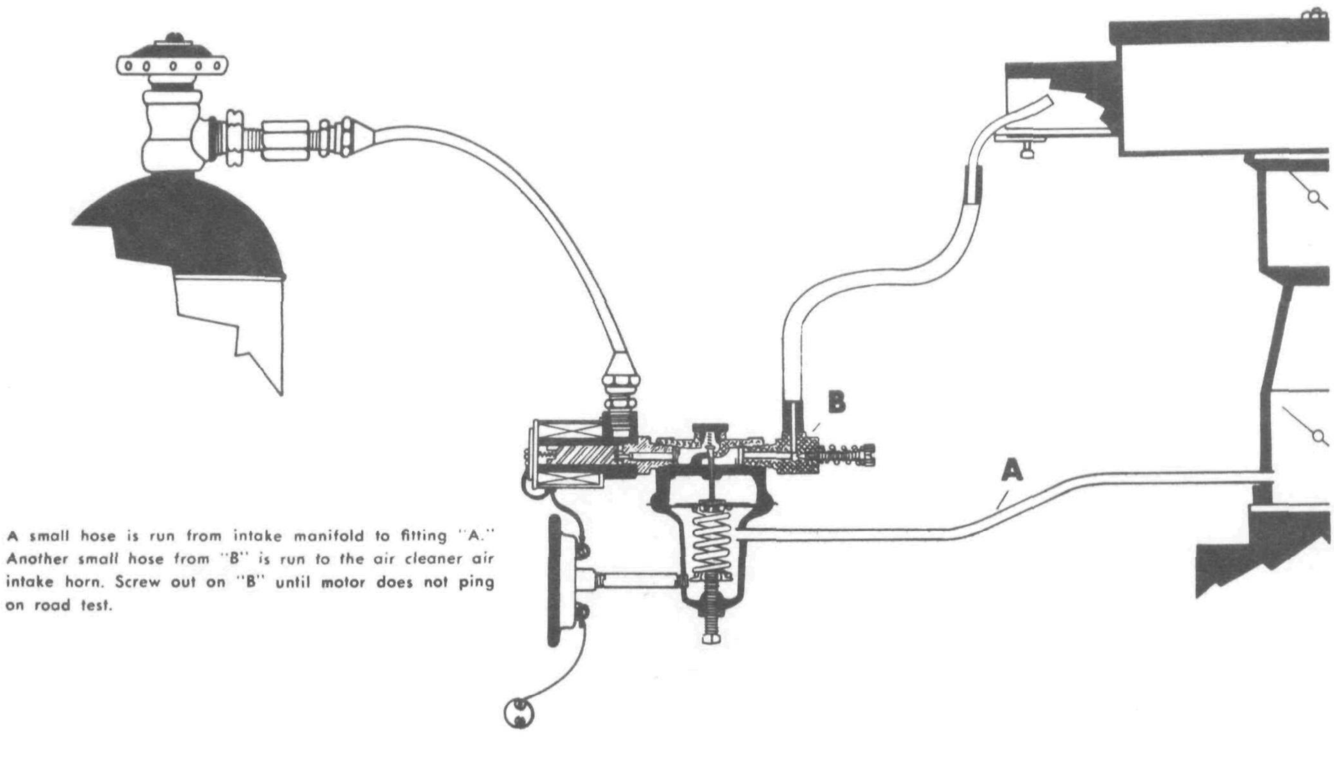


Figure 6-16. DEVICE 282 LP GAS INJECTION FUNCTIONAL SCHEMATIC

With one gallon of propane (4 pounds) the device is claimed by the developer to operate from 400 to 1,000 miles, depending on the type of load conditions to which a vehicle is subjected.

6.2.3.4 Reliability

The developer estimated the device has accumulated 600,000 miles installed on 85 vehicles. No mention of device failure was made, nor did the developer estimate device reliability.

Examination of the device indicated that the vacuum sensitive metering valve and the vacuum actuated switch have Underwriter Laboratory certification for specific service applications. To assure that the valve will operate reliably (and safely) specified maximum input pressure of 250 psi must be observed. The device must be used with a pressure regulator upstream in the propane delivery line.

The solenoid valve, when actuated at 12 volts dc, requires about 800 milliamperes current; or about 9.6 watts of power. This constitutes a vacuum switch contact derating of 50 percent (switch is rated at 12 volts dc, 1.5 amperes) to assure switch reliability. Solenoid valves of the type used typically exhibit mechanical life expectancies in excess of one million cycles of operation, provided they are not overstressed. Electrical power dissipation of only about 10 watts indicates no electrical overstress to produce premature, thermally induced failures.

In view of the foregoing, and conditioned upon the use of an upstream pressure regulator (and filter), it is estimated that the device reliability is in excess of 50,000 miles.

6.2.3.5 Maintainability

The developer stated that little or no maintenance is required, unless the LP gas is unusually dirty, in which case the regulator might need cleaning, perhaps once a year. The requirement for valve cleaning could be avoided by the use of a filter, which would be easier to clean or replace. It is estimated that filter maintenance could be performed once every 12,000 miles in less than 10 minutes, as opposed to about 45 minutes for cleaning the valve. There should be no repair requirement.

6.2.3.6 Driveability and Safety

This device was not tested during the retrofit study, nor did the developer supply driveability data. Therefore no evaluation was made as to the effects of this device on driveability.

No safety hazard has been identified provided an upstream propane pressure regulator is utilized at the LP gas container. It is required that pressure at the device not exceed its rating (250 psi maximum, for the device examined) and that the line pressure be sufficiently low to minimize stored energy release in the event of rupture.

6.2.3.7 Installation Description

The installation of this device consists in mounting an LPG tank in the trunk of the car, running a copper tube from the tank to a regulating valve assembly in the engine compartment, mounting the regulating valve assembly, attaching the pitot tube to the carburetor air intake and connecting this to the regulator valve output, and connecting a small vacuum hose from the air intake manifold to the body of the regulating valve assembly. Adjustment of the device consists in setting the output of the regulating valve assembly so that the engine does not ping on road test.

It is estimated that installation of the complete system would take about 2.5 hours. Table 6-28 summarizes the installation requirements. Installation could be accomplished in a normally equipped repair shop by the average mechanic.

6.2.3.8 Initial and Recurring Costs

Table 6-29 summarizes the installation costs for this device. From the information available, it is estimated that the installation cost, including material, would be about $117.50.

Recurring costs would increase mainly on the basis of the additional fuel that has to be bought. Assuming that an average of one gallon of propane would be used every 500 miles, 100 gallons would be used over the 50,000-mile vehicle service life assumed for retrofit applications. At 22¢ per gallon (no State road tax), the additional fuel cost would be $22.

6.2.3.9 Feasibility Summary

Though no emission data were evaluated, it would appear that this device would have only a secondary effect on the reduction of emissions, because of the small amount of propane used over many miles. The device may promote the use of low lead or unleaded gasoline, thus making the use of a catalytic converter more feasible; however, no test data indicating whether the device actually accomplishes this were provided. As a retrofit method for vehicle exhaust emission control, it may be assumed that the device as presently designed would probably not be applicable.

Table 6-28. DEVICE 282 LP GAS INJECTION INSTALLATION PROCEDURE

MINIMUM AVERAGE SKILL LEVEL: AUTOMOTIVE MECHANIC		
INSTALLATION AND ADJUSTMENT PROCEDURE	TOOLS, EQUIPMENT AND FACILITIES	TIME (MIN)
1. Mount gas regulator assembly under hood in engine compartment.	a. Electric drill b. Hand tools c. Pressure regulator assembly	30
2. Assemble a small hose with the pitot tube and attach between regulator output adjustment and air intake filter.	a. Hand tools b. Hose c. Pitot tube	10
3. Run a small hose from the regulator body input to the air intake manifold.	a. Hand tools b. T-fitting for rubber tubing	30
4. Run hose from regulator input to the LP tank which may be located in trunk of car.	a. Hole punches b. 10-20 feet 3/8-inch copper tubing c. Electrician's loom to protect tubing d. Hand tools	30
5. Install LP tank in trunk: can be 6-20 pound size bottle.	a. Brackets to hold bottle b. Hand tools c. LP tank	30
6. Install 45-degree pipe fitting on tank valve.	a. Hand tools b. 45-degree pipe fitting	5
7. Wire from vacuum switch to positive line-engine-run side of ignition switch, or use special switch in series if desired.	a. Hand tools b. Vacuum switch	15
8. Adjust screw on outlet of regulator until motor does not ping on road test.	Hand tools	30
	Total Time	3 hr

Table 6-29. DEVICE 282 LP GAS INJECTION INITIAL AND RECURRING COSTS

ITEM	DESCRIPTION	LABOR HOURS OR ITEM QUANTITY	COST (DOLLARS)
Initial Cost:			
Material			
1. Device	a. Pressure regulator assembly b. Pipe fittings c. Pitot tube d. Vacuum switch		45.00
2. Miscellaneous	a. 10-20 feet of 3/8-inch tubing b. Electricians loom c. LP gas bottle 6-20 pound capacity d. Bracket for bottle		35.00
Labor			
1. Installation		2.5 hr	31.25
2. Test and adjust		0.5 hr	6.25
		Total Initial Cost	$117.50
50,000-Mile Recurring Cost:			
Material			
1. Fuel	Additional propane (par. 6.2.3.8)	1 gal/500 miles over 50,000 miles = 100 gallons x $0.22/gal. = $22.00	$ 22.00
Labor			
1. Filter	Clean (par. 6.2.3.5)	1/6 hr every 12,000 miles at $12.50 hour over 50,000 miles	8.33
		Total Recurring Cost	$30.33
		TOTAL COSTS	$147.83

6.2.4 Device 457: Water Injection

Although no developer was found through the retrofit survey to be using water injection as a single approach to exhaust emission control, an early HEW/NAPCA report on the emission reduction benefit of water injection was obtained from EPA files (Reference 106). Information on the device was too limited to enable a complete system evaluation of this approach as a retrofit method.

Water injection as early as 1880 and during World War II, in aircraft engines, was used exclusively to prevent engine knock. It had a secondary advantage on wartime aircraft in that its cooling effect on the cylinder valves and the pistons prolonged their service life at high performance levels. The Reference 106 study was performed to confirm its effect on reducing the NOx emissions in automotive exhaust gases. This use of water injection was discussed in theory in 1960. Since NOx formation is basically a function of the peak combustion temperature and fuel-air mixture ratio (availability of oxygen), any means which affect either of these should have a corresponding effect on the NOx emissions. Reduction of NOx by use of rich fuel mixtures is not as desirable, because hydrocarbons and carbon monoxide tend to increase with a rich mixture. With water, combustion temperatures are lowered by the heat used to vaporize, superheat, and finally dissociate the water. The lower combustion temperature inhibits NOx without significantly affecting the other emissions.

Early tests indicated that at water-to-fuel ratio (on a weight basis) approaching 1:1, an 80 percent decrease in NOx could be achieved with only small fuel consumption increases and power losses, usually on the order of 10 to 12 percent.(Reference 106).

6.2.4.1 Physical Description

The water injection equipment was a commercial system sold for detonation control under a trade name. Water is introduced through a plate installed between the carburetor and intake manifold. Through incorporation of several toggle valves, the system could be made to operate whenever it was desired, as contrasted to its former use only at higher power conditions at wide open throttle. Air was introduced with the water at the large control valve to help atomize the water on discharge into the engine.

6.2.4.2 Performance Characteristics

The objective of the Reference 106 project was to confirm previous NOx reduction findings for roadload conditions and to test an intermediate engine load value representative of acceleration. Also, the effect of alcohol-water mixture at two different ratios was studied, to observe the effects on exhaust emissions. Alcohol would be added to the water in cold months to keep the water from freezing.

The results of this test program were as follows:

a. For part throttle operation with the engine tested, water injection ratios of 0.9 lbs. of water per pound of fuel gave NOx reductions of 75 to 80 percent without appreciable power losses or effects on hydrocarbon or carbon monoxide emissions.

b. Air-fuel ratios were essentially constant over the range of injection ratios investigated.

c. Exhaust gas temperatures increased with increase in the injection ratio for part throttle operations; and, conversely, under wide open throttle conditions, they decreased. Although there was no exact explanation for this, the leaning effect might account for the temperature increase.

d. Power loss was minimal with water-alcohol injection.

e. As part-throttle operation approached higher loads, the range of injection ratios becomes less due to their effect on power and hydrocarbon emissions.

Testing was performed on a 1963 Chevrolet with 283-CID engine.

Tests were conducted under the following conditions:

a. Roadloads equivalent to vehicle speeds from 30 to 70 mph, in 10 mph increments.

b. Intermediate loads (22 inches mercury manifold pressure) for the same speed range as in Step 1.

c. Wide open throttle at 30 and 50 mph.

For each of these operating conditions, the injection ratios tested ranged from 0.3 to 1.1 lbs. of water per pound of fuel. Water-alcohol injection, was tested only at 50 mph roadload on two different mixture ratios (80/20 and 60/40 percent respectively).

Changes in engine torque at constant speed settings were compensated for by throttle adjustment. Initially, spark timing changes were used to maintain engine performance. This was discontinued because of its more adverse effect on hydrocarbon emissions.

6.2.4.3 Performance Characteristics

In all cases, the largest reduction in NOx was obtained at the highest injection ratio (1.1). Through 60 mph, the NOx reduction at this ratio averaged 84.5 percent. Above 60 mph, the gains in NOx reduction became less because of the limitation on injection ratios that can be used without adversely affecting power or the other pollutant emissions. At 70 mph, roadload, the maximum ratio was 0.5. For wide open throttle operation, the only ratio which gave an NOx reduction was 0.3 and this was restricted to 30 mph. At 50 mph, wide open throttle, NOx and HC increased by 22 and 32 percent, respectively (Reference 106).

With alcohol-water injection, the 20/80 percent solution decreased NOx concentration by 80 percent with only a marginal increase of 4 percent in hydrocarbons. The 40/60 percent solution reduced NOx by 84 percent but hydrocarbon concentration increased to 52 percent. Throttle adjustments to hold power with the alcohol mixtures were very slight compared to straight water injection. With the latter, increases in manifold pressure became evident at about a 0.5 injection ratio. At the maximum ratio, the manifold pressure usually increased between 1.5 and 2.0 inches mercury above the baseline setting at any test condition (Reference 106).

6.2.4.4 Feasibility Summary

The Reference 106 report concluded that:

a. An injection system should be tested on the road and/or under cycling conditions on the chassis dynamometer for emission evaluation and driveability.

b. The continuous effects of water injection on engine durability should be evaluated.

c. The design and economic feasibility of incorporating water on a passenger car should be determined.

d. The effect water injection on specific groups of hydrocarbon under similar test conditions should be determined.

It appears to be generally accepted and reasonably substantiated that water injection modifies the combustion process such that the peak temperatures are reduced in the combustion process, thereby reducing the formation of NOx emissions. The peak temperature is reduced because of the dilutent effect of water on the combustion process in that the water must be heated to the temperature of combustion gases, but does not undergo chemical reaction or contribute to energy release.

Intake-manifold water injection has a further advantage in that its evaporation cools the gases in the induction system. This increased gas density results in higher mass flows through the engine and thereby provides higher maximum power levels. A disadvantage of water injection is the possible formation of sludge in the engine crankcase and acceleration of engine wear. Also at high injection ratios, driveability is unacceptable due to excessive power loss.

In summary, it may be concluded that water injection would offer only limited retrofit control applicability, because it is mainly an NOx control.

6.3 FUEL CONDITIONER - RETROFIT SUBTYPE 1.4.3

This category of retrofit device attempts to modify the fuel for improved combustion by means of electrical treatment. Two devices were found in this category through the retrofit method survey.

6.3.1 Device 36: Fuel Conditioning by Exposure to Electromagnetic Field

Contact with the developer of this device was not completed during the retrofit study due to insufficient address information; however, limited evaluation of the device's emission reduction effectiveness was possible on the basis of a HEW/NAPCA test report (Reference 107).

6.3.1.1 Physical Description

This device installs in the fuel line between the fuel pump and carburetor and subjects the fuel to a low intensity magnetic field from a series of permanent magnets and a 12-volt battery.

6.3.1.2 Functional Description

The developer reported to HEW/NAPCA that "the low intensity magnetic/electrostatic field orients disordered molecular arrays to improve vaporization and atomization characteristics of the fuel." The developer stated that his testing "indicated that the effects were more closely related to the pre-reaction phenomena, including pyrolysis of fuel, than the terminal phase of the combustion process." The net effect is claimed to be a change in combustion chamber deposits, less smokey exhaust, reduced engine knock with lower grade fuels, and reduced emissions.

6.3.1.3 Performance Characteristics

Emission tests conducted by HEW/NAPCA are summarized in Table 6-30. A single vehicle was driven 2,932 miles without the device to establish an emission baseline and 2,735 miles with the device to determine its emission reduction effectiveness.

At approximately 500-mile intervals, hot start emission tests (1970 Federal procedure - CVS) were conducted on the test vehicle.

6.3.1.4 Feasibility Summary

The HEW/NAPCA report concluded that, based on the test program, the device did not appear to affect exhaust emissions reductions.

Table 6-30. DEVICE 36 FUEL CONDITIONING BY EXPOSURE TO ELECTROMAGNETIC FIELD EMISSION TEST RESULTS (REFERENCE 107) (1)

VEHICLE CONFIGURATION	POLLUTANT (GM/MI)		
	HC	CO	NO_x
Without Device (2)	7.12	48.8	Not Measured
With Device (3)	8.02	50.0	
Percent Reduction	-12.5	-0.4	

(1) Average of results from 1 baseline and 11 retrofit tests using 1970 Federal Test Procedure (Reference 15)

(2) Average of 13 tests during 2,932 miles

(3) Average of 11 tests during 2,735 miles

6.3.2 Device 279: Fuel Activator

This device is patented and is currently marketed as an "activator" for either gasoline or diesel fuels. The device operates off electric power from the battery. The developer stated that the device "distorts the molecular structure of the elements present in hydrocarbon fuels and utilizes electric current to fix this distortion." The developer claims that the automatic activation of fuel by this device (1) saves as much as 15 percent of actual fuel costs, (2) eliminates air pollution by as much as 80 percent, and (3) reduces maintenance costs 25 percent.

6.3.2.1 Physical Description

A schematic of this device is shown in Figure 6-17. The device is a steel tube approximately 2 inches in diameter and 8 inches long with threaded closures on both ends. Two manganese steel electrodes enter the end caps through insulators at opposed ends. The photographed part shows two spark plugs mounted on one end. According to the drawing and developer supplied information, three magnets in the form of perforated desks are mounted inside the tube. The entire inside surface of the tube and closures is said to be coated with mercury. Two nipples are provided at opposite end closures for connection of fuel inlet and discharge lines.

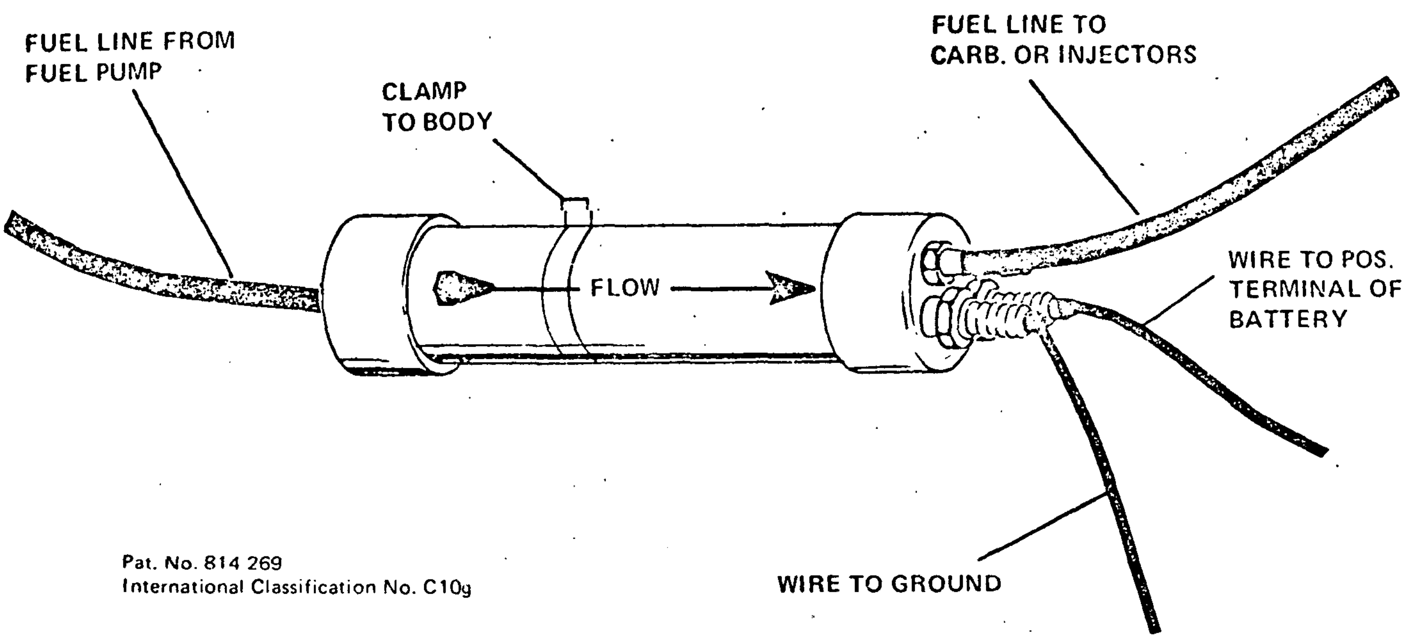


Figure 6-17. DEVICE 279 FUEL CONDITIONER FUNCTIONAL SCHEMATIC (DEVELOPER DATA)

6.3.2.2 Functional Description

The developer's patent disclosure claim is that the device is

"(1) A method for increasing the combustion efficiency of liquid fuel consisting of subjecting the fuel simultaneously to a magnetic field produced between two adjacent like poles and to an electrostatic field a short period of time prior to its combustion.

"(2) An apparatus to increase the combustion efficiency of liquid fuel, comprising a closed metal receptacle, openings in the opposite ends of said receptacle for inlet and outlet of the fuel, at least two permanent magnets with their like poles adjacent placed in the path of the fuel, two electrodes placed in the path of the fuel and a film of mercury amalgamated with the interior surface of said receptacle.

"(3) An apparatus as in Claim (2) in which said magnets are centrally perforated discs, their faces being the poles of said magnets.

"(4) An apparatus as in Claim (2) wherein said electrodes are coaxially mounted manganese steel rods."

6.3.2.3 Performance Characteristics

Table 6-31 presents a summary of performance information supplied by the developer from tests conducted on a 1969 Chevrolet by Stevens Institute of Technology in April 1971. The small decreases in HC and NOx emissions indicated by these hot start tests are not considered significant. The CO emission reduction, though relatively more effective, would not alone justify use of the device for emission control purposes.

Table 6-31. DEVICE 279 FUEL CONDITIONER EMISSION TEST RESULTS REPORTED BY DEVELOPER (1)

VEHICLE CONFIGURATION (2)	POLLUTANT		
	HC, ppm	CO, %	NO_x, ppm
Without Device	147	0.53	1,508
With Device	142	0.40	1,442
Percent Reduction	3.4	24.5	4.3

(1) Results obtained by Stevens Institute of Technology using 1970 Federal Test Procedure (Reference 15), one cycle 6 and 7 hot test without and one with the device installed.

(2) 1969 Chevrolet Kingswood equipped with 372-CID V-8 engine with two-barrel carburetor and automatic transmission. Odometer reading was 31,539 miles at beginning of the tests.

6.3.2.4 Reliability

Examination of the device's construction indicates that it should remain structurally and functionally intact for at least 50,000 miles.

6.3.2.5 Maintainability

No maintenance requirement is anticipated other than replacement of electrical wiring if necessary.

6.3.2.6 Driveability and Safety

Since the device was not tested in the retrofit study and the developer supplied no driveability data, the effects of this device on driveability were not evaluated.

Internal construction of the device, and materials used are not known. It might be possible with applied voltage across the internal insulation to cause ionization resulting in a low resistance path between the electrodes. This might cause a potential fire hazard in the fuel line.

6.3.2.7 Installation Description

Installation of this device consists in mounting the fuel activator in the engine compartment close to the fuel pump, connecting the activator into the fuel line between the fuel pump and the carburetor, and connecting the device's electrical wires to the battery and to ground.

The developer estimated that one-half hour of labor would be required to install the device. Table 6-32 summarizes the installation requirements. Installation could be accomplished in a normally equipped repair shop by the average mechanic.

Table 6-32. DEVICE 279 FUEL CONDITIONER INSTALLATION PROCEDURE

MINIMUM AVERAGE SKILL LEVEL: AUTOMOTIVE MECHANIC		
INSTALLATION AND ADJUSTMENT PROCEDURE	TOOLS, EQUIPMENT AND FACILITIES	TIME (MIN.)
1. Install Fuel Activator in engine compartment close to fuel pump using clamp to body and sheet metal screws.	a. Electric drill sheet b. Metal screws c. Fuel activator	20
2. Cut fuel line between fuel pump and carburetor and insert Fuel Activator into fuel line.	Hand tools, clamps	5
3. Connect one wire from unit to positive terminal of battery.	Wire	3
4. Connect wire from unit to ground.	Wire	2
	Total Time	0.5 hr.

6.3.2.8 Initial and Recurring Costs

The developer estimated that the purchase price of this device would be $5.00. Table 6-33 summarizes the installation costs. It is estimated that the cost of installing this device including material, would be $16.25. No recurring costs were identifiable.

6.3.2.9 Feasibility Summary

This device appears to be infeasible as a retrofit emission control device. The test data provided by the developer, though not based on a wide test sample, indicates no significant reductions in HC or NO_x emissions, and only a nominal reduction in CO.

Table 6-33. DEVICE 279 INITIAL AND RECURRING COSTS

ITEM	DESCRIPTION	LABOR HOURS OR ITEM QUANTITY	COST (DOLLARS)
Initial Cost:			
Material			
1. Device	Fuel Activator		10.00
2. Miscellaneous	a. Sheet metal screws b. Clamps c. Electric wire		(Included in above)
Labor			
1. Installation	Electric Drill	0.5	6.25
2. Test and adjust			
		Total Initial Cost	$16.25
Recurring Cost:			None
		TOTAL COSTS	$16.25

SECTION 7

GROUP 2 RETROFIT METHOD DESCRIPTIONS
CRANKCASE EMISSION CONTROL SYSTEMS

Crankcase emission control systems normally provide a means of directing crankcase blowby gases and ventilation air to the intake manifold for induction along with the carburetor air-fuel mixture. These systems are commonly referred to as positive crankcase ventilation (PCV) devices. The method of controlling the amount of blowby gases is the key to each of the approaches in this type of device. A second control provided by some devices of this type is to filter impurities from the blowby gases, to prevent the degrading effect they might have on the fuel induction system and combustion. In addition, some of these devices appear to decrease exhaust emissions. All emission test results reported for the devices were exhaust emissions data. None of these devices was tested in the retrofit program for either exhaust emissions or blowby control effectiveness.

These devices normally should control the crankcase blowby flow so that air-fuel mixtures are not upset. Normally, the blowby gas is unburned air-fuel mixture that leaks past the piston rings during compression and combustion strokes. When this blowby is recirculated to the intake manifold, it does not change the air-fuel ratio of the incoming mixture because the two mixtures are of the same air-fuel ratio. However, the crankcase ventilation air does slightly lean the air-fuel mixture.

On pre-1968 vehicles which were factory equipped with PCV systems, use of the air-bleed retrofit systems may cause excessively lean air-fuel ratios which might cause "lean misfire." This could result from a combination of high ventilation airflow rates through the PCV valve and the additional air provided by an air-bleed system installed between the PCV valve and the intake manifold. High crankcase ventilation air flow rates are more likely to occur on newer PCV-equipped vehicles, which have low blowby flow rates. As a vehicle accumulates mileage, the blowby flow rate generally increases and the amount of ventilation airflow decreases. Thus, the possibility of excessive air ventilation decreases with vehicle age. However, when PCV is used in combination with the air-bleed device, the air-bleed may reduce the PCV outlet absolute pressure, and cause the PCV valve airflow rate to increase at a given manifold vacuum. For example, at low speeds and at 14 inches of mercury manifold vacuum, the PCV valve outlet vacuum and the manifold vacuum would be about the same without the air-bleed retrofit device installed. The addition of an air-bleed device may lower the PCV outlet vacuum to 12 inches of mercury, resulting in a premature increase of PCV airflow which could overlean the air-fuel mixture.

In the retrofit study, there were five PCV systems found to be available for retrofit use. These systems are listed in Table 7-1. As shown, one of these systems is of the combination air-bleed-blowby type.

Table 7-1. GROUP 2 CRANKCASE EMISSION CONTROL SYSTEMS

CLOSED SYSTEM - TYPE 2.1	
DEVICE NO.	NOMENCLATURE
24 (1)	Heavy Duty Positive Crankcase Control Valve with Air Bleed
170 (2)	Closed Blowby Control System
315	Closed Blowby Control System
OPEN SYSTEM - TYPE 2.2	
160 (2)	Closed or Open Blowby Control System with Filter
427	Closed or Open Blowby Control System with Filter

(1) Previously tested by EPA
(2) Accredited for use in California.

7.1 CLOSED SYSTEM - RETROFIT TYPE 2.1

Crankcase emission control systems are classified as open or closed. In open systems, ventilation air is taken directly from the engine compartment through the oil filler cap and circulated through the crankcase, mixing with blowby gases, and circulated to the intake manifold. Closed systems are similar to open systems except that they receive ventilation air through the carburetor air cleaner. One of the devices described in this section is classified as a "sealed" system. In this system there is no ventilation air circulated through the crankcase. Only blowby gases are inducted into the intake manifold through the flow control system.

7.1.1 Device 24: Heavy Duty Positive Crankcase Control Valve with Air Bleed

This device is a combination air bleed and blowby recirculation system. The device is in production and, according to information from the developer, thousands have been sold. The system description is based on developer data and an EPA exhaust emissions test report. Because of the air-bleed capability, the device might have some effectiveness in controlling exhaust as well as blowby emissions.

7.1.1.1 Physical Description

The overall system consists of a variable orifice (or jet) valve (called a power booster by the developer) that connects to the intake manifold, and a blowby gas oil separator and filter unit that installs in the blowby line between the variable valve and the crankcase. The valve components and the separator unit are shown in Figure 7-1.

7.1.1.2 Functional Description

The variable valve contains a jet which proportions the amount of air added according to intake manifold vacuum. This valve replaces the conventional PCV valve. The principal component is a piston that is controlled by manifold vacuum. The jet permits additional air to be drawn through the crankcase by the vacuum. This is claimed to give effective pollution control, proper fuel mixture and full engine power; by adding air to the blowby mixture, unburned fuel in the blowby is claimed to be burned more efficiently to increase fuel mileage.

The filter (only) used in conjunction with the valve was approved by California in 1966. Basically, the filter is dual chambered with an integral series of baffles to separate oil from blowby fumes, and to filter sludge-forming hydrocarbons. The oil separated from the blowby fumes is gravity fed back to the crankcase. Since no oil is burned with the exhaust fumes, spark plugs are said to stay cleaner and last longer. Hydrocarbons are removed from the blowby by condensing them and depositing them in the sludge trap chamber. As a result, the filter is said to increase the life of exhaust and PCV parts and retard sludge buildup in the engine.

7.1.1.3 Performance Characteristics

The results of EPA exhaust emission tests on this device are summarized in Table 7-2. The EPA report concluded that the exhaust emission reductions with the device were marginal, as was any fuel savings.

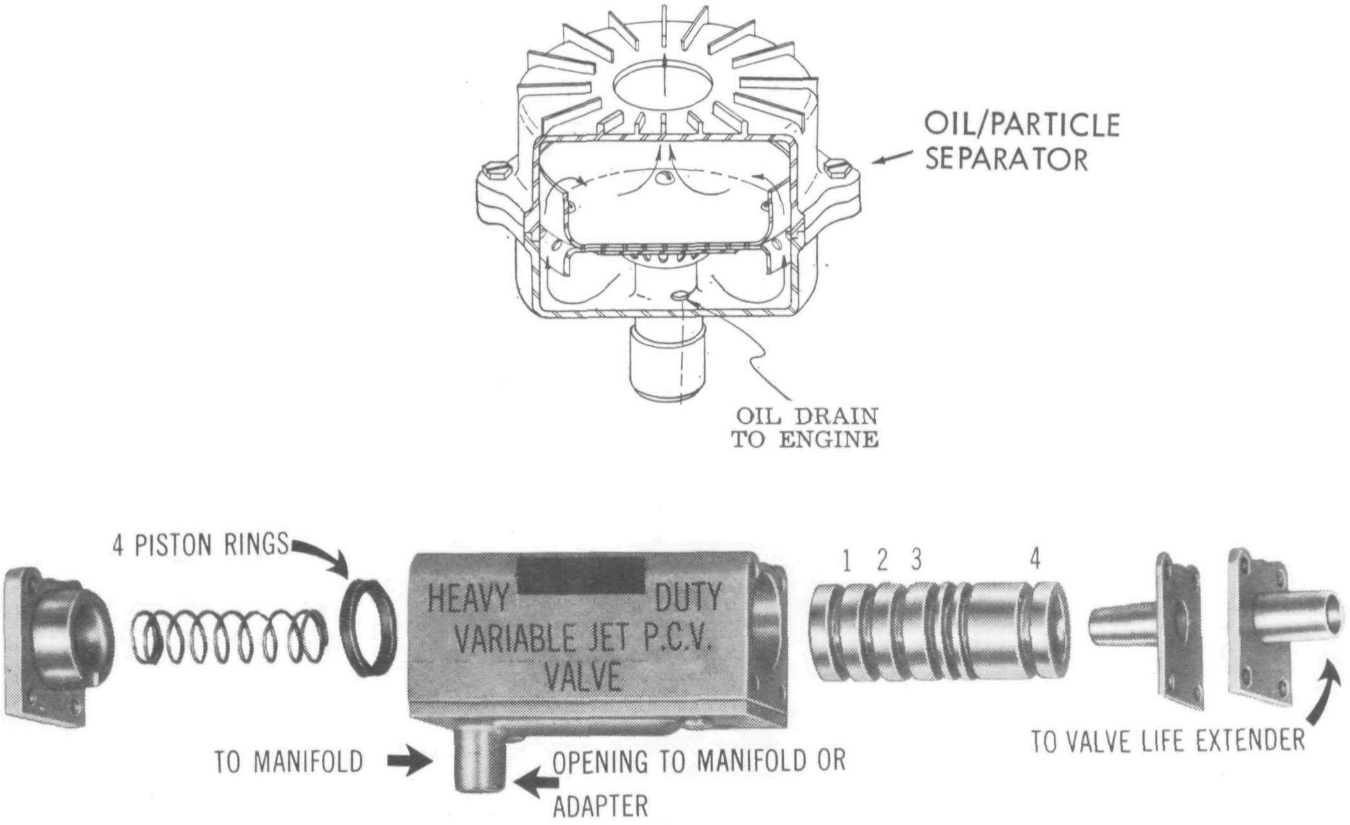


Figure 7-1. DEVICE 24 SYSTEM COMPONENTS (DEVELOPER DRAWING)

Table 7-2. DEVICE 24 HEAVY DUTY POSITIVE CRANKCASE CONTROL VALVE WITH AIR BLEED EXHAUST EMISSION TEST RESULTS REPORTED BY EPA (REFERENCE 95) (1)

VEHICLE CONFIGURATION (2)	POLLUTANT (GM/MI)		
	HC	CO	NOx
Without Device	4.63	50.36	6.59
With Device	4.45	44.03	6.10
Percent Reduction	3.9	12.6	7.4

(1) Average of 6 tests without device and 5 with device for CO and HC, and three without plus four with for NOx. All tests were performed in accordance with the 1972 Federal Test Procedure (Reference 3).

(2) 1970 Chevrolet with 350-CID engine and automatic transmission.

7.1.1.4 Reliability

Use of the device on thousands of vehicles would indicate that it has adequate service life reliability. The developer (who also manufactures the device) warrants the device for 100,000 miles without defects or partial failures. This would appear to be a reasonable MMBTF, provided that the device is maintained as specified by the developer.

7.1.1.5 Maintainability

According to the developer, the device should be removed, disassembled and cleaned with solvent every 25,000 miles (MMBM).

Both the filter and the variable orifice valve may be cleaned in carburetor cleaner or any solvent. It is not necessary to remove the piston rings when cleaning.

It is estimated that this cleaning operation would take about 15 minutes (0.25 hr MTTM).

7.1.1.6 Driveability and Safety

The device apparently has no driveability or safety problems. A major installer of the device reported that fuel economy on his own cars increased from two to five miles per gallon with greater engine power and smoother performance. His customers had the same experience with the system.

7.1.1.7 Installation Description

According to the developer, there is no restriction as to where to install the valve. It may be mounted wherever space will allow, as it can be operated in any position. The filter unit, however, must always be ahead of the valve. The vacuum passage to the carburetor must be 5/16 inch or larger. In some cases, it is necessary to remove the carburetor and run a 5/16-inch reamer through steel tubing into the aluminum housing and enlarge the hole from the bottom to meet the reamed hole. Average installation time, including adjustment of the carburetor air-fuel ratio, would be about 0.75 hr. Installation could be performed in the average repair shop with mechanic skill level.

7.1.1.8 Initial and Recurring Costs

Initial purchase and installation costs would be about $34. Unit costs are as shown in Table 7-3.

7.1.1.9 Feasibility Summary

Based on EPA test results, this device appears to provide marginal effectiveness for the reduction of exhaust gas emissions. The principal pollutant controlled appears to be CO. This conclusion is based on limited test data, and does not apply to the device's use to control blowby gases from being emitted to the atmosphere from the crankcase. As a blowby control, the device would appear to be both technically and economically feasible. Use with other air-bleed type systems would possibly require testing to establish compatibility.

Table 7-3. DEVICE 24 HEAVY DUTY POSITIVE CRANKCASE VENTILATION WITH AIR BLEED INITIAL AND RECURRING COSTS

ITEM	DESCRIPTION	LABOR HOURS OR ITEM QUANTITY	COST (DOLLARS)
Initial Costs:			
Material			
1. PCV Valve			14.95
2. Life Extender			7.95
3. Hoses			1.50
Labor			
1. Installation	Paragraph 7.1.1.7	0.75 hr (1)	9.38
		Total Initial Cost	33.78
50,000-Mile Recurring Costs:			
Material			
1. Fuel (2)			
Labor			
1. Cleaning	Clean valve and filter every 25,000 miles	0.25 hr @ $12.50 per hr x 2 cleanings	6.25
		Total Recurring Cost	6.25
		TOTAL COSTS	40.03

(1) Replacement time for the PCV valve only is estimated to be 0.2 hour.

(2) Fuel economy reported, but no specific data provided.

7.1.2 Device 170: Closed Blowby Control System

This device provides modifications which seal the crankcase from the atmosphere and provide controlled recirculation of crankcase blowby gases to the intake manifold and carburetor air cleaner. The basic purpose of this device is to control HC blowby emissions and minimize crankcase contamination. Recirculation of blowby gases to the induction system is accomplished without mixing them with air. Recirculation of additional air, as with a conventionally ventilated crankcase, is eliminated.

This device was certified as a crankcase emission control device by the California Air Resources Board in September 1965. According to the developer, approximately 10,000 units were manufactured before production was terminated. Several thousand units were marketed. California accreditation was transferred to a new legal owner in December 1970. Manufacturing and marketing plans are being implemented by the new owner.

A limited amount of test data indicates this device may be effective in reducing HC and NOx exhaust emissions, in addition to controlling crankcase blowby.

7.1.2.1 Physical Description

Components of this system are shown in the simplified drawing of Figure 7-2. The principal component is the combination pressure-relief, adjustable-flow valve shown in Figure 7-3.

The system shown in Figure 7-2 includes the following components:

a. A combination relief and adjustable flow valve (B) which regulates the recirculation of crankcase gases to the intake manifold and carburetor air cleaner.

b. A 5/8-inch inside diameter (I.D.) hose connected between the crankcase outlet (A) and the combination valve (B).

c. A 3/8-inch I.D. hose connected between the intake manifold (D) and adjustable flow valve outlet port (C) of the combination valve (B).

d. A 5/8-inch I.D. hose connected between the relief valve outlet port (E) and the carburetor air cleaner (F).

e. Crankcase sealants consisting of a rubber plug for the road draft tube and a rubber sealant for the dipstick cup.

The three hoses used in this system are standard neoprene rubber automotive hose. Sealant for the dipstick is obtained by potting the dipstick cap with room temperature vulcanizing rubber.

The principal component of the system is the combination adjustable flow and relief valve shown in Figure 7-3. This assembly consists of a molded plastic tee having four parts. Attached to one part is a plastic 5/8-inch inside diameter hose nipple which accepts the inlet hose from the crankcase.

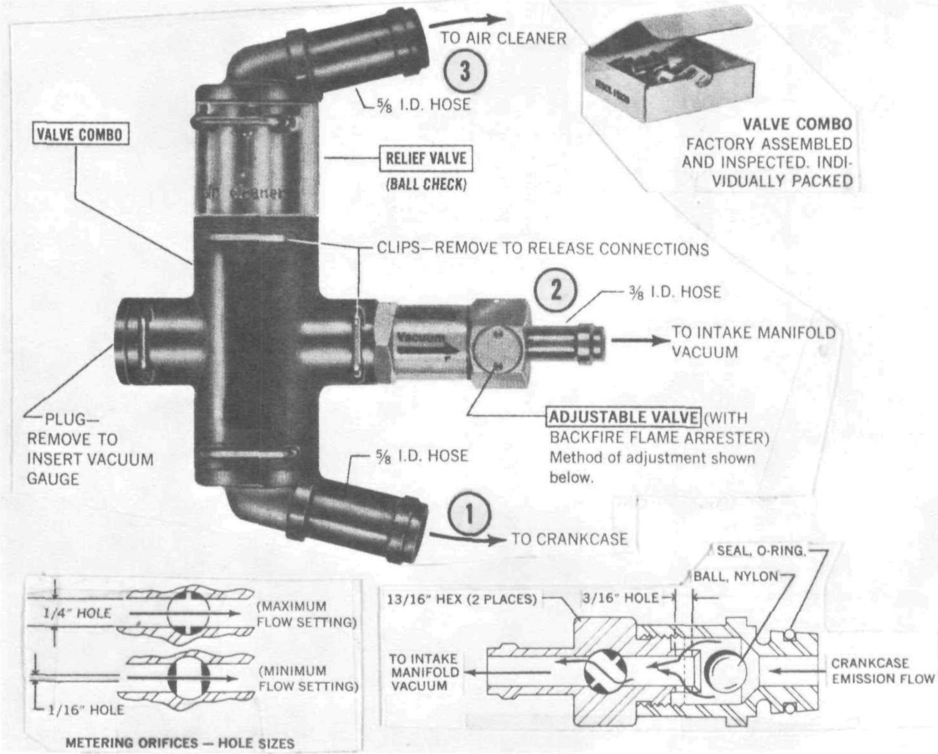


Figure 7-2. DEVICE 170 CLOSED BLOWBY CONTROL SYSTEM (DEVELOPER DRAWING)

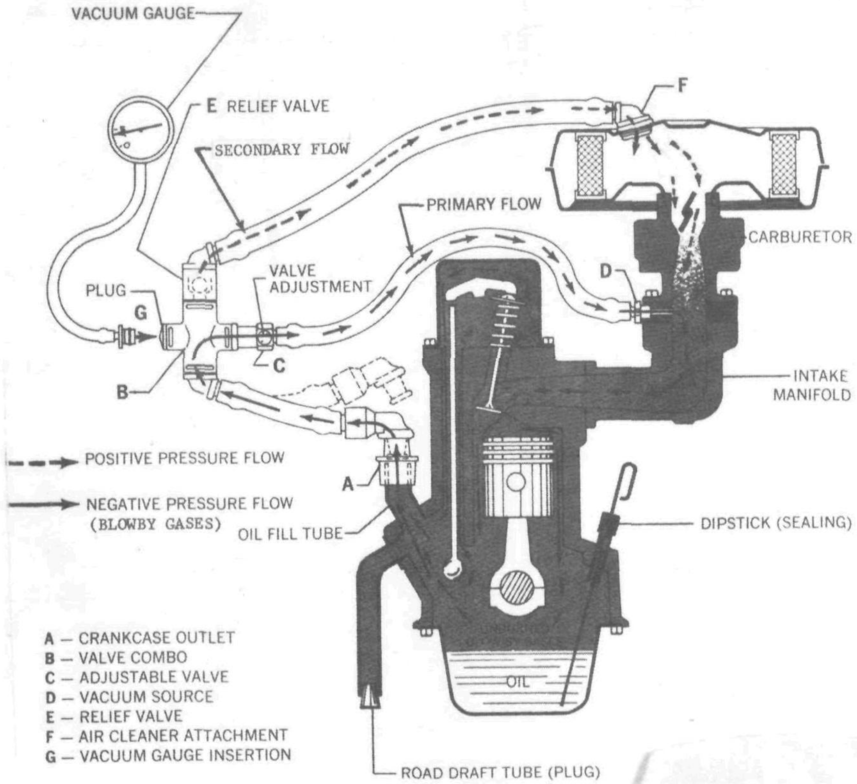


Figure 7-3. DEVICE 170 CLOSED BLOWBY CONTROL SYSTEM ADJUSTABLE BLOWBY FLOW AND PRESSURE RELIEF VALVE (DEVELOPER DRAWING)

Attached to a second port is a metal adjustable valve assembly with a 3/8-inch inside diameter hose nipple which connects to the hose leading to the intake manifold. The valve assembly includes a ball type check valve which prevents backfire from the intake manifold to the crankcase.

The adjustable valve is set at the time of installation to meter desired blowby flow and may be reset at maintenance intervals to reestablish flow regulation if required.

The third port is to a ball type relief and check valve. This valve is designed so that it only opens to flow crankcase vapor when the crankcase pressurizes to inch water above local atmospheric pressure. The valve will also check close to prevent any flow reversal into the intake manifold.

The fourth port has a removable plug which is removed for installation of a vacuum gage. The vacuum gage is used to set the adjustable metering valve during installation and maintenance.

The components described herein have been mass produced. Tooling exists for plastic molded and die cast parts.

7.1.2.2 Functional Description

Figure 7-2 indicates the functional concept of this device. At time of installation all openings leading to the crankcase are sealed or plugged to make the device a closed system. Outside air, dirt, and moisture cannot get in through the normal ventilation paths. Blowby gases are returned to the intake manifold and on to the combustion chambers.

The engine intake manifold vacuum is utilized as a motive force to circulate the flow of emissions through the hose network and to create a moderate vacuum in the crankcase at warm idle condition. A crankcase vacuum of 4 to 5 inches of mercury at idle conditions is established by adjusting the metering valve (B in Figure 7-2). The adjustment is made using a special valve adjust tool provided by the developer.

The closed system operates as follows (Figure 7-2):

a. Primary flow blowby gases are withdrawn from crankcase at outlet (A). They are metered through variable orifices in the adjustable valve (C), then flow into the intake manifold through a fitting located at or near base of carburetor at (D). Flow is active in this part of the system during all modes of operation.

b. Secondary Flow - When intake manifold vacuum is inadequate to handle all blowby gases in the primary flow circuit, crankcase will start to pressurize. The relief valve at (E) responds and opens at about 0.5-inch water crankcase pressure and allows excess blowby to pass into carburetor inlet through a fitting on the air cleaner (F).

c. Backfire Condition - Ball-check flame arresters are located at (C) and (E) to prevent backfire from entering crankcase at all times.

7.1.2.3 Performance Characteristics

Presented in Table 7-2 is a summary of exhaust emission performance data supplied by the developer. The emission data shown consist of a single California seven-mode hot start test conducted on a 1956 Chevrolet with and without the device. This single test indicates that the device may be effective in reducing HC and NOx exhaust emissions. Examination of the developer's report indicates that exhaust baseline data were obtained with "device disconnected."

Table 7-4. DEVICE 170 CLOSED BLOWBY CONTROL SYSTEM EXHAUST EMISSION TEST RESULTS (DEVELOPER DATA) (1)

VEHICLE CONFIGURATION	POLLUTANT (GM/MI)		
	HC (PPM)	CO (%)	NOx (PPM)
Without Device	440	3.5	1,520
With Device	395	4.4	810
Percent Reduction	10	-31	47

(1) Results of one 7-mode hot start cycle with and without device installed on a 1956 Chevrolet, using the California 7-cycle, 7-mode test procedure (Reference 115). The vehicle had a 265-CID engine with 4-barrel carburetor and automatic transmission. Odometer reading was 82,677 miles at start of testing.

7.1.2.4 Reliability

The developer estimated a device reliability of 100,000 mean-miles-before-total-failure (MMBTF). The estimate is based upon an estimated 7,000 vehicle installations with no report of failure. The device is accredited by the California Air Resources Board. Since the device consists functionally of two simple free-ball valves and a metering orifice, the manufacturer's reliability estimate appears reasonable.

7.1.2.5 Maintainability

The developer estimated the need for 15 minutes of maintenance at 12,000-mile intervals. This would consist in cleaning the device and resetting the orifice, if necessary. Following are the developer's detailed maintenance requirements:

<u>Relief Valve</u>

1. Remove from hose network and disassemble by withdrawing clip.

2. Submerge parts in solvent or kerosene. Clean all surfaces with stiff brush. Rinse with clean solution and dry using air gun.

3. Inspect nylon ball and O-rings. Replace if required.

4. Assemble valve and re-install to system.

Note: Replacement O-rings and nylon balls are supplied in the inspection and maintenance kit.

Hoses and Hardware

All hose interiors should be flushed with solvent or kerosene. Force dry using air gun.

All other hardware components to be cleaned by conventional methods.

Adjustable Valve

1. Remove valve from hose network and disassemble, using 13/16" hex wrench.

   Caution - hold hand in position to catch nylon ball if it drops out when the parts separate.

2. Submerge parts in solvent or kerosene to soften hard deposits and varnish.

3. Probe all hole passages with proper size drills. To clean orifices, use valve adjust tool. Rotate orifices to align holes for cleaning. Drills should be rotated with hand pressure only.

4. Rinse all parts in clean solution and dry with air gun.

5. Inspect nylon ball. If badly pitted or worn, it should be replaced. O-ring seals distorted or damaged also should be replaced.

6. Assemble the valve and re-install to original location in the system.

7. Reset orifices for idle-vacuum per inspection procedure.

Inspection Procedure

1. Start engine and establish warm-idle condition.

2. Insert vacuum gauge into system to read crankcase idle-vacuum.

3. Read idle-vacuum. If gauge reads -4 to -5, system is O.K. If reading is below -4, restore the idle vacuum by increasing flow through the adjustable valve. (Insert tool as shown in Figure 7-4 and rotate toward maximum setting.)

It is estimated that the indicated maintenance could be accomplished in 15 minutes, exclusive of engine warmup time after the device has been cleaned. No repair requirement is anticipated.

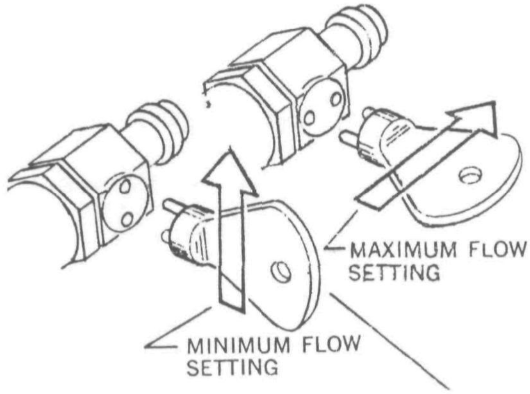


Figure 7-4. DEVICE 170 CLOSED BLOWBY CONTROL SYSTEM ADJUSTMENT PROCEDURE

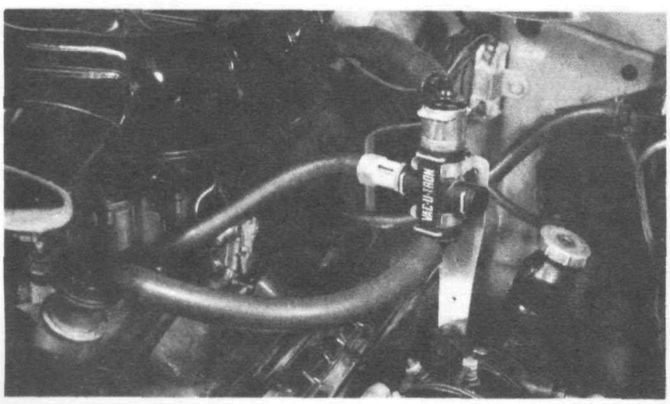
7.1.2.6 Driveability and Safety

This device was not tested during the retrofit study and the developer supplied no driveability data. Although no evaluation was possible as to the effects of this device on driveability, the fact that it has been used on 7,000 vehicles would indicate that it does not affect driveability adversely.

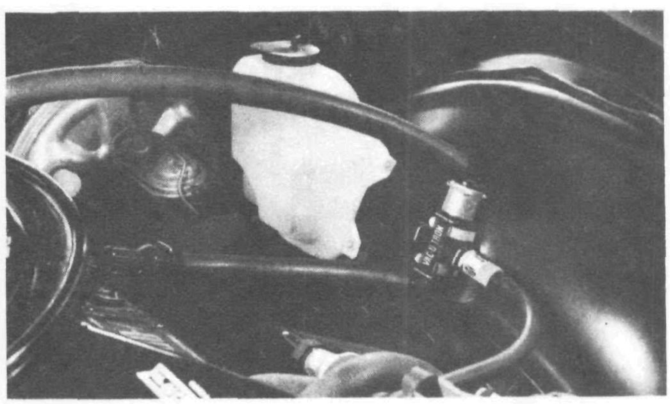
7.1.2.7 Installation Description

This device installation consists in removing the presently installed PCV valve, installing a special valve in the engine compartment, connecting hoses from the valve to the crankcase, air cleaner, and intake manifold, and sealing all other outlets to the crankcase. Adjustment of the device consists in setting the valve so that crankcase vacuum reads 5 inches of mercury with the engine at idle. Adjustment of the engine requires adjusting the carburetor idle mixture as necessary to restore normal idle.

Table 7-5 contains a more detailed description of the installation procedure and identifies tools and special equipment required. Figure 7-4 illustrates adjustment of the valve and Figure 7-5 shows a typical installation. Installation can be accomplished in a normally equipped repair shop with average skills.



VALVE COMBO attached directly to engine accessory to utilize shorter length hoses.



VALVE COMBO attached to structure of engine compartment for ease of installation.

Figure 7-5. DEVICE 170 CLOSED BLOWBY CONTROL SYSTEM INSTALLATION (DEVELOPER PHOTOS)

Table 7-5. DEVICE 170 CLOSED BLOWBY CONTROL SYSTEM INSTALLATION PROCEDURE

MINIMUM AVERAGE SKILL LEVEL: AUTOMOTIVE MECHANIC		
INSTALLATION AND ADJUSTMENT PROCEDURE	TOOLS, EQUIPMENT AND FACILITIES	TIME (MIN.)
1. Inspect engine for leakage to insure that when system is installed the crankcase can maintain a vacuum		15
2. Install mounting bracket in engine compartment	a. Hand tools b. Mounting bracket	5
3. Attach valve combination to mounting bracket	a. Hand tools b. Valve combination	5
4. Remove PCV valve and hose	Hand tools	5
5. Install hose hookup to rocker arm cover	a. Hand tools b. Hose hookup	15
6. Install hose hookup to air cleaner	a. Hand tools b. Hose hookup	15
7. Connect hose from rocker arm cover to valve combination, from valve to intake manifold, and from valve to air cleaner	Hose	10
8. Plug and seal all other outlets to crankcase	a. Hand tools b. Plugs and sealant	20
9. Start engine and adjust valve until vacuum gage installed at valve reads 5 inches of Hg	Vacuum gage	5
10. Make adjustments as necessary to carburetor to restore normal idle	Tachometer	10
	Total Time	1.75 hr

7.1.2.8 Initial and Recurring Costs

The developer estimated that the cost of the device should be $12 to $17. Table 7-6 summarizes the installation costs for this device. From the information available, it is estimated that the cost for installing this device, including material, would be $33.87 to $38.87.

7.1.2.9 Feasibility Summary

Limited test data provided by the developer indicate that this device might be effective in reducing HC and NOx exhaust emissions, with a possible penalty in increased CO emissions. Additional tests would be required to establish the statistical significance of this exhaust emission reduction effectiveness. The device is well designed for production as an accredited retrofit crankcase control device in California, and several thousand units have been manufactured and sold in California for this application.

Table 7-6. DEVICE 170 CLOSED BLOWBY CONTROL SYSTEM INITIAL AND RECURRING COSTS

ITEM	DESCRIPTION	LABOR HOURS OR ITEM QUANTITY	COST (DOLLARS)
Initial Cost:			
Material			
1. Device	a. Valve mounting bracket b. Valve combination		12.00-17.00
2. Miscellaneous	a. Hose hookup b. Hose c. Plugs and sealant		(Included in above)
Labor			
1. Installation	Table 7-5	1.5 hr	18.75
2. Test and adjust	Table 7-5	0.25 hr	3.12
		Total Initial Cost	33.87-38.87
50,000-Mile Recurring Cost:			
Labor			
1. Inspect, clean, and adjust	Paragraph 7.1.2.5	0.25 hr every 12,000 miles @ $12.50 per hr	12.50
		Total Recurring Cost	12.50
		TOTAL COSTS	51.37

7.1.3 Device 315: Closed Blowby Control System

Categorized as a Type 2.1 closed crankcase emission control retrofit system, the device described below is actually (as described by its developer) a sealed system. That is, there is no opening for ventilation airflow and flow of blowby gases and crankcase fumes other than the controlled passage to the intake manifold. However, a relief or safety valve may be installed in the crankcase. The device includes provisions designed to facilitate a more thorough mixing of fuel and air (presumably) along with the crankcase emissions.

The principal feature of Device 315 is its blowby flow control method, a throttle linkage operated flow control valve. Auxiliary to the main device, and included in the installation, is the fuel "vaporizer," intended to cause a "more thorough mixing of the fuel, air," and the crankcase emissions.

This device is in the prototype development stage. According to the developer, 16 such devices have been manufactured and installed on 16 vehicles which have accumulated 440,000 miles of operation. Data regarding the tests performed on two of these vehicles have been furnished by the developer.

7.1.3.1 Physical Description

The principal component of Device 315 is the engine vent valve assembly and its linkage to the throttle control arm. Figure 7-6 illustrates the installation of this valve on a two-barrel carburetor (replacing the PCV hose connection). As may be noted in the figure, this prototype kit included a valve assembly (1) with a carburetor adapter fitting (2) at its outlet and a hose fitting (3) at the inlet; a valve body support bracket (4) bolted to the carburetor body; and a throttle linkage adapter (5) fastened to the throttle arm with a connecting rod (6) to the valve slide.

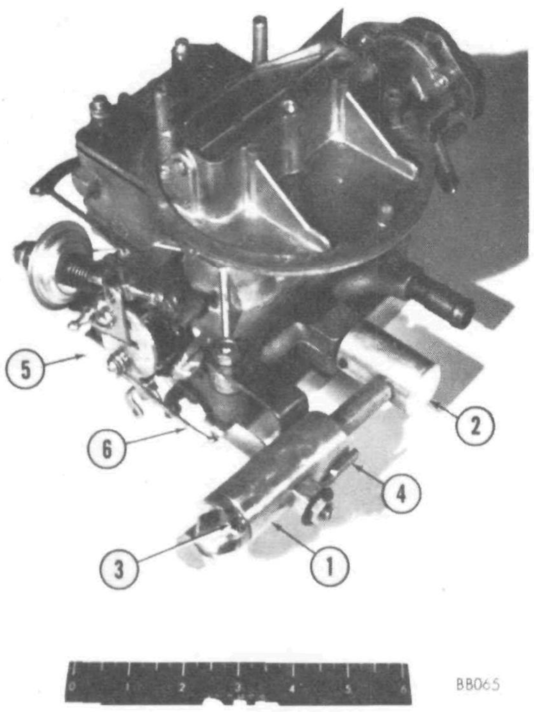
An auxiliary component, also seen in Figure 7-6, is the vaporizor assembly which includes an adapter plate (7) with two free spinning turbine wheels (8).

Not shown are the hose and fittings connecting the valve inlet to the crankcase (i.e., rocker arm cover), necessary fittings or replacement parts to disconnect and seal crankcase vent openings (i.e., oil filler cap) and carburetor air cleaner hose connection; and a crankcase relief valve assembly (if required for safety purposes).

The valve body is 1-1/4 inch in diameter by 3 inches; the valve slide is 1/2-inch square by 3 inches. The overall length of the installation is 7 inches from inlet fitting to outlet fitting.

7.1.3.2 Functional Description

This device connects the crankcase (or valve cover) to the downstream side of the carburetor throttle blades to draw crankcase emissions into the intake manifold in a manner similar to the conventional PCV valve and hose. However, for this device, valve operation is by direct linkage to the throttle control. The flow control valve, as shown in Figure 7-7, varies in orifice area as the valve is operated, to provide minimum flow at idle, and increases as the throttle is opened. Figure 7-7 depicts a rotating type control valve design. The prototype device in Figure 7-6



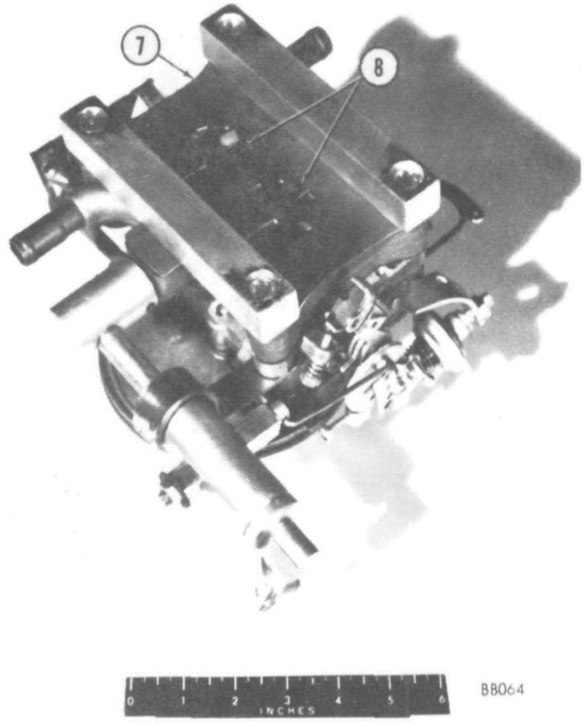


Figure 7-6. DEVICE 315 CLOSED BLOWBY CONTROL SYSTEM INSTALLED ON CARBURETOR

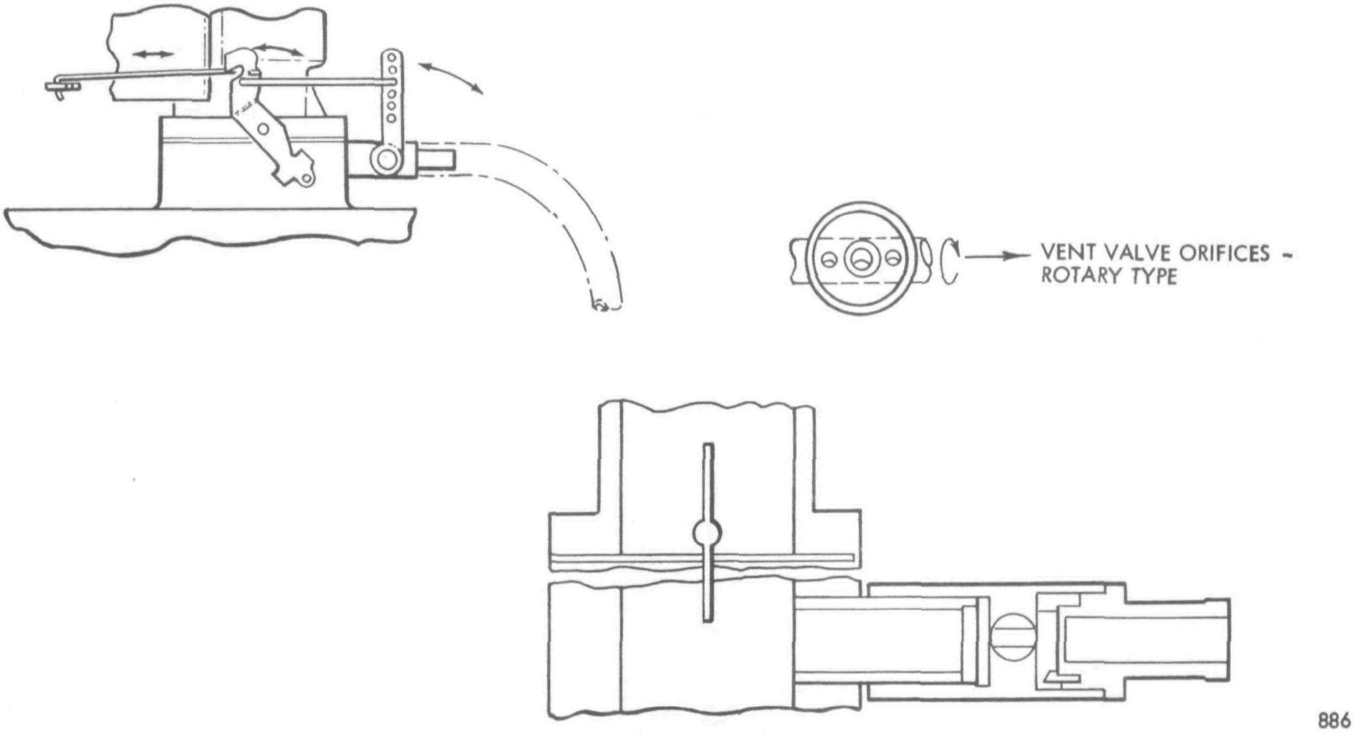


Figure 7-7. DEVICE 315 CLOSED BLOWBY CONTROL SYSTEM VENT VALVE CONFIGURATION (BASED ON DEVELOPER DRAWINGS)

applies a slide valve mechanism as depicted in Figure 7-8. The developer states that the "sliding motion (whether rotary or linear) coupled with orifice shape promotes a self-cleaning action, minimizing the maintenance problem." He further points out that the valve inhibits backfire (if it occurs) from reaching the crankcase.

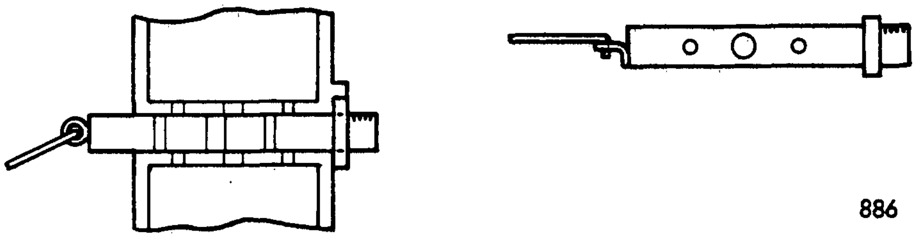


Figure 7-8. DEVICE 315 SLIDE MECHANISM (BASED ON DEVELOPER DRAWINGS)

The vaporizer element of this device (shown in Figure 7-6) is described by the developer as follows:

> "A bladed wheel, fan, turbine or the like is mounted in or below the downdraft side of the carburetor and has an even number of equidistantly spaced blades, alternate ones of which are tilted at a relatively large angle to the axis of the turbine to cause rotation of the turbine by the fuel intake suction while the remaining blades, each of which is positioned between two propulsion blades, have any angle of tilt with respect to the tilt angle of the propulsion blades such that said remaining blades resist and slow down the speed of rotation of the turbine while causing more thorough mixing of the fuel and air mixture, consequent to increased vaporization of the fuel."

7.1.3.3 Performance Characteristics

Table 7-7 summarizes the exhaust emission test results reported for this device compared to the baseline vehicle without the device installed. These results indicate that the device may have some effectiveness for control of exhaust HC and CO. Further testing would be required, however, to substantiate the statistical significance of this effectiveness.

7.1.3.4 Reliability

Examination of the carburetor modifications indicated that a fully engineered system would have a potential reliability in excess of 50,000 mean-miles-before-total-failure. Of particular interest is the selection of material for corrosion resistance in the gas flow circuit and valve. Additional consideration should be given the structural integrity of the free-spinning turbine vaporizer to preclude fatigue failures.

Table 7-7. DEVICE 315 CLOSED BLOWBY CONTROL SYSTEM EXHAUST EMISSION TEST RESULTS REPORTED BY DEVELOPER (1)

VEHICLE CONFIGURATION	POLLUTANT		
	HC (PPM)	CO (%)	NOx (PPM)
Without Device	201	82	(2)
With Device	144	59	
Percent Reduction	28.3	28.0	

(1) Results obtained from one 7-cycle, 7-mode test with and without device installed on a 1969 Ford, with 390-CID engine and automatic transmission.

(2) Not reported.

7.1.3.5 Maintainability

It is anticipated that maintenance requirements for a fully engineered device would be limited to cleaning and adjusting at such times as the carburetor would be normally cleaned and/or adjusted. An MMBM of 25,000 miles and MTTM of 0.75 hour are estimated.

7.1.3.6 Driveability and Safety

In the device configuration examined, corrosion of the blowby control valve could result, ultimately, in jamming the throttle full open.

This device was not tested and the developer supplied no driveability data. Therefore, no evaluation was made as to the effects of this device on driveability. The developer did report, however, that the device has caused no adverse effect on vehicle performance as noticed by the driver during tests on a chassis dynamometer and during road driving.

7.1.3.7 Installation Description

The installation of this device consists in removing the presently installed PCV valve and installing an adjustable flow control valve in the line from the valve cover to the intake manifold, connecting the control valve linkage to the accelerator pedal linkage, replacing the oil fill cap with a pressure relief cap that does not admit air, and installing an adapter plate that contains rotating turbine type blades between the carburetor and intake manifold. Adjustment of the device consists in setting the control valve so that a constant vacuum of one-half inch of mercury is maintained at the valve cover at idle conditions. It is estimated that installation of the system should take about one and one-half hours.

Table 7-8 contains a more detailed description of the installation procedure and identifies tools and special equipment required. Installation can be accomplished in a normally equipped repair shop with normal skills.

Table 7-8. DEVICE 315 CLOSED BLOWBY CONTROL SYSTEM INSTALLATION PROCEDURE

MINIMUM AVERAGE SKILL LEVEL: AUTOMOTIVE MECHANIC		
INSTALLATION AND ADJUSTMENT PROCEDURE	TOOLS, EQUIPMENT AND FACILITIES	TIME (MIN.)
1. Remove the hose that connects the PCV valve to the intake manifold		3
2. Install the adjustable flow control valve on the inlet to the intake manifold	a. Hand tools b. Flow control valve	6
3. Remove PCV valve and replace with hose connector that imposes no restriction on flow	a. Hand tools b. Hose connector	6
4. Connect hose between adjustable flow control valve and connector just installed	a. Hand tools b. Hose	4
5. Connect linkage from adjustable flow control valve to accelerator pedal linkage	a. Hand tools b. Linkage	10
6. Remove oil fill cap and replace with cap that incorporates a pressure relief valve but does not admit fresh air	Special oil fill cap	1
7. Remove carburetor from intake manifold	Hand tools	15
8. Install adapter plate containing rotating blades between carburetor and intake manifold	Adapter plate	3
9. Reinstall carburetor	Hand tools	15
10 Adjust the flow control valve opening at engine idle so that the suction applied to the valve cover is about 0.5 inch of mercury	Vacuum meter	15
11 Adjust the linkage so that at higher engine rpm the flow control valve will open sufficiently to maintain the 0.5 inch of mercury vacuum at the valve cover	Vacuum meter	15
	Total Time	1.5 hr

7.1.3.8 Initial and Recurring Costs

Table 7-9 summarizes the installation costs for this device. From the information available, it is estimated that the cost for installing this device, including material, would be $68.75.

Table 7-9. DEVICE 315 CLOSED BLOWBY CONTROL SYSTEM INITIAL AND RECURRING COSTS

ITEM	DESCRIPTION	LABOR HOURS OR ITEM QUANTITY	COST (DOLLARS)
Initial Cost:			
Material			
1. Device	a. Flow control valve b. Adapter plate		40.00
2. Miscellaneous	a. Special oil fill cap b. Linkage c. Hose connector d. Hose		10.00
Labor			
1. Installation	Table 7-8	1.0 hr	12.50
2. Test and adjust	Table 7-8	0.5 hr	6.25
		Total Initial Cost	68.75
50,000-Mile Recurring Cost:			
Labor			
1. Maintenance	Paragraph 7.1.3.5	0.75 hr every 25,000 miles @ $12.50 per hr	18.75
		Total Recurring Cost	18.75
		TOTAL COSTS	87.50

7.1.3.9 Feasibility Summary

This sealed crankcase emission control system would appear to be at least comparable to the standard PCV valve system in recycling crankcase emissions. Further exhaust emissions testing would be required to establish the statistical significance of the device's performance as an exhaust emission control.

7.2 OPEN SYSTEMS - RETROFIT TYPE 2.2

7.2.1 Device 160: Closed or Open Blowby Control System

Available in kit form for either the closed or open category crankcase emission control retrofit system, Device 160 includes a crankcase emission control valve as an integral part of a crankcase emissions filter assembly. It is offered as a closed system only in California. This system is presented by its manufacturer as being available in kits for all vehicles over 140 cubic inch displacement, with approximately 200,000 installations made to date. This device received accreditation from the California Air Resources Board as a closed crankcase control retrofit system on 19 November 1963.

7.2.1.1 Physical Description

Figure 7-9 illustrates this device for the closed-system configuration. The filter-valve assembly of this device (Figure 7-10) is approximately 4 inches in diameter by 10-1/2 inches tall. This assembly consists of a case (with upper and lower clip assemblies) which holds a filter element, a top cover with integral PCV valve assembly, and a residue collection jar which attaches to the bottom. The remainder of the kit includes the filter-valve assembly installation brackets, hose and fittings for connection from the crankcase through the filter assembly to the intake manifold, and the ventilation hose from the carburetor air cleaner to the crankcase.

The open system kit has an oil-bath type air cleaner for the air intake into the crankcase (Figure 7-11).

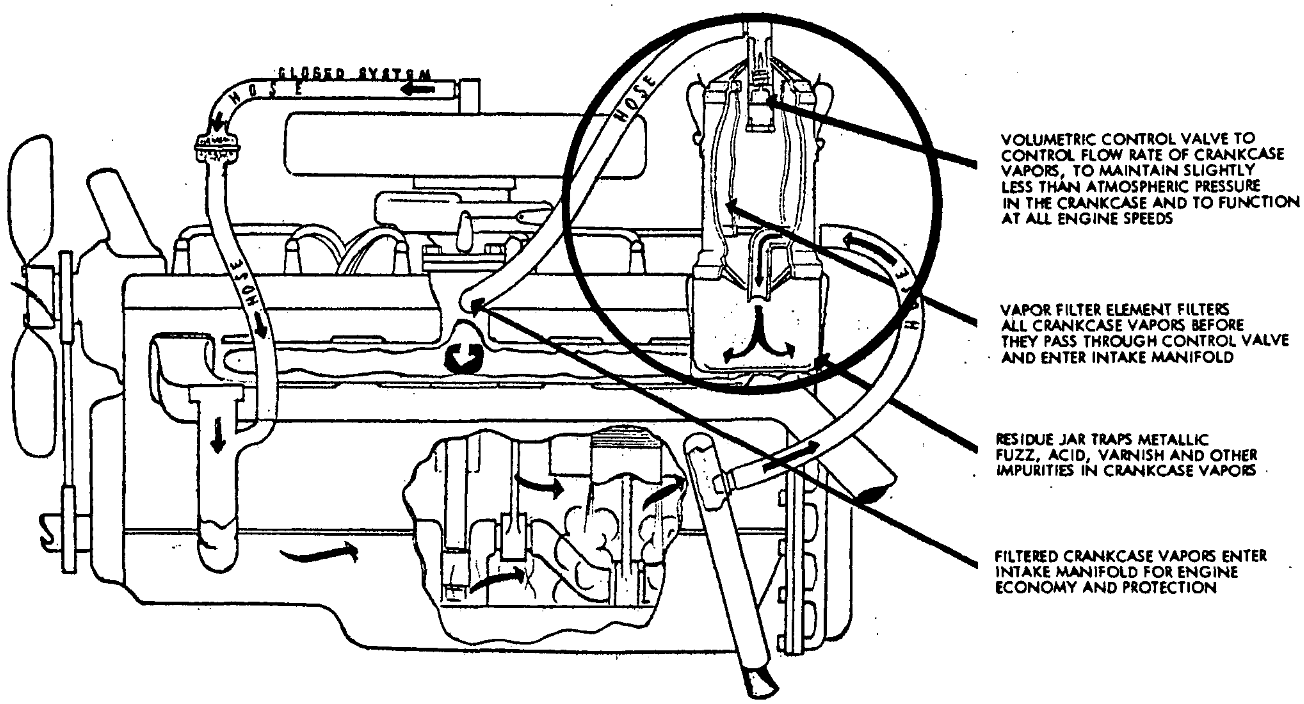


Figure 7-9. DEVICE 160 CLOSED SYSTEM WITH FILTER TYPICAL INSTALLATION (DEVELOPER DRAWING)

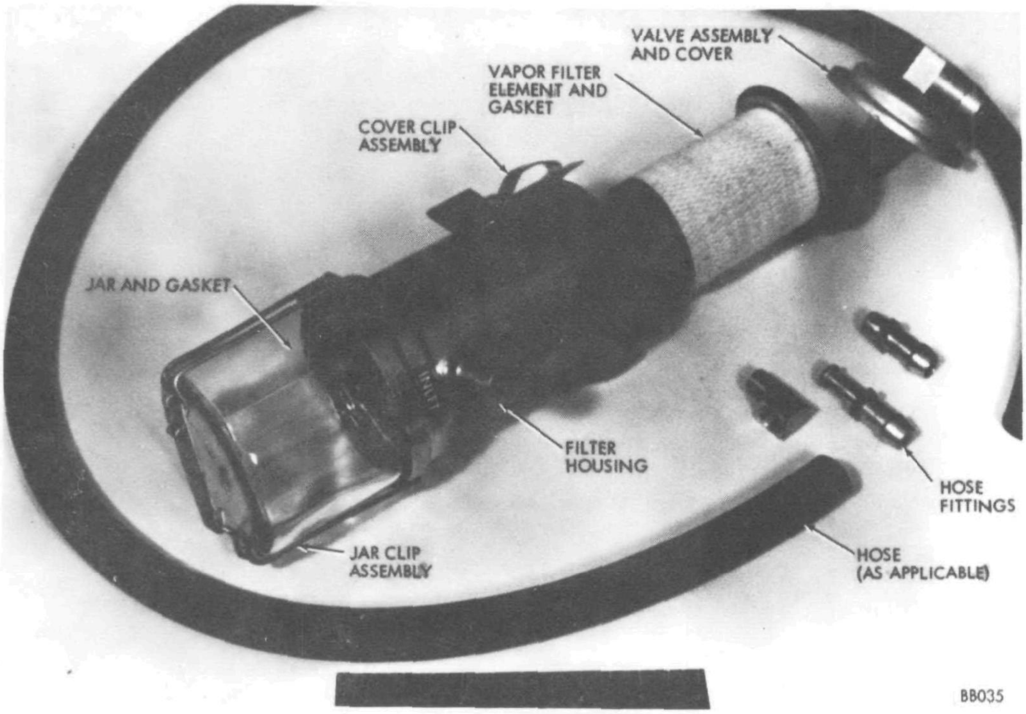


Figure 7-10. DEVICE 160 CLOSED BLOWBY CONTROL SYSTEM WITH FILTER: PCV VALVE AND FILTER ASSEMBLY

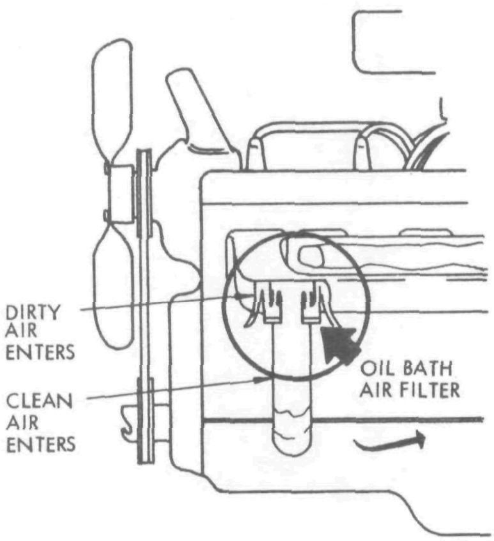


Figure 7-11. DEVICE 160 OIL-BATH TYPE AIR CLEANER FOR OPEN BLOWBY SYSTEMS (DEVELOPER DRAWING)

7.2.1.2 Functional Description

The volumetric control valve integral to the cover of the filter/valve assembly provides the positive crankcase ventilation control in a like manner as provided by an original equipment PCV valve. The valve restricts blowby flow under high intake manifold vacuum. According to the developer, the upstream filter element is intended to:

> "extract . . . acid, varnish, soot, abrasives, water, sludge, oil vapor and other impurities (prior to passing blowby gases on to the intake manifold). The light ends of oil, water vapor, and combustible materials are then drawn through the filtering material and through the volumetric control valve into the intake manifold of the engine. Oil vapor for upper lubrication - water vapor for improved combustion and to dissolve carbon deposits on spark plugs and in the combustion chamber - combustible vapors from blowby gases are used as additional fuel."

When supplied as an open type system, an oil bath air filter replaces the standard dry type filter to provide added protection to the crankcase against ". . . dust, dirt, abrasive particles, lint and other airborne impurities."

7.2.1.3 Performance Characteristics

Emission data obtained in a recent test on a 1972 Cadillac are presented in Table 7-10. However, no baseline test (without device) was conducted for comparison purposes.

Table 7-10. DEVICE 160 CLOSED OR OPEN BLOWBY CONTROL SYSTEM WITH FILTER EMISSION TEST RESULTS REPORTED BY DEVELOPER(1)

VEHICLE CONFIGURATION (2)	POLLUTANT (GM/MI)		
	HC	CO	NOx
Without Device	(3)	(3)	(3)
With Device	0.37	8.36	2.32
Percent Reduction	(3)	(3)	(3)

(1) Results of one 7-cycle, 7-mode cold start test.

(2) 1972 Cadillac with 472-CID engine (2,520 miles indicated on odometer). Commercial 91 octane gasoline was used.

(3) Not measured; therefore, percent reduction could not be calculated.

By nature of the design, the emission reduction performance of this device should be similar to that of a standard PCV valve installation. Without definitive data, the benefit of the filter would be expected primarily in the area of maintaining a clean emission control valve throughout the maintenance period. There may be indirect emission control benefit derived from facilitating maintenance of a cleaner engine.

Emission tests performed in 1960 on three vehicles with and without the device installed indicated a 50 percent reduction in CO. These were special tests in which the engine was operated at 2,000 rpm for 60 seconds and then returned to normal idle speed. A sample of the exhaust gas was taken while the engine was at idle. The three vehicles were a 1958 Chevrolet V-8 with 25,925 miles, a 1960 Ford Thunderbird with 2,048 miles, and a 1955 Pontiac V-8 with 40,509 miles.

7.2.1.4 Reliability

The manufacturer estimated that 200,000 units have been installed in light and heavy duty vehicles since 1935. The manufacturer claimed no failures reported, but did not estimate device reliability. According to the developer, the device received a certificate of approval as a crankcase ventilation system from the State of California Motor Vehicle Control Board on 19 November 1963. In view of the foregoing, and after examination of the device, it is assumed that its reliability is in excess of 75,000 mean-miles-before-total-failure provided it is installed and maintained in accordance with the manufacturer's instructions.

7.2.1.5 Maintainability

The manufacturer recommended the following maintenance for automotive applications:

a. During normal operation, the vapor filter element should be inspected frequently and replaced at least every 12,000 miles. When the element appears to have little droplets of oil on the outside, it should be changed.

b. Empty residue jar when it becomes one-half full.

c. Clean volumetric control valve located in the cover at each element change. The valve may be cleaned without removing it from the cover. With the engine at high idle, or under load, remove the cover and spray a good grade of smog valve cleaner into valve for approximately 60 seconds. It is important that the spring not be removed.

It is estimated that the indicated maintenance, including cleaning of the residue jar, can be performed in less than 15 minutes. No partial repair is anticipated, although the device hoses are subject to the same deteriorization as other hoses in the engine compartment and might require preventive maintenance replacement prior to accumulating 50,000 miles.

7.2.1.6 Driveability and Safety

The developer reported that the device has acceptable driveability characteristics. No safety hazards were identified.

7.2.1.7 Installation Description

For the closed system, installation consists in mounting the filter-valve unit in the engine compartment, installing hose fittings, and connecting hoses as shown in Figure 7-9. For the open system, the oil bath filter unit (Figure 7-11) would be installed also.

It is estimated that installation of this device should take about 1.25 hours. Table 7-11 contains a more detailed description of the closed system procedure and identifies the tools and special equipment required. Figure 7-9 shows a typical installation. Installation can be accomplished in a normally equipped repair shop by the average mechanic.

Table 7-11. DEVICE 160 CLOSED BLOWBY CONTROL SYSTEM WITH FILTER INSTALLATION PROCEDURE

MINIMUM AVERAGE SKILL LEVEL; AUTOMOTIVE MECHANIC		
INSTALLATION AND ADJUSTMENT PROCEDURE	TOOLS, EQUIPMENT AND FACILITIES	TIME (MIN.)
1. Install filter unit in vertical position using the brackets supplied. Check hood clearance.	a. Electric drill b. Hand tools c. Filter unit	30
2. Install hose adapter fittings to carburetor air cleaner, intake manifold, oil-fill tube, and road draft tube (sealed).	a. Hand tools b. Adapter fittings	20
3. Install hoses from oil-fill cap to carburetor air cleaner, from intake manifold to PCV valve, and from road draft tube to filter inlet.	a. Hand tools b. Hose	10
4. Adjust idle after engine has reached operating temperature for smoothness and desired rpm. Mechanical tappets should be checked after a few days of operation for proper clearance.	a. Hand tools	15
	Total Time	1.25 hr
Note: For open system, install oil-bath filter at oil-fill tube.		

7.2.1.8 Initial and Recurring Costs

Table 7-12 summarizes the installation costs for this device. From the information available, it is estimated that the cost for installing this device, including material, will be $46.77 to $69.12. Recurring costs would include both labor and materials for maintenance of the system in clean operating condition.

7.2.1.9 Feasibility Summary

Device 160, available as a closed or open system (depending on state regulations), has been on the market for 10 years as a blowby control. It is available in kit form for vehicles over 140 cubic inch displacement at list prices in the order of $30 to $50.

Table 7-12. DEVICE 160 CLOSED BLOWBY CONTROL SYSTEM WITH FILTER INITIAL AND RECURRING COSTS

ITEM	DESCRIPTION	LABOR HOURS OR ITEM QUANTITY	COST (DOLLARS)
Initial Cost:			
Material			
1. Kit	a. Adapter fittings b. Filter unit c. Hose		31.15-53.50
2. Miscellaneous	Mounting bracket		(Included in above)
Labor			
1. Install	Table 7-11	1 hr	12.50
2. Test and adjust	Table 7-11	1/4 hr	3.12
		Total Initial Cost	47.77-69.12
50,000-Mile Recurring Cost:			
Material			
1. Maintenance parts	Filter and cleaning agent	$2.50 average cost of maintenance parts every 12,000 miles	10.00
Labor			
1. Maintenance	Paragraph 7.2.1.5	0.25 hr every 12,000 miles @ 12.50	12.50
		Total Recurring Cost	22.50
		TOTAL COSTS	91.62

The emission data presented are not conclusive as to the exhaust emission reduction effectiveness of this device. However, the nature of the device should make it comparable in performance to a standard PCV valve installation. The filter, in addition to facilitating maintenance of cleaner engine parts, may also contribute to the crankcase emission system upholding its performance during the latter stages of a maintenance period, as compared to a standard PCV valve installation without filter. Further emission tests would be required to determine whether the device provides any significant exhaust emission reduction. As a blowby control, the device appears to be both technically and economically feasible.

7.2.2 Device 427: Closed or Open Blowby Control System with Filter

Device 427 is available in kit form for either the Type 2.1 closed or the Type 2.2 open crankcase emission control retrofit system. It is marketed as an open system primarily for industrial-type users (e.g., forklift trucks). For passenger vehicle use, the kit offered is a filter-control valve device that replaces the standard PCV valve installation in an existing system. The developer also reported that the device indicates some effectiveness for exhaust CO control.

7.2.2.1 Physical Description

The principal unit of Device 427 is the filter-valve assembly shown in Figure 7-12. Its overall dimensions are approximately 4-1/2 inches in diameter by 11 inches in height. Figure 7-13 details its components. Item 6 in Figure 7-13 is the blowby emission control valve, which is integral to the filter assembly. The filter-valve assembly is installed as a part of the blowby emission ventilation path between the engine valve cover or crankcase and the intake manifold, such as that provided by the typical PCV valve and hose installation. When installed as an open system (e.g., for industrial applications) an engine ventilation air filter, approximately 5 inches in diameter by 7 inches tall, is mounted to provide crankcase inlet air.

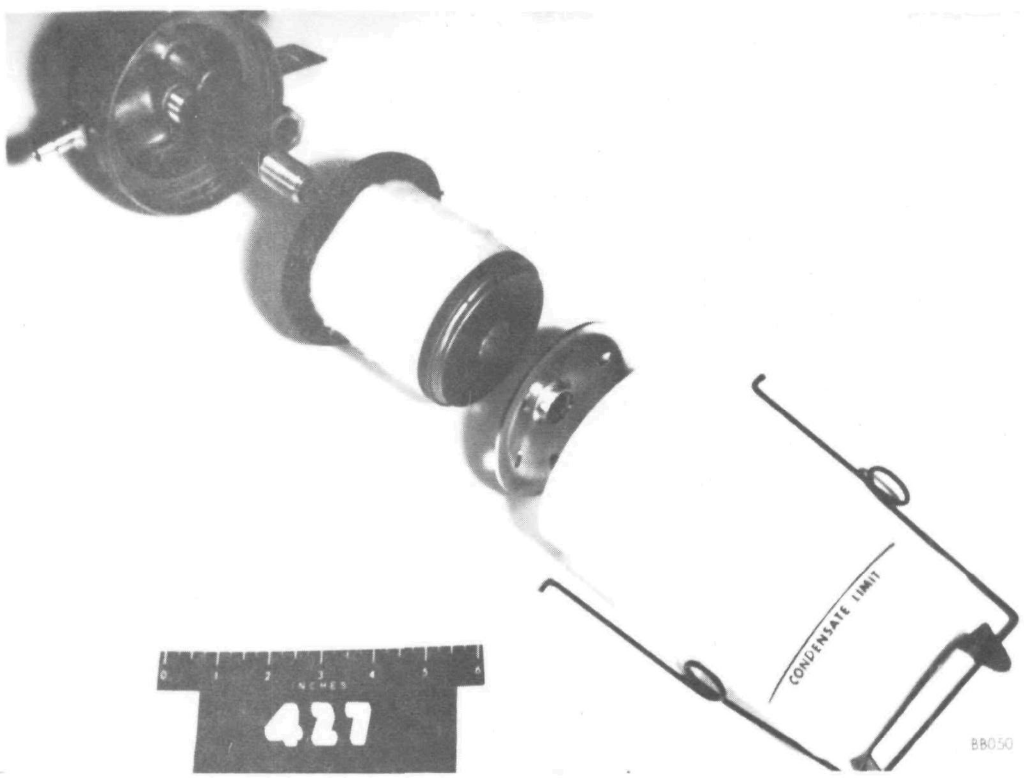


Figure 7-12. DEVICE 427 CLOSED BLOWBY CONTROL SYSTEM FILTER-VALVE ASSEMBLY

7.2.2.2 Functional Description

Figure 7-14 illustrates the functional flow of this blowby control system. The volumetric control valve, which is integral to the filter assembly, provides crankcase

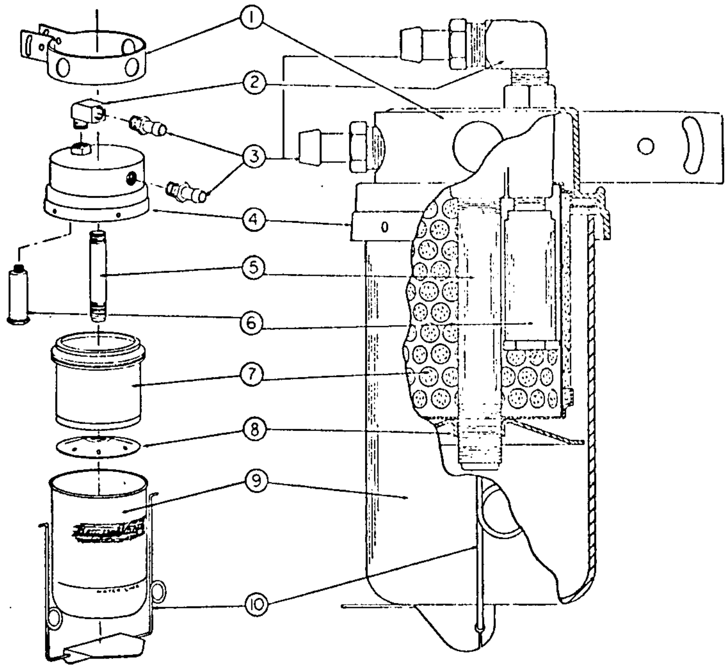


Figure 7-13. DEVICE 427 CLOSED BLOWBY CONTROL SYSTEM FILTER-VALVE ASSEMBLY DETAILS (DEVELOPER DRAWING)

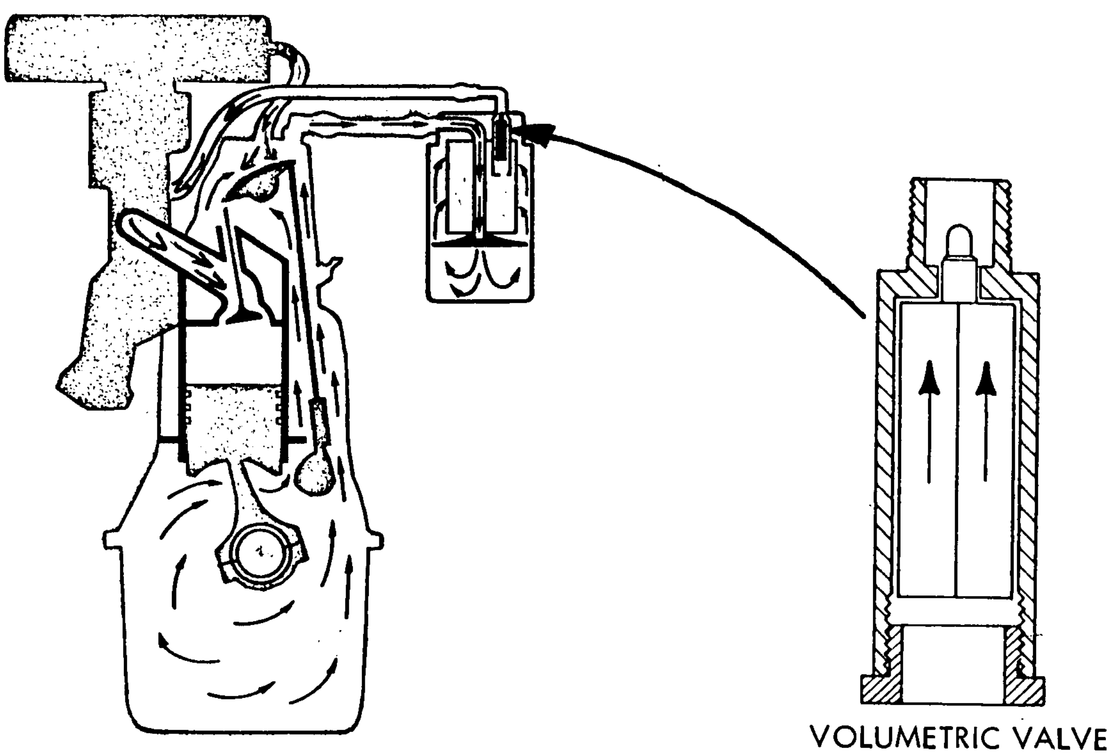


Figure 7-14. DEVICE 427 CLOSED BLOWBY CONTROL SYSTEM WITH FILTER FUNCTIONAL DIAGRAM (DEVELOPER DRAWING)

ventilation control. The device flow control valve has a free metering pin. It has no spring and uses only vacuum, flow, and gravity for operation. The piston is triangular in shape to minimize contact surface and ensure correct alignment.

The developer stated that his device "reduces engine maintenance and increases engine efficiency by virtue of the filter trapping emissions which are harmful to the engine, and passing steam, fuel and oil vapors on through for improved engine operation and combustion."

7.2.2.3 Performance Characteristics

The developer provided hot start exhaust emission data which compared his device's performance with that for a standard PCV valve installation. As shown in Table 7-13, these data indicate that the HC and NOx emissions had no substantial change (a slight edge in favor of the device) while the CO emissions were reduced by 49 percent.

Table 7-13. DEVICE 427 CLOSED BLOWBY CONTROL SYSTEM WITH FILTER EXHAUST EMISSION REDUCTION PERFORMANCE (DEVELOPER DATA) (1)

VEHICLE CONFIGURATION (2)	POLLUTANT		
	HC (PPM)	CO (%)	NOx (PPM)
Without Device	236	0.74	2,194
With Device	223	0.38	2,183
Percent Reduction	5.5	48.6	0.5

(1) Average of two tests with and without device installed in lieu of a conventional PCV valve, using 7-cycle, 7-mode hot start test procedure.

(2) 1968 Ford Galaxie with 302-CID engine, 2-barrel carburetor, and automatic transmission (73,000+ miles indicated on odometer).

1969 Chevrolet Impala with 350-CID engine, Rochester 4-barrel carburetor, and automatic transmission (23,000 miles indicated).

Test fuel was Indolene 30.

This developer also provided carburetor air-fuel ratio change test data taken on a fleet of 10 vehicles. These data revealed that only one of the 10 vehicles exceeded the California standard of 6 percent allowable enrichment for the 10th decile blowby conditions; and this was by 0.4 percent. All other data were within the standard, specified in Reference 121.

7.2.2.4 Reliability

The developer estimated that 600 million miles have been accumulated with the device installed on 30,000 vehicles. The developer claimed that there has been no reported failure. In view of the foregoing, and after review of device drawings and photographs, it is assumed that the device's reliability would be in excess of 50,000 mean-miles-before-total-failure, if it is installed and maintained in accordance with the developer's instructions.

7.2.2.5 Maintainability

The developer noted the following maintenance requirements:

a. Visually inspect residue in condensate jar every 5,000 miles; empty and clean if required

b. Change filter element every 15,000 miles

c. Check condition of hose and valve annually; replace hose and clean valve, if required.

It is estimated that the indicated maintenance could be performed in less than 15 minutes (0.25 MTTM). A 10,000-MMBM interval is estimated.

No repair is anticipated, although the device hoses are subject to the same deterioration as other hoses in the engine compartment and might require replacement prior to accumulating 50,000 miles.

7.2.2.6 Driveability and Safety

Table 7-14 summarizes the driveability data supplied by the developer. No safety hazards have been identified.

Table 7-14. DEVICE 427 CLOSED BLOWBY CONTROL SYSTEM WITH FILTER DRIVEABILITY RESULTS REPORTED BY DEVELOPER

Critical Driveability Elements:	No effect
General Driveability Elements	No effect
Acceleration Time (0-60 mph):	Constant at 13.0 sec
Deceleration Time (60-40 mph):	Constant at 22.3 sec
Gas Mileage (mpg)	No data

7.2.2.7 Installation Description

The installation of this device consists in mounting a filter unit on a bracket in the engine compartment, replacing any existing PCV valve with the filter-valve assembly provided, and connecting hoses to filter unit and intake manifold. Idle adjustment of the engine may be necessary after one week of use.

It is estimated that installation of the device would take about 1.25 hour. Table 7-15 presents a more detailed description of the installation requirements. Installation can be accomplished in a normally equipped repair shop by the average mechanic.

7.2.2.8 Initial and Recurring Costs

Table 7-16 summarizes the initial installation cost for this device. From the information available, it is estimated that the cost for installing this device, including material would $67.62. Some recurring cost would be incurred for filter replacement and maintenance.

7.2.2.9 Feasibility Summary

In addition to providing blowby control, it would appear that this device has some control capability for exhaust CO. Further testing would be required to establish the significance of this. With respect to its basic function as a blowby control, the device appears to be technically feasible. The device is available for passenger vehicles in kit form for retrofit. The filter element of this device (if properly maintained) may contribute to the reliability of the emission control valve element, as well as keep the engine parts cleaner.

Table 7-15. DEVICE 427 CLOSED BLOWBY CONTROL SYSTEM WITH FILTER INSTALLATION PROCEDURE

MINIMUM AVERAGE SKILL LEVEL: AUTOMOTIVE MECHANIC		
INSTALLATION AND ADJUSTMENT PROCEDURE	TOOLS, EQUIPMENT AND FACILITIES	TIME (MIN.)
1. Filter unit must be installed vertically in engine compartment with connecting hose kept as short as possible.	a. Hand tools b. Electric drill c. Filter unit	30
Position unit 4 to 12 inches from exhaust manifold, out of fan air blast.	Hand tools	
2. Connect inlet to PCV replacement part after original PCV valve is removed, or install adapters for filter-valve installation.	a. Hand tools b. PCV valve replacement c. Adapters/hose	20
3. Connect return connection to intake manifold, using the proper adapters and hoses.	a. Hand tools b. Adapters c. Hose	5
4. Check system for leaks while engine is idling, pinch inlet hose, engine speed should change and an audible click should be heard in 3-5 seconds as the valve of the unit drops. CAUTION: If moisture is present in the jar, release pressure slowly or filter may be ruined.	Hand tools	5
5. After one week's use a slight adjustment of the carburetor may be necessary.	a. Hand tools b. Tachometer	15
	Total Time	1.25 hr

Table 7-16. DEVICE 427 CLOSED BLOWBY CONTROL SYSTEM WITH FILTER INITIAL AND RECURRING COSTS

ITEM	DESCRIPTION	LABOR HOURS OR ITEM QUANTITY	COST (DOLLARS)
Initial Cost:			
Materials			
1. Kit	a. Filter unit b. PCV valve replacement c. Hose adapters		52.00
2. Miscellaneous	Hose		(Included in above)
Labor			
1. Installation	Table 7-15	1.0 hr	12.50
2. Test and adjust	Table 7-15	0.25 hr	3.12
		Total Initial Costs	$ 67.62
50,000-Mile Recurring Cost:			
Materials			
1. Filter	Blowby filter element	$3 every 15,000 miles	9.00
Labor			
1. Maintenance	Paragraph 7.2.2.5	0.25 hr every 10,000 miles @ $12.50/hr	15.63
		Total Recurring Cost	24.63
		TOTAL COSTS	92.25

SECTION 8

GROUP 3 RETROFIT METHOD DESCRIPTIONS
EVAPORATIVE EMISSION CONTROL SYSTEMS

Federal emission standards applicable to 1971 models (1970 models in California) require that fuel systems be equipped or designed to limit fuel evaporation from the fuel tank and carburetor vents to 6 grams per test (Reference 15). Gasoline tanks and carburetors on used vehicles before 1970 are vented to the atmosphere. Losses at the carburetor occur almost entirely during the hot soak period after shutting off a hot engine. The residual heat causes the temperature of the fuel bowl to rise to 150° to 200°F, resulting in substantial boiling and vaporization of the fuel in the carburetor. Losses vary because of many factors, but as much as 29 grams of fuel per soak period without evaporative controls have been measured from the gas tank and carburetors of light duty vehicles (Reference 122).

Two evaporative control methods are presently under development and in use on new cars: the vapor-recovery and the absorption-regeneration systems. The first stores fuel vapors in the crankcase during engine shutdown, and the second uses an activated charcoal trap or canister to hold fuel vapors when the engine is stopped.

Evaporative emissions are a function of fuel vapor pressure and ambient temperature. Current evaporative emission control systems are designed to be used with fuels of 9 pounds or less Reid Vapor Pressure.

A typical new car installation of the absorption-regeneration system is evaluated in this section, to determine its economic feasibility for retrofit to uncontrolled used cars. This system was selected for evaluation because it appears to be the one favored by most car manufacturers. The typical absorption-regenerative system is shown in Figure 8-1.

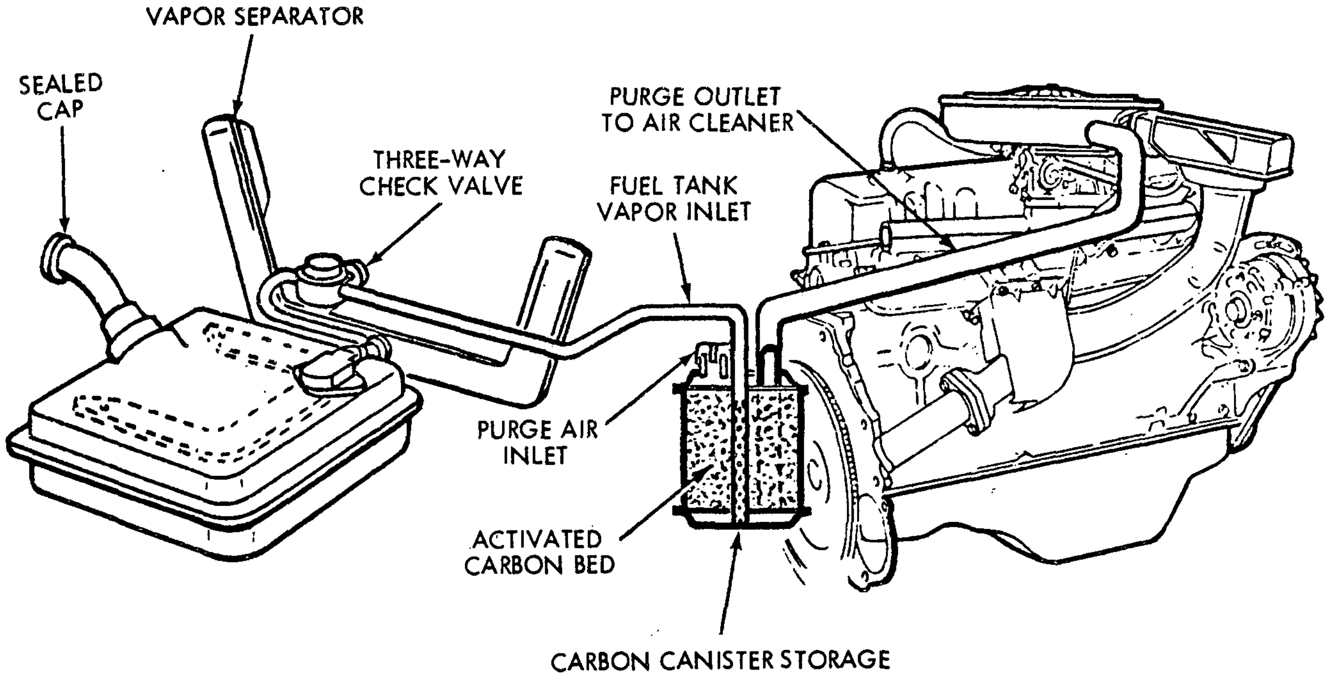


Figure 8-1. ABSORPTION-REGENERATIVE FUEL EVAPORATION CONTROL SYSTEM

8.1 DEVICE 467 ABSORPTION-REGENERATIVE FUEL EVAPORATION CONTROL SYSTEM

Although no retrofit evaporative emission control systems were submitted for evaluation, a brief evaluation of installation procedures and costs are presented for the absorption-regenerative system to weigh its cost feasibility for retrofit use.

8.1.1 Typical Installation Description

The system installation consists in replacing the presently installed gas tank with a tank containing the vapor separation installation, installing the vapor separator in the vicinity of the gas tank, installing a check valve, installing a carbon canister, and connecting hoses from the vapor separator to the carbon canister, and from the carburetor to the carbon canister to the air filter. Inspection of the system to make sure there are no vapor leaks is necessary.

Table 8-1 contains a detailed description of the installation procedure and identifies tools and special equipment required; however, no estimate is made of possible structural or body modifications required to accommodate the system. Installation can be accomplished in a normally equipped repair shop by the average mechanic.

8.1.2 Typical Installation Initial and Recurring Cost

Table 8-2 summarizes the estimated initial costs for this device. The material costs were retail prices and were obtained from the parts department of a new car dealer (Reference 123) and applied to a 1970 model car with a 390-CID engine. From the information available, it is estimated that the cost for installing this device, including material, would be $136.62.

Recurring cost would be incurred because of the requirement to replace the canister filter every 12,000 miles, and at the same time check for system leaks.

8.1.3 Feasibility Summary

Based on the costs and potential complexity of installation, it does not appear that a fuel evaporative system of the production canister type configuration would be economically feasible for retrofit applications. The principal cost impact is represented by the parts and not labor. Thus it would appear that a system of less design complexity would have to be devised for retrofit use.

Table 8-1. DEVICE 467 ABSORPTION-REGENERATIVE FUEL EVAPORATION CONTROL SYSTEM INSTALLATION PROCEDURE

MINIMUM AVERAGE SKILL LEVEL: AUTOMOTIVE MECHANIC		
INSTALLATION AND ADJUSTMENT PROCEDURE	TOOLS, EQUIPMENT AND FACILITIES	TIME (MIN.)
1. Remove presently installed gas tank.	a. Car lift b. Hand tools	30
2. Install sealed gas tank containing vapor separation components.	a. Hand tools b. Gas tank	30
3. Install vapor separator under car in vicinity of gas tank.	a. Hand tools b. Vapor separator	60
4. Connect vapor separator to gas tank.	a. Hand tools b. Hose, clamps	5
5. Install three-way check valve in vicinity of gas tank.	a. Hand tools b. Hose, clamps c. Three-way check valve	15
6. Connect vapor separator to check valve and install line under body of car to the engine compartment.	a. Hand tools b. Hose, clamps	20
7. Install carbon canister in engine compartment.	a. Hand tools b. Carbon canister	20
8. Install hose connecter in body of air-filter	a. Hand tools b. Hose connecter	15
9. Connect line from three-way check valve to carbon canister to air filter.	a. Hand tools b. Hose, clamps	10
10. Install connecter in fuel bowl of carburetor	a. Hand tools b. Hose connecter	15
11. Connect carburetor to check valve to carbon canister.	a. Hand tools b. Hose, clamps c. Check valve	5
12. Inspect for leaks		15
	Total Time	4.0 hrs

Table 8-2. DEVICE 467 ABSORPTION-REGENERATIVE FUEL EVAPORATION CONTROL SYSTEM INITIAL AND RECURRING COSTS

ITEM	DESCRIPTION	LABOR HOURS OR ITEM QUANTITY	COST (DOLLARS)
Initial Cost: Material			
1. Device	a. Carbon canister		21.00
	b. Gas tank		42.00
	c. Vapor separator		22.00
	d. Three-way check valve		3.00
	e. Check valve		3.00
2. Miscellaneous	Hose, clamps, and hose connector		5.00
Labor			
1. Installation		3.0 hrs	37.50
2. Test and adjust		0.25 hr	3.12
		Total Initial Cost	136.62
50,000-Mile Recurring Cost: Material			
1. Filter	Paragraph 8.1.2	$1.00 every 12,000 miles	4.00
Labor			
1. Inspection	Filter replacement and inspection for leaks	0.25 hr every 12,000 miles @ $12.50/hr	12.50
		Total Recurring Cost	16.50
		TOTAL COSTS	153.12

SECTION 9

GROUP 4 RETROFIT METHOD DESCRIPTIONS EMISSION CONTROL COMBINATIONS

There are three basic types of automobile emissions; these are exhaust emissions, crankcase emissions, and fuel system evaporative emissions. These have been classified as Groups 1, 2, and 3 and devices falling within those groups have been described in previous paragraphs. As described in Section 2, exhaust emissions account for 60 percent of the total HC emissions of an uncontrolled car, 100 percent of total CO emissions and 100 percent of NOx emissions. Crankcase emissions account for 20 percent of the HC total, and evaporative emissions account for 20 percent of the HC total.

Group 4 emission control devices involve a combination of any two or all three of groups 1, 2, and 3. Table 9-1 lists the four combination types studied in the retrofit program.

Table 9-1. GROUP 4 EMISSION CONTROL COMBINATION RETROFIT DEVICES

DEVICE NO.	NOMENCLATURE
59	Three-Stage Exhaust Gas Control System
165	Exhaust Gas Afterburner/Recirculation with Blowby and Fuel Evaporation Recirculation
408	Exhaust Gas and Blowby Recirculation with Intake Vacuum Control and Turbulent Mixing
469	Thermal Reactor with Exhaust Gas Recirculation and Particulate Control

9.1 DEVICE 59: THREE-STAGE EXHAUST GAS CONTROL SYSTEM

A single prototype unit of this device has been fabricated by the developer and tested (March, 1970) on a 1964 automobile using 1968 Federal (seven mode-seven cycle) cold start test procedures. Results of this test indicate reductions in HC, CO, and NOx emissions.

The developer has declined to provide any descriptive information on this device except to describe it as a three-stage exhaust device.

9.1.1 Physical Description

The developer has declined to provide any descriptive information on this device.

9.1.2 Functional Description

The developer declined to provide any functional description of this device except to state that it is a three-stage exhaust device.

9.1.3 Performance Characteristics

Emission performance characteristics supplied by the developer are summarized in Table 9-2.

Table 9-2. DEVICE 59 THREE-STAGE EXHAUST GAS CONTROL SYSTEM EMISSION TEST RESULTS (DEVELOPER'S DATA) (1)

VEHICLE CONFIGURATION	POLLUTANT		
	HC (PPM)	CO (%)	NOx (PPM)
Without Device	811	4.65	602
With Device	552	3.80	535
Percent Reduction	32	18.3	11

(1) 1968 Federal Procedure (7-mode, 7-cycle) Cold Start Tests - 1964 Chevrolet Impala, 283-CID, 2V carburetor, automatic transmission. One test conducted by Olson Laboratories, Dearborn, Michigan, March 4, 1970.

9.1.4 Reliability

The developer provided no estimate of device reliability and insufficient information was available for reliability evaluation. No reliability estimate could be made.

9.1.5 Maintainability

The developer states in response to the inquiry for periodic maintenance/ inspection requirements: "One year - and cost is pennies." Sufficient information was not available to evaluate the device for maintenance requirements.

9.1.6 Driveability and Safety

Sufficient information was not available to perform a safety hazard analysis.

This device was not tested and the driveability data was supplied by the developer. Table 9-3 summarizes this information.

Table 9-3. DEVICE 59 THREE-STAGE EXHAUST GAS CONTROL SYSTEM DRIVEABILITY (DEVELOPER DATA)

Critical Driveability Elements	No affect	
General Driveability Elements	No affect	
Acceleration Time (0-60 mph)	Increased from 23.3 to 28.7 sec	
Deceleration Time (60-40 mph)	Increased from 24.7 to 25.7 sec	
Gas Mileage (mpg)	City	Highway
Without Device	10.2	17.1
With Device	17.8	15.6

9.1.7 Installation Description

There was insufficient installation description information available from the developer.

9.1.8 Initial and Recurring Costs

The initial and recurring costs information was not available from the developer.

9.1.9 Feasibility Summary

Insufficient information was available to determine the feasibility of this device.

9.2 DEVICE 165: EXHAUST GAS AFTERBURNER/RECIRCULATION WITH BLOWBY AND FUEL EVAPORATION RECIRCULATION

This device performs the combination of functions its title implies, using an integrated system. They are differentiated from systems in which exhaust gas recirculation, crankcase emissions, and evaporative emissions are controlled by separate devices which function independently.

This device is an integral system which performs functions of exhaust gas recirculation, crankcase emission, and evaporative emission control. These functions are performed by drawing a portion of the exhaust gas into an "afterburner unit" where, with no addition of air, combustion is completed in the presence of a continuously firing spark plug.

Afterburner gases are then passed through a heat exchanger for cooling and then divided into two routes for recirculation into the induction system. One route is direct to the carburetor inlet through the air cleaner. A second route ports to the intake manifold through a micro (micron size) filter. Vapors from the gas tank and crankcase are piped to a metering assembly, and then fed into the exhaust recirculation line entering the intake manifold. Positive flow of gasoline tank vapor, crankcase vapor, and recirculated exhaust gas are maintained by intake manifold vacuum. A single prototype device has been developed for installation in a 1965 Ford Falcon (200 CID, single-barrel carburetor).

9.2.1 Physical Description

A photograph of the device installed in a 1965 Ford Falcon is shown in Figure 9-1. Principal elements of the prototype device are:

a. An exhaust adapter which apportions exhaust flow between the afterburner and exhaust pipe, and receives returning flow from the afterburner.

b. An afterburner consisting of a cast iron chamber and bolted closure having three ports - inlet, return to exhaust pipe (bypass flow), and discharge to heat exchanger.

c. A coil and spark plug assembly which provides a continuous spark to the afterburner chamber.

d. A finned tube heat exchanger - formed into a 90-degree elbow for the prototype installation. (The heat exchanger discharges to a T-fitting where flow is split between a hose line to the carburetor air cleaner and a steel line connected to the fuel evaporation line to the intake manifold.)

e. A stainless steel mesh micro filter.

f. Hoses from the gasoline tank and valve cover (crankcase emissions) are ported to a metering assembly (adjustable needle-valves) which are adjusted to control intake manifold suction on the gasoline tank and crankcase vapors.

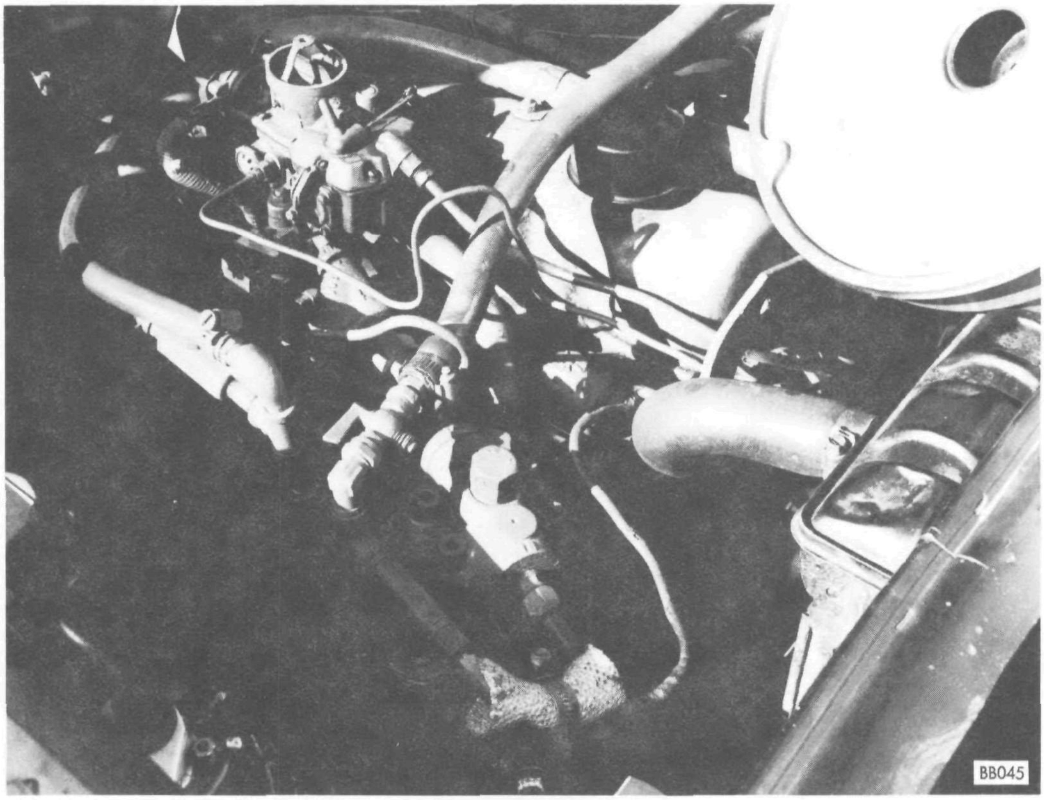


Figure 9-1. DEVICE 165 EXHAUST GAS AFTERBURNER/RECIRCULATION WITH BLOWBY AND FUEL EVAPORATION RECIRCULATION INSTALLATION

g. A line from the metering assembly which passes fuel and crankcase vapors into the line discharging recirculated exhaust gas into the intake manifold.

9.2.2 Functional Description

The functions performed by this system are related by the functional block diagram of Figure 9-2. As indicated, crankcase and gasoline tank vapors are drawn, under intake manifold suction, to a metering device. The metering device apportions and restricts the vapor flow from these sources. The vapors are then mixed with recirculated exhaust gas and drawn into the intake manifold.

Reduction of CO and HC emissions are controlled by tapping a portion of the normal exhaust gas and porting it to an accumulator type afterburner where combustion of unburned CO and HC reportedly occurs under the influence of a continuous high voltage spark. No air is ported to the afterburner in this unit. A portion of the exhaust passed through the afterburner is returned to the exhaust pipe for discharge to the atmosphere. The remaining portion of the exhaust gas is passed through a finned tube heat exchanger and split along two paths. Along one path the gas is directed to the carburetor air cleaner, filtered by the air cleaner, and mixed with air entering the carburetor. The

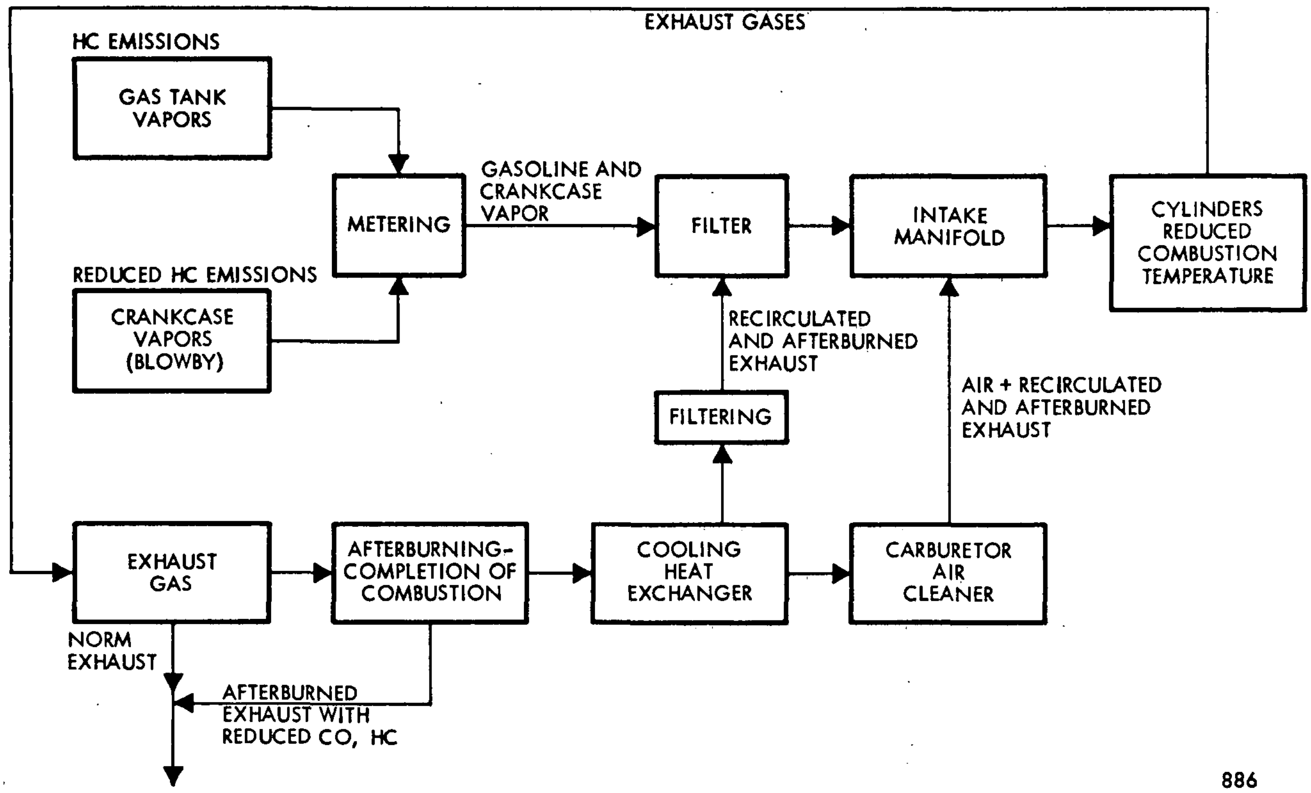


Figure 9-2. DEVICE 165 EXHAUST GAS AFTERBURNER/RECIRCULATION WITH BLOWBY AND FUEL EVAPORATION RECIRCULATION FUNCTIONAL BLOCK DIAGRAM

heated mixture of recirculated exhaust and air is intended to provide increased vaporization of gasoline to provide a more homogeneous air fuel mixture.

Exhaust gas directed along the secondary path passes through a micro (micron) size filter and mixes with gasoline and crankcase vapors before entering the intake manifold. Overall effect of recirculated exhaust gas is to provide an inert diluent to the fuel-air mixture which lowers combustion temperature, resulting in reduced formation of NOx.

9.2.3 Performance Characteristics

The emission reduction test results of the subject retrofit device as reported by the developer are summarized in Table 9-4. All of the tests used a six cylinder 1965 Ford Falcon test vehicle (200 CID). Recent data measured by Olson Laboratories are also included in Table 9-4. No baseline data were reported to calculate emission reduction.

Table 9-4. DEVICE 165 EXHAUST GAS AFTERBURNER/RECIRCULATION WITH BLOWBY AND FUEL EVAPORATION RECIRCULATION EXHAUST EMISSION TEST RESULTS

VEHICLE CONFIGURATION	POLLUTANT		
	HC (PPM)	CO (%)	NOx (PPM)
1. Developer Data on 1965 Ford Falcon 200 CID engine with device:			
a. May 1970 Fed. Test (1)	556	2.3	716 (NO) 13 (NO_2)
b. June 1970 Test (169-1) (2)	326	0.97	704
c. Dec. 1970 Test (169-1) (2)	188	1.04	1083
d. June 1971 Test (19603) (2)	249	0.59	---
2. OLI test data on 1965 Ford Falcon 200 CID engine with device (3)	329	1.53	726

(1) Results of one standard Federal 7-mode (cold start) exhaust emission test.

(2) California Air Resources Board emission test results from one test using California 7-mode (hot start) cycles.

(3) Results of one standard Federal hot start emission test.

9.2.4 Reliability

Insufficient retrofit developer data were available to determine mean-miles-before-total-failure (MMBTF). However, it appears that the afterburner ignition subsystem reliability would be the primary constraint to meeting the system MMBTF of 50,000 miles. Developer data indicates that the ignition device is a glow plug, in which case replacement would be required prior to burnout to achieve a system MMBTF of 50,000 miles. Examination of an installed system indicated that the ignition device is a spark plug. It appeared that the spark plug is driven by an ignition coil with a vibrator to actuate the primary. If this is the case, the vibrator and spark plug would require maintenance prior to failure to achieve an MMBTF of 50,000 miles.

If it can be assumed the foregoing have been considered in the design (provision for maintenance before failure and component selection), then a system MMBTF of 50,000 miles appears achievable.

9.2.5 Maintainability

Minimum maintenance would require cleaning or replacement of the afterburner ignition device, inspection/adjustment of the ignition power source, and cleaning or replacement of the "Micro Clean Filtering and Air Intake Unit." Such maintenance could be accomplished in one-half hour every 12,000 miles provided it has been a design consideration to permit ease of access for inspection and removal and replacement of components when necessary.

Additional maintenance which might be required cannot be determined without long term test data relating to waste products deposition in the various gas transport lines throughout the system. Such data could indicate the need for periodic cleaning of one or more lines.

9.2.6 Driveability and Safety

Critical review of the final design should place primary emphasis on interface of the system with the fuel tank. Any fuel vapor in the interface might constitute an explosive train initiated by backfire through an intake valve and the evaporative control line which terminates in the gas tank.

This device was not tested for driveability in the retrofit program. The following data were supplied by the developer. Table 9-5 summarizes this information.

Table 9-5. DEVICE 165 EXHAUST GAS AFTERBURNER/RECIRCULATION WITH BLOWBY AND FUEL EVAPORATION RECIRCULATION DRIVEABILITY (DEVELOPER DATA)

Critical Driveability Elements	No affect
General Driveability Elements	No affect
Acceleration Time (0-60 mph)	No data
Deceleration Time (60-40 mph)	No data
Gas Mileage (mpg)	No data

9.2.7 Installation Description

The installation of this device consists of installing an afterburner unit on the exhaust line, installing a pipe fitting into the intake manifold, connecting the afterburner unit to the intake to permit gases to flow to intake, installing line from fuel tank emission accumulator, installing line from crankcase emission, connecting these lines to intake manifold, installing high voltage coil, glow plug, flow control valves, and micro-cleaning filter. Adjustment of the device consists of regulating the flow through the several control valves to give the best overall engine performance.

Table 9-6 contains a more detailed description of the installation procedures. Figure 9-2 is a functional block diagram that illustrates the manner in which this device would be installed. Installation can be accomplished in a normally equipped repair shop with normal skills.

9.2.8 Initial and Recurring Costs

The developer estimates the retail cost of the device at $175 for material and installation cost for labor at $50. Table 9-7 summarizes the costs for this installation. From the information available, it is estimated that the cost for installing this device, including material, would be $237.50.

9.2.9 Feasibility Summary

Limited test data provided by the developer did not include baseline emissions and the emission reduction effectiveness could not be calculated. The device is, however, too complex and costly to be considered for retrofit application.

Complexity of the device is demonstrated by the following factors:

a. The device incorporates exhaust afterburning, exhaust gas recirculation, crankcase vapor recirculation, and fuel tank vapor suction in a single integrated system. The interactions between these various functions and their effect on overall emission may vary from model to model.

b. The system requires interface penetrations at five points (exhaust manifold, fuel tank, crankcase, air cleaner, intake manifold) on the vehicle, installation of three components and five lines.

The existing prototype unit will require substantial development and redesign before it can be manufactured in quantity. The developer's estimate of an initial cost of $175 per unit is a rough estimate and is not based on a reliable manufacturing cost analysis. The developer currently has no plan for marketing this device.

Table 9-6. DEVICE 165 EXHAUST GAS AFTERBURNER/RECIRCULATION WITH BLOWBY AND FUEL EVAPORATION RECIRCULATION INSTALLATION PROCEDURE

MINIMUM AVERAGE SKILL LEVEL: AUTOMOTIVE MECHANIC		
INSTALLATION AND ADJUSTMENT PROCEDURE	TOOLS, EQUIPMENT AND FACILITIES	TIME (MIN.)
1. Remove hose fitting from intake manifold and drill and tap for 3/8-inch NPT pipe fitting.	a. Hand tools b. Electric drill c. Threading die	15
2. Drill 1-1/16-inch diameter hole and ream with 1-inch pipe taper reamer into exhaust manifold to fit locking taper fitting adapter of afterburner unit.	a. Electric drill b. Pipe reamer	15 15
3. Disassemble exhaust inlet pipe and install stainless steel perforated buffer disc; reassemble.	a. Hand tools b. Buffer disc	20
4. Burn out 1-5/16-inch hole in exhaust inlet pipe and weld connection.	a. Oxyacetalyene torch b. Connection fitting	30
5. Install two engine mounting brackets and mounting strap for afterburner unit.	a. Hand tools b. Mounting brackets & straps	
6. Install afterburner unit.	a. Hand tools b. Afterburner unit	10
7. Install line from exhaust inlet.	a. Pipe b. Hand tools	5
8. Install heat transfer unit to afterburner unit.	a. Hand tools b. Heat transfer unit	10
9. Install line from heat transfer unit to microcleaning filter and air bleed unit.	a. Hand tools b. Pipe c. Microcleaning filter unit	15
10. Install line from heat transfer unit to air intake.	a. Hand tools b. Pipe c. Flow control valve	15
11. Install Y-type filter to intake manifold.	a. Hand tools b. Y type filter	20
12. Install line from microcleaning filter to Y type filter.	a. Hand tools b. Pipe c. Flow control valve	10

Table 9-6. DEVICE 165 EXHAUST GAS AFTERBURNER/RECIRCULATION WITH BLOWBY AND FUEL EVAPORATION RECIRCULATION INSTALLATION PROCEDURE (CONCL)

MINIMUM AVERAGE SKILL LEVEL: AUTOMOTIVE MECHANIC		
INSTALLATION AND ADJUSTMENT PROCEDURE	TOOLS, EQUIPMENT AND FACILITIES	TIME (MIN.)
13. Install line from Y-type filter to fuel tank emission accumulator.	a. Hand tools b. Pipe c. Flow control valve d. Fuel evaporate flow control valve	20
14. Install line from crankcase emission blowby vent to Y-type filter	a. Hand tools b. Pipe	10
15. Install glow plug in afterburner unit	a. Hand tools b. Glow plug	5
16. Install high voltage coil for glow plug.	a. Hand tools b. High voltage coil	10
17. Wire glow plug to coil, and coil to primary ignition circuit	a. Hand tools b. Wire	10
18. Adjust flow rates through control valves to give best overall driveability.	a. Hand tools b. Engine analyzer	60
	Total Time	5 hrs

Table 9-7. DEVICE 165 EXHAUST GAS AFTERBURNER/RECIRCULATION WITH BLOWBY AND FUEL EVAPORATION RECIRCULATION INITIAL AND RECURRING COST

ITEM	DESCRIPTION	LABOR HOURS OR ITEM QUANTITY	COST (DOLLARS)
Initial Cost:			
Material			
1. Device	a. Buffer disc b. Y-type filter afterburner c. Gloplug d. Heat transfer unit e. Microcleaning filter unit f. Flow control valves		175.00
2. Miscellaneous	a. Connection fitting b. Mounting brackets and straps c. Pipe d. High voltage coil e. Electric wire		(Included in above)
Labor			
1. Installation		4 hrs	50.00
2. Test and adjust		1 hr	12.50
		Total Initial Cost	$ 237.50
50,000-Mile Recurring Cost:			
Material			
1. Maintenance Parts	Par. 9.2.5	Average cost of maintenance parts	2.50
Labor			
1. Inspection	Par. 9.2.5	0.5 hr every 12,000 miles @ $12.50 per hr	25.00
		Total Recurring Cost	$ 27.50
		TOTAL COSTS	$ 265.00

9.3 DEVICE 408: EXHAUST GAS AND BLOWBY RECIRCULATION WITH INTAKE VACUUM CONTROL AND TURBULENT MIXING

9.3.1 Physical Description

Device 408 consists of an adapter plate which fits under the carburetor and connects by hose to the crankcase blowby recirculation system. It also connects to the exhaust manifold through a flexible metal conduit. The adapter plate is about 3/4 inch in thickness, 1 inch wider than the carburetor base, and 2 inches longer than the carburetor base. The adapter plate has a device in each carburetor throat to induce "turbulation" into the air-fuel mixture as it flows into the intake manifold. In front and in the rear of the adaptor plate are tubular sections which contain vacuum operated valves for control of the exhaust and blowby gases. Figures 9-3 and 9-4 are photographs of the device.

9.3.2 Functional Description

Device 408 operates on the principle of injecting exhaust and blowby gases into the intake manifold and creating "turbulent" flow in the manifold. The following description was provided by the developer:

> "As a source of heat, the high temperature air of recycled exhaust gas is drawn from the exhaust sytem through a heat exchanger into the "little black box" where it is mixed in ratio with the blowby gases drawn from the crankcase of the vehicle. During the deceleration cycle of an automobile the deceleration valve of the device opens to capacity providing an unrestricted flow of recycled exhaust gases beneath the carburetor thereby relieving the vacuum demand upon the idling circuit of the carburetor ....
>
> "A high efficiency turbulator element is built into the base of each device throat which imparts a vortical turbulence inertial action to the air-fuel mixture as it passes through the turbulator, thus compounding the mixing and blending of the now preheated gaseous gasoline vapors and air to the point of saturation and uniformity.
>
> "The self-compensating, vacuum actuated, bleed air regulator or acceleration valve opens progressively in ratio to diminishing manifold vacuum of the engine, thus maintaining a progressive volume increase in the preheated air, gasses and fumes approximately parallel, percentage wise, to the increasing volume of gasoline passing through the carburetor and device. Hence, an ample quantity of preheated air, gasses and fumes are present to vaporize the increased volume of gasoline.
>
> "By replacing the o.e.m. oil filter breather cap of any vehicle with a one-way, inlet only, type filler breather cap, the device readily becomes a closed positive crankcase ventilation device capable of controlling the severest cases of crankcase blowby emissions."

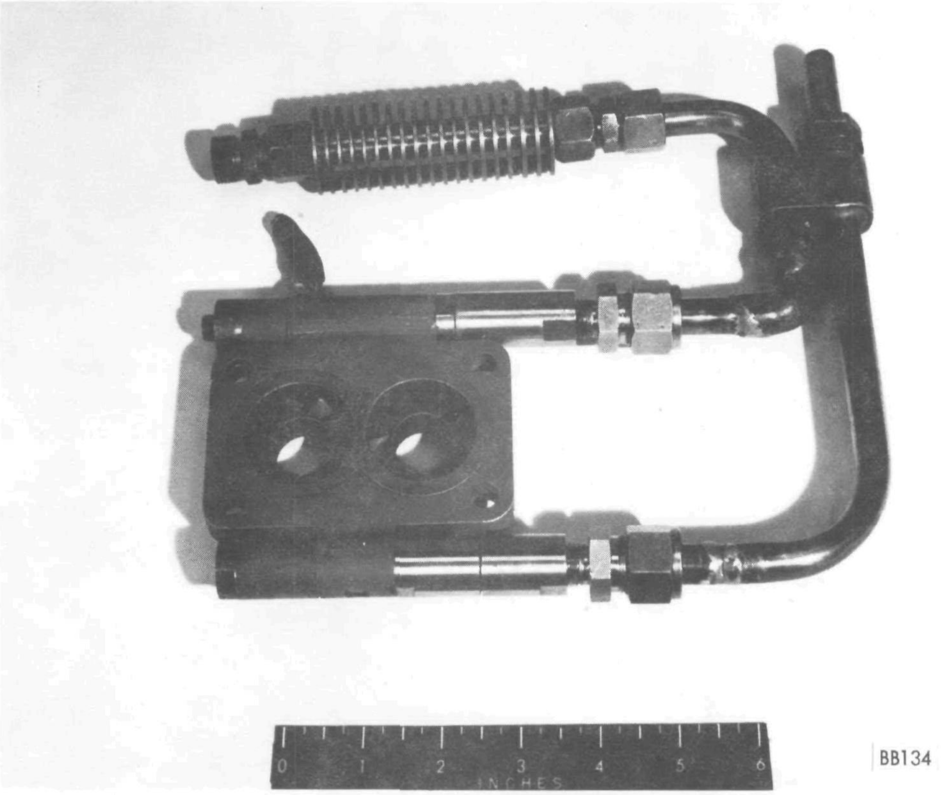


Figure 9-3. DEVICE 408 EXHAUST GAS AND BLOWBY RECIRCULATION WITH INTAKE VACUUM CONTROL AND TURBULENT MIXING ASSEMBLY

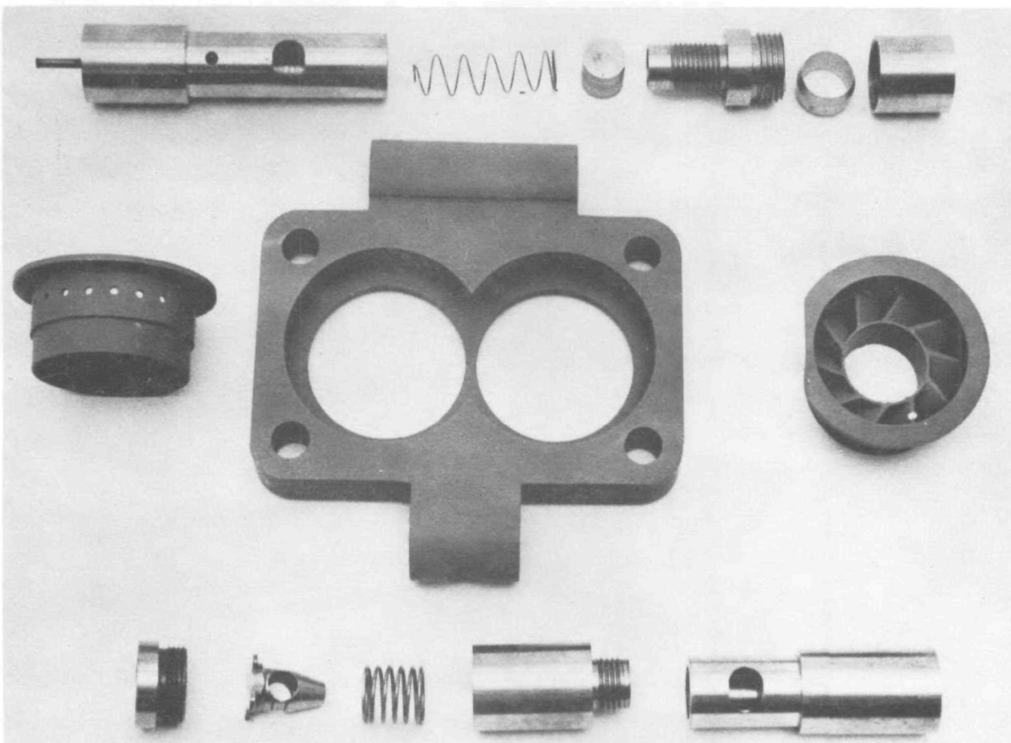


Figure 9-4. DEVICE 408 EXHAUST GAS AND BLOWBY RECIRCULATION WITH INTAKE VACUUM CONTROL AND TURBULENT MIXING COMPONENTS

9.3.3 Performance Characteristics

No exhaust emission data or driveability data were supplied for this device; therefore, it is not possible to evaluate performance.

9.3.4 Reliability

Functionally, the device consists of gas passages and two spring-loaded valves. The device appears capable of demonstrating a reliability in excess of 50,000 mean-miles-before-total-failure with proper maintenance. It is essential that corrosion resistant materials be utilized where required to enable appropriate disassembly for maintenance.

9.3.5 Maintainability

The following maintenance should be performed:

a. The crankcase blowby device valve should be inspected and cleaned at the same intervals as the standard PCV valve.

b. The device exhaust gas control valve should be inspected every 12,000 miles for exhaust products build-up or metal erosion and cleaned or replaced as required.

It is estimated that the required routine maintenance can be performed in 30 minutes provided that components are not corroded and can be disassembled. Additionally, the device should be cleaned, particularly orifices and the fixed turbine blades, every time the carburetor is cleaned or overhauled. Broken valve springs or eroded valves can be replaced during routine maintenance. No other repairs are anticipated.

9.3.6 Driveability and Safety

The probability of igniting the carbureted fuel mixture is increased by the method of exhaust gas recirculation. This could constitute a safety hazard if the basic carburetor used with the device is not capable of suppressing a backfire without conflagration of the raw fuel or the air filter. No other potential safety hazards have been identified.

This device was not tested by OLI and driveability data were supplied by the developer. Table 9-8 summarizes this information.

9.3.7 Installation Description

The installation of this device consists of installing an induction unit between the carburetor and intake manifold, connecting a flexible metal conduit from the exhaust line to the induction unit, attaching the hose from the PCV valve to the induction unit, and replacing the oil fill breather cap with a new one-way inlet flow only cap. Adjustment of the device consists of setting the acceleration valve and deceleration valve. The acceleration valve is adjusted to provide the minimum exhaust gas inlet at approximately 21 inches

Table 9-8. DEVICE 408 EXHAUST GAS AND BLOWBY RECIRCULATION WITH INTAKE VACUUM CONTROL AND TURBULENT MIXING DRIVEABILITY (DEVELOPER DATA)

Critical Driveability Elements	Increased stall during both cold start and hot start acceleration
General Driveability Elements	No affect
Acceleration Time (0-60 mph)	Constant at 19.1 sec
Deceleration Time (60-40 mph)	Constant at 9.5 sec
Gas Mileage (mpg)	No data

of vacuum at idle. The deceleration valve is adjusted to open at approximately 25 inches of vacuum during deceleration.

The developer estimates that the installation of the device should take about one hour. Table 9-9 contains a more detailed description of the installation procedure and identifies tools and special equipment required. Installation can be accomplished in a normally equipped repair shop with normal skills.

9.3.8 Initial and Recurring Costs

The developer estimates that the cost of the device is $20. Table 9-10 summarizes the installation costs. From the information available, it is estimated that the cost for installing this device, including material, would be $35.62.

9.3.9 Feasibility Summary

Due to the lack of developer emission data, the evaluation of the feasibility of this device for retrofit control of exhaust emissions from used cars is inconclusive.

A detailed marketing plan has been supplied involving dealer franchises but at the present time the unit is not available on the market.

Table 9-9. DEVICE 408 EXHAUST GAS AND BLOWBY RECIRCULATION WITH INTAKE VACUUM CONTROL AND TURBULENT MIXING, INSTALLATION PROCEDURE

MINIMUM AVERAGE SKILL LEVEL: AUTOMOTIVE MECHANIC		
INSTALLATION AND ADJUSTMENT PROCEDURE	TOOLS, EQUIPMENT AND FACILITIES	TIME (MIN.)
1. Remove carburetor and studs to intake manifold.	Hand tools	15
2. Install new longer studs in intake manifold.	Hand tools - Longer studs for intake manifold	4
3. Install induction unit on intake manifold so that it is installed between carburetor and manifold.	Hand tools Induction unit	
4. Reinstall carburetor on engine.	Hand tools	6
5. Burn hole in exhaust line between muffler and manifold.	Oxyacetylene torch	15
6. Install connection to exhaust line.	a. Hand tools b. Connection clamps	7
7. Connect flexible metal conduit from connection on exhaust line to induction unit on intake manifold.	a. Hand tools b. Flexible metal conduit c. Clamps	8
8. Attach hose from PCV to induction.	a. Hose, clamps	2
9. Replace oil-fill breather cap with one-way inlet flow only cap.	Special oil-fill breather cap	1
10. Adjustment of the device is made to provide the minimum exhaust gas and fume inlet at the approximately 21-inches of vacuum at idle. This is made on the acceleration valve.	Engine analyzer	8
11. Adjustment of the deceleration valve is made to provide the valve to open at approximately 25-inches of vacuum during deceleration.	Engine analyzer	7
	Total Time	1.25 hrs

Table 9-10. DEVICE 408 EXHAUST GAS AND BLOWBY RECIRCULATION WITH INTAKE VACUUM CONTROL AND TURBULENT MIXING INITIAL AND RECURRING COSTS

ITEM	DESCRIPTION	LABOR HOURS OR ITEM QUANTITY	COST (DOLLARS)
Initial Cost:			
Material			
1. Device	a. Induction unit b. Flexible metal conduit c. Hose d. Special oil filler e. Breather cap		20.00
2. Miscellaneous	a. Larger studs for intake manifold b. Connection clamps		(Including above)
Labor			
1. Installation		1 hr	12.50
2. Test and adjust		0.25 hr	3.12
		Total Initial Cost	$ 35.62
75,000-Mile Recurring Cost:			
Material			
1. Maintenance Parts		Average cost of maintenance parts	2.00
Labor			
1. Inspection		0.5 hr every 12,000 miles @ $12.50 per hr	39.00
		Total Recurring Cost	$ 41.00
		TOTAL COST	$ 76.62

9.4 DEVICE 469: THERMAL REACTOR WITH EXHAUST GAS RECIRCULATION AND PARTICULATE CONTROL

This device, according to the developer's report (Reference 73), is a total exhaust emission control system.

The thermal reactor used in this system is a device 244 model (described in Section 3, paragraph 3.2.1).

9.4.1 Physical Description

This emission control system combines three major devices. These are:

a. An exhaust manifold thermal reactor to control the hydrocarbons and carbon monoxide. (1)

b. An exhaust gas recirculation system to control nitrogen oxide levels.

c. Particulate trap.

9.4.2 Functional Description

9.4.2.1 Thermal Reactor

The exhaust manifold reactors are mounted on the engine in place of the conventional exhaust manifolds and air is injected into the exhaust ports from the air injection system used on many production cars. The reactors provide a high-temperature zone in which the hydrocarbons and carbon monoxide are oxidized thermally to carbon dioxide and water. A detailed description is presented for this reactor in Section 3.

9.4.2.2 Exhaust Gas Recirculation

A portion of the exhaust gas is taken from the exhaust pipe just ahead of the muffler and is directed into the carburetor between the venturi section and the throttle plate, Figure 9-5. The introduction of the exhaust gas into the carburetor dilutes the incoming fuel/air mixture to the engine and lowers the peak combustion temperatures within the cylinder, thus reducing the formation of nitrogen oxides. The amount of exhaust gas which enters the carburetor is metered by an orifice located in the recirculation line. The system was set to give a recirculation rate of approximately 15 percent. A vacuum-operated, on-off valve shuts off the recirculation at idle to give smooth engine operation and also at wide-open-throttle to prevent loss in vehicle performance. A small cyclone separator to remove particles which might plug the recirculation system can be incorporated in the recirculation line if needed.

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(1) The reactor system alone was evaluated and presented as Device 244 in Section 3, paragraph 3.2.1.

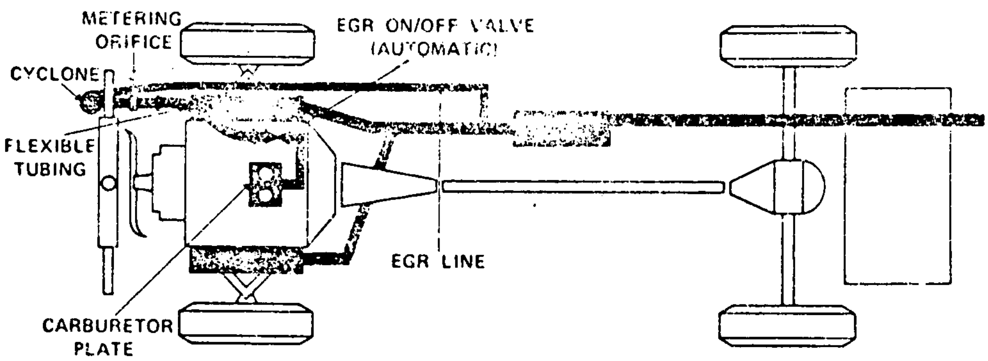

Figure 9-5. EXHAUST GAS RECIRCULATION SYSTEM

9.4.2.3 Exhaust Particulate Trap

To trap particulate matter effectively, three important functions must be accomplished by the trapping system. First, the exhaust must be cooled so that the potential particulate matter can solidify in the exhaust stream. Secondly, the fine particles must be agglomerated into larger particles so that they can be easily separated from the gases. Finally, the particles must be separated from the gas stream with some device such as a cyclone trap and then retained in the exhaust system.

A schematic diagram of an exhaust particulate trapping system employing these three principles is shown in Figure 9-6. This system will be called System A. The cooling of the exhaust gas as it passes through a dual exhaust system is enhanced by the use of fluted pipes which provide more surface area than ordinary pipes and thus more effective cooling. Each exhaust line empties into a trap box in which the exhaust gas first passes through wire mesh to agglomerate the particles and then through a cyclone separator to separate the particles from the gas. The separated particles are collected in one portion of the box and the exhaust gas exits to the atmosphere through a tailpipe. The boxes have sufficient capacity to store all the separated lead salts for the life of the car, or 100,000 miles. The connection between the two exhaust lines just ahead of the trap boxes merely serves to balance the pressure in the two exhaust

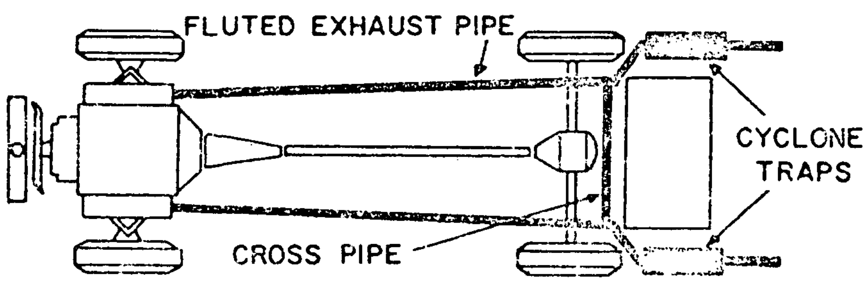

Figure 9-6. EXHAUST PARTICULATE MATTER TRAPPING SYSTEM A

lines. A photograph of a trap box cut away to show the cyclone separator is shown in Figure 9-7. The wire mesh packing is omitted to permit a view of the cyclone separator.

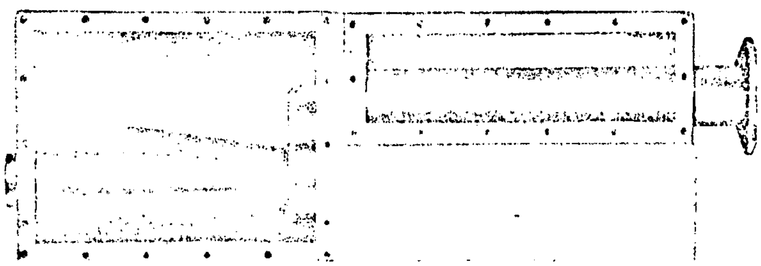

Figure 9-7. CYCLONE SEPARATOR AND COLLECTION BOX

9.4.3 Performance Characteristics

Table 9-11 shows that the reactor performance with exhaust gas recirculation (EGR) exhibits substantial reductions (77 and 60 percent for HC and NOx) from similar test cars with the auto manufacturer emission control systems installed.

To measure particulate emission rates, the vehicles were operated on a programmed chassis dynamometer using a modification of the AMA driving cycle (Reference 73). To simulate motorist-type driving the 40.7-mile AMA cycle was divided into nine trips ranging in length from less than one mile to a maximum of 15 miles. The vehicles were stopped at the end of each trip and the engines and exhaust systems force-cooled. At the time these tests were being conducted, mileage accumulation was being conducted on both cars A and B. No subsequent data were reported by the developer. Also at the time of these tests (November 20, 1971), measuring techniques had not been established by the Federal Government (Reference 73).

The developer reported that the combined control systems (reactor, EGR, and trap) also reduce particulates as indicated below (Reference 73).

	Particulate Emission Rate (GM/MI)	
	Leaded Salts	Total Particulate Matter
Car A	0.033	0.041
Car B	0.017	0.029

Table 9-11. DEVICE 469 EMISSION REDUCTION RESULTS
(EPA REFERENCES 74 AND 75)(1)

VEHICLE CONFIGURATION	POLLUTANT (GM/MI)		
	HC	CO	NOx
Without Device (2)	3.07	37.35	3.24
With Device (1)	0.60	20.74	1.12
Percent Reduction	80	44	65

(1) Results are from two EPA 9-Cycle, 7-Mode Tests (Reference 16).
(2) Average baseline data for six 1970 350-CID vehicles with standard factory emission control equipment. Used in this report for baseline comparison purposes only.

9.4.4 Reliability

The developer's report provided some information on the reliability of the combined systems. Although not yet tested as extensively as exhaust manifold reactors, the exhaust gas recirculation system had been operated for 50,000 miles without maintenance. The vehicle has been operated on a programmed chassis dynamometer on a non-detergent fuel containing 3 grams of lead per gallon and without a cyclone separator in the exhaust gas recirculation line. During this entire test the exhaust gas recirculation system required no maintenance. The gas recirculation rate remained at 15 percent and the nitrogen oxide levels did not change. Some deposits accumulated in the throttle section of the carburetor. Additional tests were being conducted with a fuel containing a carburetor detergent (Reference 73).

The particulate trapping systems also have not been tested as extensively as exhaust manifold reactors but various versions reportedly have been operated for up to 64,000 miles without maintenance or attention.

Reference 2 does point out some reliability problems for the combination systems described here.

The developer supplied six cars to California Air Resources Board in the fall of 1970 for its evaluation in a two-year program. These cars were 1970 Chevrolets with 350 CID engines and automatic transmissions, and were equipped with the DuPont particulate-trapping system as well as thermal reactor and EGR. The six test cars, along with six production vehicles for comparison, were assigned to the State Motor Pool in California for normal driving service by state employees. In June 1971, the average of the odometer readings of the six vehicles was 17,954 miles. As the vehicles had about 3000 miles of operation prior to incorporation of the emission control system, about 15,000 miles of durability testing of the emission control system were actually logged.

Near the end of August 1971, a failure of a timing chain occurred in one of the six test vehicles. The failure was described as an elongation of the timing chain, which eventually caused a hole to be rubbed in its cover. None of the six vehicles in the control fleet was affected.

The developer stated that similar wear was observed in three of the six California Air Resources Board test cars. Symptoms of similar wear had been previously detected in three reactor vehicles tested by the developer. Timing chain pins, cam followers, rocker arms, and valve guides were affected. The developer was convinced that the wear problems was due to the lapping action of small (0.02-0.05 micron) metal oxide particles mixed in the engine oil, and that these small particles come from the reactor core and find their way through the EGR line to the lubrication system.

Severe oxidation of the reactor core 310 stainless steel material was demonstrated in the developer's tests of two reactors which lost 0.5 pound of core weight (23 percent) after 20,000 miles of testing. The developer stated that the wear problem could be overcome by using a material such an Inconel 601 in the reactor core. Since oxidation of any part of the exhaust system is a potentially similar hazard, a more complete solution would be to use an EGR gas source upstream of the thermal reactor.

Because of these problems, the California Air Resources Board test program was discontinued. The developer of the reactor plans to concentrate on the development of an improved thermal reactor emission control system for new vehicles, rather than for retrofit applications (Reference 73).

9.4.5 Maintainability

As stated above in the performance section, the EGR portion of the combined systems did not require any maintenance. However, some deposits accumulated in the throttle section of the carburetor which suggest that normal cleaning procedures and mileages intervals should be followed. The EGR valve should probably be cleaned concurrently with the carburetor. Such maintenance could be accomplished in one-half hour every 12,000 miles.

9.4.6 Driveability and Safety

The developer (Reference 73) and EPA (References 74 and 75) did not supply any driveability data.

The combination system described here appears to have no safety problems.

9.4.7 Installation Description

Installation descriptions were not supplied by the developer.

9.4.8 Initial and Recurring Costs

No installation costs were provided by the developer for retrofitting the described system. Based on data in Reference 2, the additional cost for EGR would be about $25 higher than the basic thermal reactor system cost (refer to Table 3-20). The particulate trap cost would also have to be added.

None of the references (2, 73, 74, 75) contained any fuel consumption data.

9.4.9 Feasibility Summary

The "total control system" comprising exhaust manifold thermal reactors, exhaust gas recirculation and traps will control hydrocarbons, carbon monoxide, nitrogen oxides and particulate matter and appears to be technically feasible. Exhaust manifold thermal reactors appear to be able to operate satisfactorily with leaded fuels and it is believed, based on data from the developer, that an exhaust gas recirculation system can be developed which also will operate satisfactorily with leaded fuels.

Only limited cost data were available for new car applications. Retrofitting the "total control system" appears to be economically unfeasible due to the mechanical complexity of the entire system.

SECTION 10

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