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STUDY OF CONTROL STRATEGIES FOR IN-USE HEAVY DUTY VEHICLES

FINAL REPORT

STUDY OF CONTROL STRATEGIES FOR IN-USE HEAVY DUTY VEHICLES

Final Report

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Submitted to Project Officer
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Region II publication No. 902/4-81-001 a

ADDENDUM

This ADDENDUM attempts to resolve ambiguities and omissions in the text that have been pointed out by reviewers.

1. On page 1 and again on page 19 it is stated that Nox results are not significant at the 95% confidence level, but no mention is made of the statistical criteria for the CO, HC and fuel economy results. It should be understood that these were also tested at the 95% level.

2. Apparent contradictions appear in the tables that show the average of the measured pollutant levels before and after tune up and also the average of the percent change in pollutant levels. One example of these contradictions appears in Table IV-D-1 for the CO levels measured in C39 tests. The first line shows that CO emissions averaged 262.90 g/mi before tune up and the second lines shows that tune up reduced the average to 245.96 g/mi, a reduction of about 7%. Yet the third line, which gives the percentage change in emissions per vehicle, averaged over all vehicles, shows an average increase of 15% in emission level.

The reason for this apparent contradiction is the occurance of vehicles with unusually low emission for the pollutant and for which the emission increased after tune up. Since the emission is small this vehicle has a proportionally small influence on the ration of the averages before and after tune up as found from rows one and two. However, because its emission is small the percentage increase in emission can be large for that vehicle. One or more vehicles with these characteristice can outweigh the percentage reduction in emission from the other vehicles when averaged to find row three.

It is interesting to compare the uses of the percent reduction in emission that is found from the ration of row one and row two with the percentage change per vehicle given in row three. An air pollution control engineer concerned with evaluating results of an I/M program would be interested in the changes in average emissions found from rows one and two. An engineer concerned with setting up and instrumenting program would be concerned with being able to measure the increases in emissions that sometimes occur after tune up as shown in row three.

3. On page 20 it is noted that the dynamometer could not test the heaviest vehicles under full load. It has been suggested that a correction factor be used to compensate for the effect of underload on emissions from the heaviest vehicles. Such a factor might be calculated, for example, by making a linear regression analysis of the test data to determine how emissions vary with vehicle weight. However, it is unlikely that the results of such analyses would be reliable enough to justify the effort.

4. A question was raised about the possible cost of an EGR retrofit device. The report did not provide a cost estimate because such devices are no longer being manufactured and it is difficult to extrapolate the cost of a retrofit EGR device from the cost of original equipment EGR systems. However, when retrofit kits were available they were priced at under $35. Allowing for inflation and changes in technology it is probable that, if the market was created, manufacturers of o.e. EGR systems would offer retrofit kits in the $60 to $90 price range.

5. It was suggested that it would be helpful to summarize the results of EGR retrofit tests in a table similar to Table IV-J that summarizes results on ADAKS air bleed devices. As explained in the report, by the time the study was ready to start extensive testing of EGR retrofits they were no longer being manufactured. Insufficient EGR retrofit test data were taken to warrent preparation of a table similar to Table IV-J.

6. It was pointed out that in Table IV-J, Figures 4-A thru 4-J and the graphs of APPENDIX II no indication is given of the procedure used to find the results. Unless otherwise stated all the results were obtained from New York Quick cycle tests.

7. Typographical errors were pointed out in Table IV-I. The Description line for the Air Jet/Ball-Matic device should read "Air bleed to PCV line, spark advance" and the correct description for the A.Q.P. Pure Power device should read "Capacitor discharge ignition system".

ABSTRACT

To collect baseline information for heavy duty vehicle Inspection/Maintenance programs, a large fleet of in-service gasoline powered vehicles were chassis dynometer tested for HC, CO and NOx emissions and fuel economy in as-received condition and again after being tuned to their manufacturers' specifications. Computer analysis of the changes produced by tuning are presented and discussed.

To investigate the suitability of commercially available non-catalytic emissions control devices for heavy-duty-vehicle retrofit programs over fifteen such devices were screened. Exhaust gas recirculation devices, air bleeds and lean mixture carburetors were selected as promising candidates for retrofitting. These devices were installed on in-service heavy duty vehicles. Emissions and fuel economy were tested immediately after installation. The vehicles were recalled and retested periodically to monitor changes in devices effectiveness with use and time. Test results are evaluated to determine the applicability of the devices to a heavy duty retrofit program.

TABLE OF CONTENTS

LIST OF TABLES

Table

LIST OF FIGURES

SUMMARY

The present study is divided into two parts; one to evaluate retrofit of heavy duty vehicles with non-catalytic emissions control devices, the other to investigate heavy duty inspection and maintenance by measuring the change in exhaust levels of hydrocarbons, carbon monoxide, oxides of nitrogen and in fuel economy after engines were tuned to manufacturer's specifications.

To evaluate retrofit, over 15 commercially available devices were screened to determine their potential for a heavy duty vehicle retrofit program. Exhaust gas recirculation devices, air bleeds and lean mixture carburetors were selected as promising devices. Commercially available models of the three devices were installed on in-service heavy duty vehicles. Emissions and fuel economy were measured before and after retrofit by chassis dynamometer tests.

After testing, the vehicles were returned to their owners and were periodically recalled and retested. Where possible retests were performed with the retrofit device operational and also with the device detached in order to evaluate the reduction in emissions produced by it.

A heavy duty retrofit program appears to require an obligatory inspection/maintenance program. The Inspection/Maintenance study was conducted to get baseline data for such a program. A large sample of heavy duty gasoline powered vehicles from ten commercial, municipal, state and federal fleets were tested.

Fuel economy and emissions from the vehicles were measured in as-received condition by chassis dynamometer testing. The engines were then tuned to manufacturers' specifications and the vehicles were retested.

When after-tune-up tests were complete those vehicles that were also part of the Retrofit study had a retrofit device installed. Data recorded during the Inspection/Maintenance and Retrofit tests and engine parameters recorded during tune up were keypunched and entered on magnetic tape allowing electronic data processing to be used for statistical analysis of the results.

Analysis of 181 pairs of before-and-after tune up tests from the Inspection/Maintenance study shows that tune up resulted in average reductions of about 36% in hydrocarbon emissions and 33% in carbon monoxide emissions. There was no statistically significant change in oxides of nitrogen emissions. Fuel economy increased almost 4% which, at a fuel price of $1.30 a gallon, would represent a savings of $8.80 for every 1,000 miles driven.

Tests on the three retrofit devices showed them capable of producing sizeable reductions in emissions. However, other studies at this facility indicate the potential of catalytic converters for a heavy duty retrofit program is superior to non-catalytic devices.

The durability of the devices, when properly installed, was good. Exhaust gas recirculation devices are more difficult to install in heavy duty vehicles than in lighter vehicles. Unless properly maintained they may cause drivability problems. These factors weigh against their use in a heavy duty retrofit program.

Air bleeds and lean carburetors can make considerable improvement in emissions from older vehicles. For newer vehicles most of this improvement has already been realized by other means. The devices could be considered as elements in a broader retrofit strategy.

A program for retrofitting with lean mixture carburetors would have to be preceded by a study of how to select the carburetors and how to adjust them to minimize emissions.

I. GOALS OF THE STUDY

Controlling undesirable emissions of pollutants from heavy duty (HD) vehicles by retrofitting them with control devices was proposed in the New York City Metropolitan Area Air Quality Implementation Plan in 1973.(1)* A study of retrofit devices for HD vehicles was conducted under an Environmental Protection Agency grant by the Bureau of Motor Vehicle Pollution Control of the New York City Department of Environmental Protection.(2)

In that investigation, which will be referred to as the "Grant" study, existing control devices were screened to determine their suitability for retrofit. Catalytic converters, air bleed devices, lean carburetors and exhaust gas recirculation devices were chosen as promising and examples of these controls were retrofitted on in-service vehicles and tested.

The present study was devided into two parts; one to evaluate retrofit, the other to investigate inspection and maintenance (I/M).

RETROFIT

Existing non-catalytic control devices were screened to determine their suitability for retrofit. Factors considered included emissions reduction potential, cost, availability, ease of installtion, effects of installation on vehicle operation and fuel economy and possible mechnaical and safety problems.

Devices selected in the screening process were installed on in-use vehicles and tested. The vehicles were periodically retested to investigate durability and reliability of the devices under in-service conditions.

The study is an extension of the earlier Grant study and wherever possible incorporates the results of that study.

* References are in Section VI.

Inspection/Maintenance

For a retrofit strategy to be effective in controlling emissions an inspection/maintenance program will be required to ascertain that the retrofit is properly installed and that the device and the vehicle are properly maintained. To provide baseline data for an I/M program a large group of HD vehicles were gathered from ten municipal and privately owned fleets. The vehicles were tested at the New York City Emissions Control Laboratory in their "as received" condition to obtain baseline data on hydrocarbon, carbon monoxide and oxides of nitrogen emissions levels and fuel economy as well as information on engine condition and general condition. The vehicles were then tuned to manufacturers' specifications and retested.

For the first time data were collected on a large group of in-service gasoline powered HD vehicles that allow comparison of emissions levels and fuel economy in the on-the-road condition with levels in the tuned-to-specifications condition. The data will help establish realistic criteria for I/M programs.

II. THE TESTS

II.A. THE TEST PLAN

All vehicles were inspected when first received and information including the owner, chassis identification number, owner's identification number, service type, make, model, model year, and general condition were recorded on vehicle I.D. forms.

Vehicles were then tested for the I/M study on a chassis dynamometer in "as received" condition. The vehicles were driven through a set of driving cycles referred to as the New York Quick Cycle, the C39 cycle and the C39H cycle. The vehicle was also driven through a standard Clayton (2) Keymode cycle.

The N.Y. Quick cycle, developed in 1968 for the N.Y. State Dept. of Health to represent N.Y. City driving conditions is illustrated in Fig.1. The C39 cycle, developed to represent HD vehicle driving conditions in N.Y. City traffic is shown in Fig.2. Early in the study it was found that drivers were having difficuty in following the C39 cycle and it was slightly modified. The modified version, called C39H, is shown in Fig.3. Aside from the length of the cycles the main difference between the N.Y. Quick and the C39 cycles is the greater number of accelerations and decelerations in the C39 cycle.

A typical set of I/M tests consisted of two independent N.Y. Quick cycle tests, two independent C39 or C39H cycle tests and one standard Keymode Test. Emissions of HC, CO and NOX and fuel economy were measured and manually recorded on test-record forms. Ambient atmospheric temperature, pressure and humidity were also recorded.

When the as-received I/M test sets were complete the engine of the vehicle was tuned. Engine parameters recorded before and after tune up include idle r.p.m., timing and dwell angles, air/fuel ratio, spark plug gap, idle HC and CO emissions measured by inspection-station-type instrumentation, air filter and PCV valve condition and general engine condiiton. Parts replaced, adjustments and engine repairs, if any, were also recorded. Vehicles were tuned by adjusting the engine parameters to manufacturer's specifications. Where the specification indicated a permissible range for a parameter the value in the range that minimized CO emissions levels without unduly increasing HC emissions was selected.

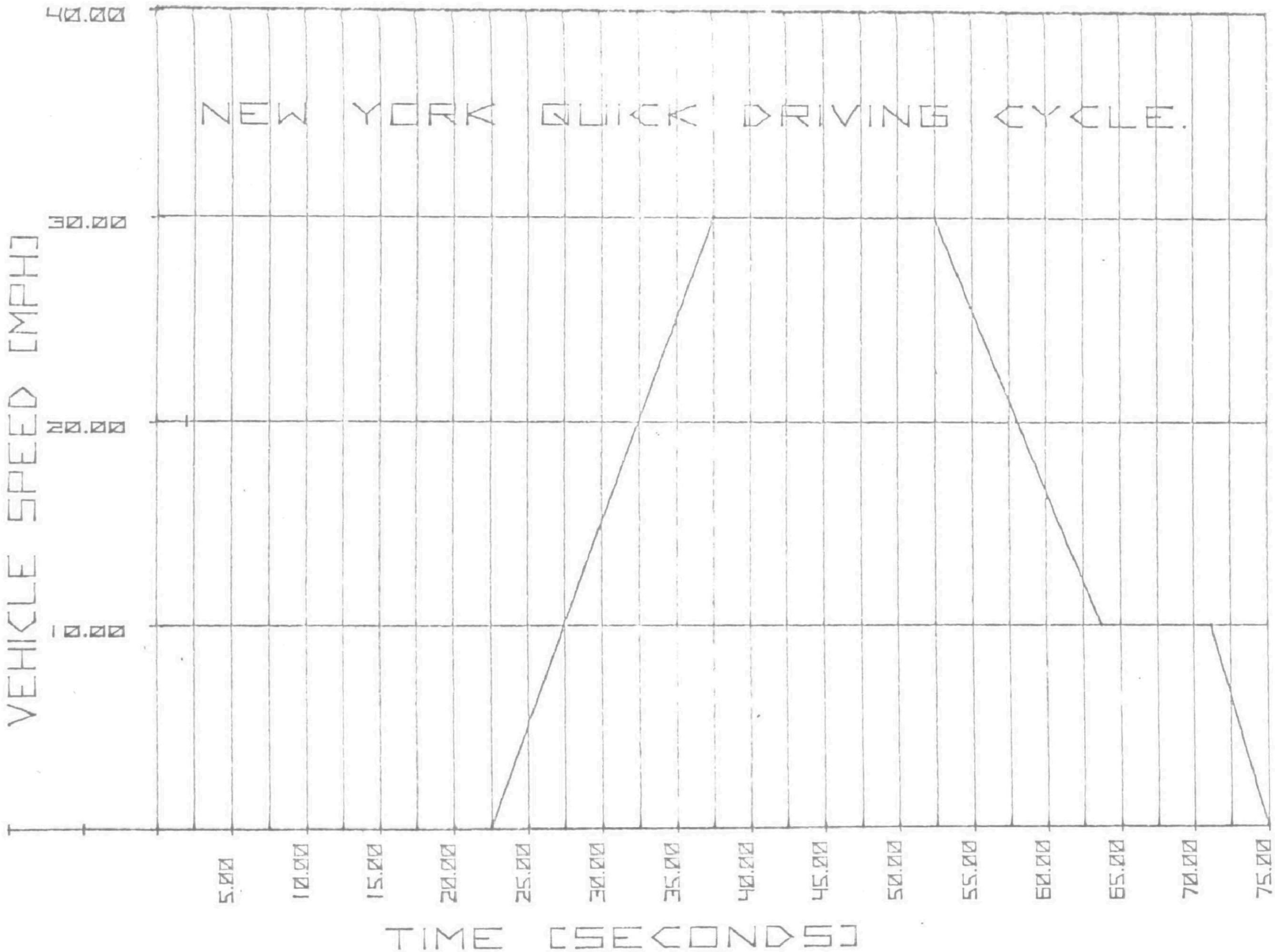

Fig. 1 The New York Quick driving cycle

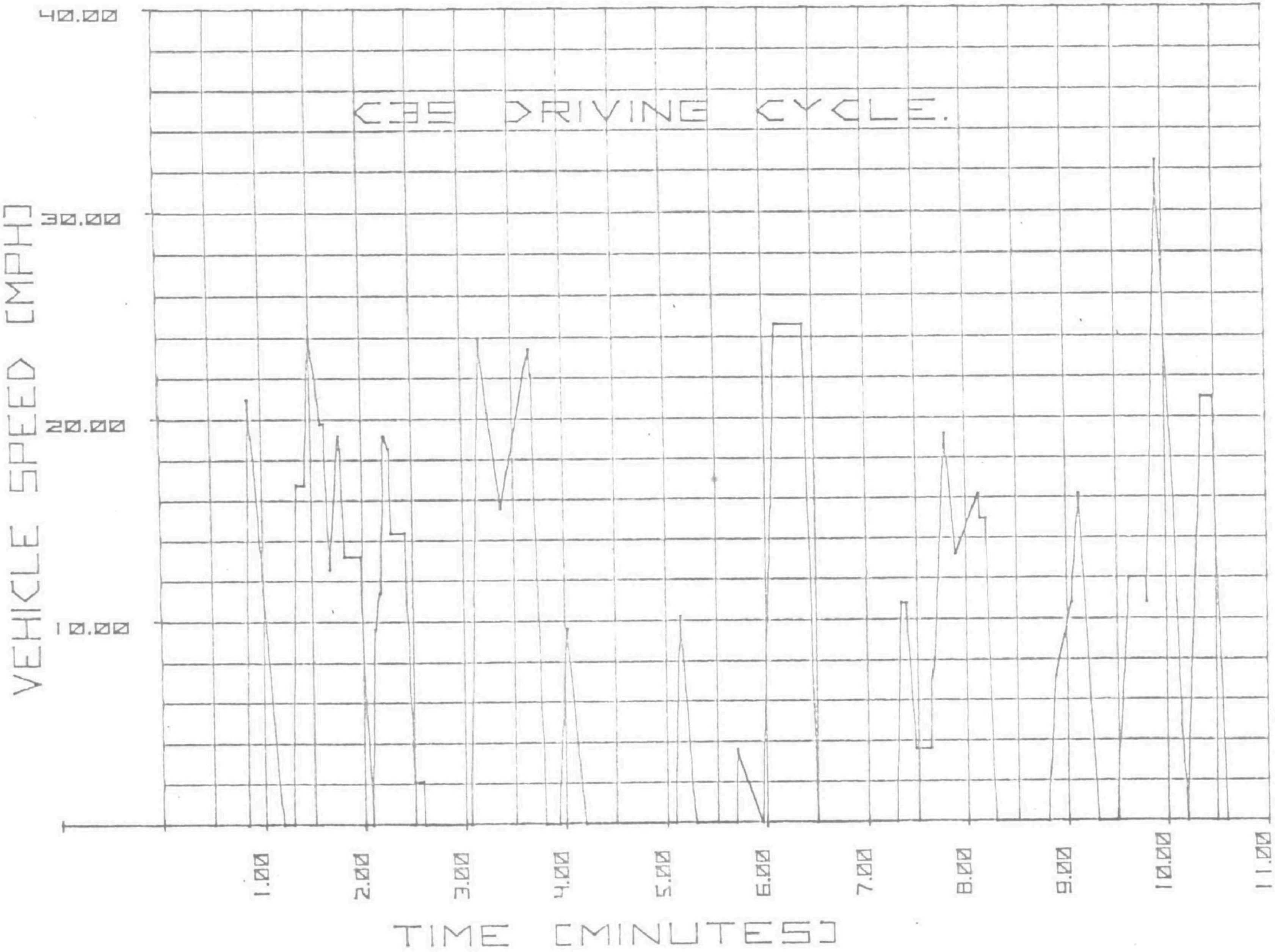

Fig. 2 The C39 driving cycle

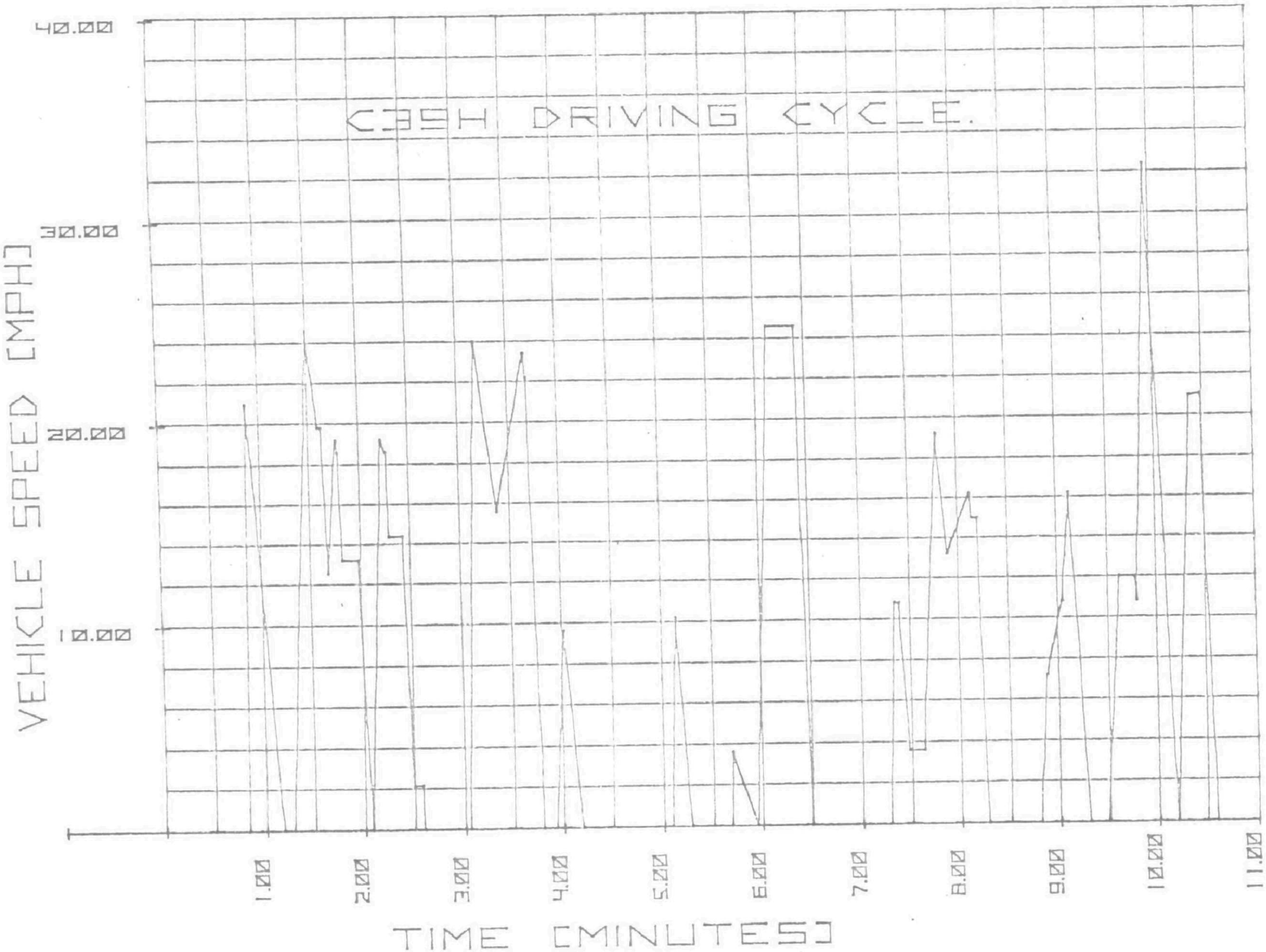

Fig. 3 The C39H driving cycle

After tuning the vehicle was again tested on the dynamometer and the "after-tune-up" test set results were recorded. For identification, each test set was assigned a unique four digit tests set number. Test set number were assigned in chronological order. Test set results and engine parameters were coded, key punched and recorded on magnetic computer tape.

After I/M tests were finished those vehicles that were also part of the RETROFIT study were retrofitted with an emissions control device installed and adjusted to manufacturers specifications. An hour meter initially set to zero was also installed to measure the number of engine operating hours from retrofit. When necessary, minor adjustments to the engine parameters were made according to the installation procedures recommended by the control device manufacturer. After retrofit vehicles were given a set of tests on the dynamometer.

A tune up is part of the manufacturer's recommended installation procedure for all retrofit emissions control devices. In the present study comparison of the before-tune-up- and after-tune-up I/M test sets show the emissions reduction and fuel economy improvement resulting from the tune up alone. The after-tune-up I/M set represents a "baseline" for a properly tuned engine. Comparison of this baseline and the after-retrofit set allows evaluation of the improvement attributable to the device.

RETROFIT vehicles were retested at periodic intervals. The vehicles were not tuned before retesting, but were tested in "as received" condition. The only exceptions were vehicles received so out-of-tune that they could not be retested without tuning.

Where possible the vehicles were retested with the device attached and also with the device detached or rendered inoperative. This was done because emissions from the in-service vehicles varied widely from retest to retest. However, comparison of test sets taken with and without the device provided a measure of the effectiveness of the device in controlling emissions.

II.B. INSTRUMENTATION.

Tests were driven on a Clayton Dynamometer CT200 with direct drive inertia loading from 1,750 to 13,500 lb.

Exhuast sampling used a Scott Constant Volume Sampler 302H set at positive-displacement-pump flow rates of 325 or 500 cubic feet per minute.

Exhaust hydrocarbons and carbon monoxide were measured during tune up with garage grade instruments. Horiba GSM-300 and Sun EPA-75 non dispersive infrared analyzers were used. The Horiba was also used in Keymode tests.

The laboratory grade gas analyzers used with the CVS system were:

Hydrocarbons - Scott 116 flame ionization detector.

Carbon monoxide - Beckman 865 NDIR.

Oxides of nitrogen - Scott 125 Chemiluminescence.

III. VEHICLES AND FLEETS

Obtaining a large group of heavy duty vehicles for testing was a formidable job. Committing trucks to a test program, even a few hours, represented an appreciable expense to commercial operators. To New York City municipal fleets responsible for maintaining essential services with limited resources the diversion of a vehicle for testing was a serious consideration. A free tune up, the operators reward for participating in the study was hardly enough compensation for allowing a vehicle to be tested.

Possibly anticipated public relations benefits influenced private fleet owners to participate in the study. City commissioners and assistant commissioners exerted some influence on municipal fleets to secure vehicles although their influence was limited by the overwhelming priority of maintaining public services. Ultimately the study had to rely on the good will and public spirit of the fleet operators and gratitude is due for their response.

Many problems were encountered. Even though these vehicles were in service a number were received in too poor condition for testing. Early in the study considerable repair work was done on such vehicles to make testing possible, but the time and cost of repairs soon made it necessary to stop this practice.

Vehicles in the RETROFIT study were scheduled to return periodically for retesting. Tests were frequently delayed or cancelled by an emergency requirement for the vehicle, because of drivers' srtikes, or a variety of other reasons. Sometimes the control device was disconnected or removed during emergency repair of a vehicle.

Over 178 vehicles were supplied by ten commercial, municipal and other fleets. The fleets and vehicles are identified in the following list.

Several vehicles involved in the study are not listed. These include vehicles received in too poor condition for testing, trucks withdrawn from the study by their owners and vehicles used in screening tests on devices that were considered not worth including in this report.

***** BROOKLYN UNION GAS CO. *****

OWNER'S ID NUMBER	GROSS WEIGHT	MODEL YEAR	ENGINE DISPLACEMENT	XMISSION CODE	MAKE	MODEL
3123	10000	1973	350	M4	GMC	3500
4071	10000	1971	250	M4	CHEVROLET	30
4202	21000	1970	330	M5	FORD	C600
4251	24000	1971	318	M5	DODGE	D500
4274	21000	1971	330	M4	FORD	C600
4308B	21000	1970	330	M5	FORD	C600
4419	21000	1969	330	M5	FORD	C600
4595	21200	1975	330	M5	FORD	C600
4662	21000	1971	330	M5	FORD	C600
4706	17000	1973	330	M5	FORD	F600
4780	21000	1968	330	M5	FORD	C600
6119	34000	1971	400	M5	WHITE	2300
6589	21000	1963	292	M5	FORD	C600
6719	21000	1966	330	M5	FORD	C600
9851	24000	1968	391	M5	FORD	C750

NUMBER OF VEHICLES 15

-12-

***** CONSOLIDATED EDISON CO. *****

OWNER'S ID NUMBER	GROSS WEIGHT	MODEL YEAR	ENGINE DISPLACEMENT	XMISSION CODE	MAKE	MODEL
4172	10000	1968	292	M4	GMC	3500
4306	10000	1973	292	M4	GMC	3500
5162	19500	1967	292	A6	CHEVROLET	50
5210	14000	1970	292	M4	GMC	3500
5302	19500	1969	292	A6	CHEVROLET	50
5344	14000	1974	350	M4	GMC	3500
5355	14000	1969	292	M4	GMC	3500
5419	32500	1970	351	A6	GMC	6500
5470	21200	1973	345	A4	I-H	1610A
5522	23000	1971	361	A4	FORD	F700
5613	19500	1962	261	M4	FORD	C600
5724	19500	1969	292	A6	CHEVROLET	C50
5927	17000	1976	330	A4	FORD	C600
6201	34000	1971	413	A6	DODGE	M800
6303	24000	1968	351	A6	GMC	7500
6325	24000	1969	366	A6	CHEVROLET	60
6349	26000	1969	400	A6	WHITE	3200H
6362	26000	1969	400	A6	WHITE	3200H

6399	25500	1971	361	M5	FORD	F700
6513	21000	1973	366	A4	GMC	6500
6910	22000	1961	318	M4	DODGE	D600

NUMBER OF VEHICLES 21

***** NEW YORK CITY DEPT. OF AIR RESOURCES *****

OWNER'S ID NUMBER	GROSS. WEIGHT	MODEL YEAR	ENGINE DISPLACEMENT	XMISSION CODE	MAKE	MODEL
T49	10000	1969	307	A3	CHEVROLET	P30
117009	07500	1969	307	A3	CHEVROLET	CE20

NUMBER OF VEHICLES 2

***** NEW YORK CITY DEPT. OF SANITATION *****

OWNER'S ID NUMBER	GROSS WEIGHT	MODEL YEAR	ENGINE DISPLACEMENT	XMISSION CODE	MAKE	MODEL
09A018	44000	1973	501	A4	I-H	1910A
25D047	37800	1970	478	A6	GMC	8500
25D082	37800	1970	478	A6	GMC	8500
25D085	37800	1970	478	A6	GMC	8500
25D092	37800	1970	478	A6	GMC	8500
25D116	37800	1970	478	A6	GMC	8500
25D141	37800	1970	478	A6	GMC	8500
25D201	37800	1970	478	A6	GMC	8500
25D318	37800	1970	478	A6	GMC	8500
25D369	37800	1970	478	A6	GMC	8500
25D384	37800	1970	478	A6	GMC	8500
25E020	37800	1972	478	A6	GMC	8500
25E021	37800	1972	478	A6	GMC	8500
25E146	37800	1972	478	A6	GMC	8500
25E150	37800	1972	478	A6	GMC	8500
25E155	37800	1972	478	A6	GMC	8500
25E156	37800	1972	478	A6	GMC	8500
25E157	37800	1972	478	A6	GMC	8500
25E159	37800	1972	478	A6	GMC	8500
25E160	37800	1972	478	A6	GMC	8500
25E161	37800	1972	478	A6	GMC	8500
25E163	37800	1972	478	A6	GMC	8500
25E164	37800	1972	478	A6	GMC	8500
25E165	37800	1972	478	A6	GMC	8500
25E166	37800	1972	478	A6	GMC	8500
25E168	37800	1972	478	A6	GMC	8500
25E169	37800	1972	478	A6	GMC	8500

25E170	37800	1972	478	A6	GMC	8500
25E171	37800	1972	478	A6	GMC	8500
25E177	37800	1972	478	A6	GMC	8500
25E182	37800	1972	478	A6	GMC	8500
25E183	37800	1972	478	A6	GMC	8500
25G055	40000	1973	501	A6	I-H	2010A
25G059	40000	1973	501	A6	I-H	2010A
25G080	40000	1973	501	A6	I-H	2010A
25G089	40000	1973	501	A6	I-H	2010A
25G090	40000	1973	501	A6	I-H	2010A
25G091	40000	1973	501	A6	I-H	2010A
25G184	40000	1973	501	A6	I-H	2010A
25G190	40000	1973	501	A6	I-H	2010A
25G192	40000	1973	501	A6	I-H	2010A
25G193	40000	1973	501	A6	I-H	2010A
25H173	40000	1976	478	A4	I-H	2010A
26B012	37800	1970	478	A6	GMC	8500
26D008	40000	1973	478	A6	GMC	8500
26D024	40000	1973	478	A6	GMC	8500
26D055	40000	1973	478	A6	GMC	8500
26D066	40000	1973	478	A6	GMC	8500
287016	39850	1968	478	A6	GMC	8500

NUMBER OF VEHICLES 49

***** NEW YORK CITY DEPT. OF WATER RESOURCES *****

OWNER'S ID NUMBER	GROSS WEIGHT	MODEL YEAR	ENGINE DISPLACEMENT	XMISSION CODE	MAKE	MODEL
112004	31000	1970	406	M5	I-H	1910A
125001	24000	1970	318	M4	DODGE	D500
125002	24000	1970	318	M4	DODGE	D500
125003	24000	1970	318	M4	DODGE	D500
125005	24000	1970	318	M4	DODGE	D500
137002	10000	1969	240	M4	FORD	F350
137004	10000	1969	240	M4	FORD	F350
145001	21000	1968	300	M4	FORD	F600
145004	21000	1968	300	M4	FORD	F600
145005	21000	1970	300	M4	FORD	F600
147001	20000	1970	300	M4	FORD	F600
147002	20000	1970	300	M4	FORD	F600
160003	17000	1967	300	M4	FORD	F600
175001	17000	1965	300	M4	FORD	F600
176001	17000	1967	300	M4	FORD	F600
176002	17000	1967	300	M4	FORD	F600
178002	19500	1968	300	M4	FORD	F600
182001	27000	1966	361	M5	FORD	C800

221002	07120	1972	225	A3	DODGE	D200
279001	15000	1965	300	M4	FORD	F600
282003	07500	1971	225	A3	DODGE	D200
282019	07500	1971	225	A3	DODGE	D200
282020	07500	1971	225	A3	DODGE	D200
282021	07500	1971	225	A3	DODGE	D200
282022	07500	1971	225	A3	DODGE	D200
290003	10000	1972	225	M4	DODGE	D300
290009	10000	1972	225	M4	DODGE	D300
290010	10000	1972	225	M4	DODGE	D300
290011	10000	1972	225	M4	DODGE	D300
290012	10000	1972	225	M4	DODGE	D300
290013	10000	1972	225	M4	DODGE	D300
290014	10000	1972	225	M4	DODGE	D300
290015	10000	1972	225	M4	DODGE	D300
290016	10000	1972	225	M4	DODGE	D300
290017	10000	1972	225	M4	DODGE	D300
290018	10000	1972	225	M4	DODGE	D300
293004	10000	1970	225	M4	DODGE	D300
297001	07120	1972	225	A3	DODGE	D200
297002	07120	1972	225	A3	DODGE	D200
323001	18200	1970	304	M4	I-H	1600
330001	15000	1967	300	M4	FORD	F600
343005	07500	1973	258	A3	I-H	1210
343006	07500	1973	258	A3	I-H	1210
343007	07500	1973	258	A3	I-H	1210
343016	07500	1973	258	A3	I-H	1210
343017	07500	1973	258	A3	I-H	1210
409003	06700	1974	258	A3	I-H	200
409006	07500	1974	258	A3	I-H	200
416002	15700	1974	345	A4	I-H	1600
416003	15700	1974	345	A4	I-H	1600
416004	15700	1974	345	A4	I-H	1600
416005	15700	1974	345	A4	I-H	1600
419001	08300	1969	360	A3	FORD	F350
422007	03200	1974	258	A3	I-H	200
422008	08200	1974	258	A3	I-H	200
450001	20000	1975	345	M4	I-H	1600
450004	20000	1975	345	M4	I-H	1600
450005	19500	1975	345	M4	I-H	1600
450006	19500	1975	345	M4	I-H	1600
452001	18400	1975	345	M4	I-H	1600

NUMBER OF VEHICLES 60

***** NEW YORK STATE DEPT. OF ENVIRONMENTAL CONSERVATION *****

OWNER'S ID NUMBER	GROSS WEIGHT	MODEL YEAR	ENGINE DISPLACEMENT	XMISSION CODE	MAKE	MODEL
684352	20000	1968	300	M4	FORD	F600
704526	27300	1970	366	M5	CHEVROLET	C60
714192	08000	1971	318	M4	DODGE	PW200
714398	24000	1971	361	M4	DODGE	D500

NUMBER OF VEHICLES 4

***** NEW YORK TELEPHONE CO. *****

OWNER'S ID NUMBER	GROSS WEIGHT	MODEL YEAR	ENGINE DISPLACEMENT	XMISSION CODE	MAKE	MODEL
200630	14000	1970	350	A3	GMC	3500
200633	14000	1970	350	A3	GMC	3500
200634	14000	1970	350	A3	GMC	3500
200637	14000	1970	350	A3	GMC	3500
200640	14000	1970	350	A3	GMC	3500
200642	14000	1970	350	A3	GMC	3500

NUMBER OF VEHICLES 6

***** UNITED PARCEL SERVICE *****

OWNER'S ID NUMBER	GROSS WEIGHT	MODEL YEAR	ENGINE DISPLACEMENT	XMISSION CODE	MAKE	MODEL
10704	15000	1971	300	M4	FORD	P500
10715	15000	1971	300	M4	FORD	P500
11338	15000	1971	300	M4	FORD	P500
16944	15000	1972	300	M4	FORD	P500
16952	15000	1972	300	M4	FORD	P500
18056	17000	1972	300	M5	FORD	P500
19542	15000	1970	300	M4	FORD	P500
19892	15000	1970	300	M4	FORD	P500
19899	15000	1970	300	M4	FORD	P500
43424	17000	1974	300	M5	FORD	P500
43834	17000	1974	300	M5	FORD	P505
47704	8000	1959	240	M4	FORD	P350
47718	8000	1959	240	M4	FORD	P350
47720	8000	1959	240	M4	FORD	P350
55467	8000	1960		M4	I-H	AM150M

NUMBER OF VEHICLES 15

***** UNITED STATES POSTAL SERVICE *****

OWNER'S ID NUMBER	GROSS WEIGHT	MODEL YEAR	ENGINE DISPLACEMENT	XMISSION CODE	MAKE	MODEL
801349	21200	1976	361	A4	FORD	C600
801425	21200	1976	361	A4	FORD	C600
810080	20200	1976	361	A4	FORD	F700
810131	20200	1976	361	A4	FORD	F700

NUMBER OF VEHICLES 4

***** WESTERN ELECTRIC CO. *****

OWNER'S ID NUMBER	GROSS WEIGHT	MODEL YEAR	ENGINE DISPLACEMENT	XMISSION CODE	MAKE	MODEL
7791	25000	1970	401	M5	GMC	7500

NUMBER OF VEHICLES 1

***** MISCELLANEOUS VEHICLES *****

OWNER'S ID NUMBER	GROSS WEIGHT	MODEL YEAR	ENGINE DISPLACEMENT	XMISSION CODE	MAKE	MODEL
D7C30T	06025	1977	401	A3	JEEP	CHRKEE

NUMBER OF VEHICLES 1

IV. RESULTS

IV.A. Results Of The Inspection/Maintenance Study.

A total of 181 pairs of before-tune-up and after-tune-up tests were performed on HD vehicles. The distributions of the vehicles by fleet, weight and model year are shown in Tables IV-A-1 and IV-A-2.

Ten vehicles were tested and retested after intervals ranging from eighteen to twenty-four months. These vehicles are counted twice in Tables IV-A. After such long in-service intervals between tests it is appropriate to consider the results of the later tests to be independent of the results of the earlier tests. The owners' I.D. numbers of the ten vehicles are 10704, 10715, 11338, 16944, 10856, 19542, 19892, 19899, 47704 and 47718.

Two vehicles were already properly tuned to manufacturer's specifications when received. Since no before-and-after tune up comparisons could be made for these vehicles they are not included in Tables IV-A.

The test results were transcribed onto magnetic tape. This massive collection of data was analyzed using the SPSS package of statistical computer programs.(4)

The results of analyses, summarized in the following Tables, only scratch the surface. Many important questions about the effect of engine parameters on pollutant emissions and fuel economy could be answered by further analysis of the data. It is hoped that people investigating such problems will make use of the test data file on magnetic tape described in Appendix I.

Data from the N.Y. Quick, the C39 and the C39H driving cycles were analyzed. Clayton Keymode results were not analyzed because the variable format in which Keymode data were recorded would have made analysis difficult. Also, Keymode tests were judged to be less applicable to determining pollution effects of on-the-road vehicles than were the driving cycle tests.

Test results for all vehicles are summarized in Table IV-B. All vehicle were given NY Quick cycle tests. Forty-one vehicles were also given C39 tests and eighty-nine were given C39H tests.

TABLE IV-A-1

DISTRIBUTION OF I/M TESTS BY FLEET AND VEHICLE WEIGHT

GVWC (COUNT / ROW PCT / COL PCT / TOT PCT)	FLEET: BROOKLYN UNION G 1	CON. EDI SON 2	NYC-AIR RESOURCE 3	NYC-SANI TATION 4	NYC-WATE R RESOUR 5	NYS-ENVI RONMNTL 6	NEW YORK TELEPHO 7	UNITED P ARCEL 8	WESTERN ELECTRIC 10	ROW TOTAL
1	2	3	2	0	9	1	2	6	0	25
GVW=1-14000 LB.	8.0	12.0	8.0	0.0	36.0	4.0	8.0	24.0	0.0	26.3
	14.3	18.8	100.0	0.0	32.1	50.0	100.0	33.3	0.0	
	2.1	3.2	2.1	0.0	9.5	1.1	2.1	6.3	0.0	
2	11	11	0	0	17	0	0	12	1	52
GVW=14001-26000	21.2	21.2	0.0	0.0	32.7	0.0	0.0	23.1	1.9	54.7
	78.6	68.8	0.0	0.0	60.7	0.0	0.0	66.7	100.0	
	11.6	11.6	0.0	0.0	17.9	0.0	0.0	12.6	1.1	
3	1	2	0	12	2	1	0	0	0	18
GVW ABOVE 26000	5.6	11.1	0.0	66.7	11.1	5.6	0.0	0.0	0.0	18.9
	7.1	12.5	0.0	100.0	7.1	50.0	0.0	0.0	0.0	
	1.1	2.1	0.0	12.6	2.1	1.1	0.0	0.0	0.0	
COLUMN TOTAL	14	16	2	12	28	2	2	18	1	95
	14.7	16.8	2.1	12.6	29.5	2.1	2.1	18.9	1.1	100.0

For model year 1971 and earlier.

Top number in each group is the number of tests, second number is percent of the row total, third number is percent of the column total, last number is the percent of all tests on Table.

TABLE IV-A-2

DISTRIBUTION OF I/M TESTS BY FLEET AND VEHICLE WEIGHT

GVWC	FLEET COUNT ROW PCT COL PCT TOT PCT	BROOKLYN UNION G 1	CON. EDI SON 2	NYC-SANI TATION 4	NYC-WATE R RESOUR 5	UNITED P ARCEL 8	US POSTA L SERVIC 9	MISCELLA NEOUS 98	ROW TOTAL
1 GVW=1-14000 LB.		1 3.8 33.3 1.2	2 7.7 40.0 2.3	0 0.0 0.0 0.0	22 84.6 71.0 25.6	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 3.8 100.0 1.2	26 30.2
2 GVW=14001-26000		2 8.0 66.7 2.3	3 12.0 60.0 3.5	0 0.0 0.0 0.0	9 36.0 29.0 10.5	7 28.0 100.0 8.1	4 16.0 100.0 4.7	0 0.0 0.0 0.0	25 29.1
3 GVW ABOVE 26000		0 0.0 0.0 0.0	0 0.0 0.0 0.0	35 100.0 100.0 40.7	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	35 40.7
COLUMN TOTAL		3 3.5	5 5.8	35 40.7	31 36.0	7 8.1	4 4.7	1 1.2	86 100.0

For model year 1972 and later.

TABLE IV-B

MEANS AND STANDARD DEVIATIONS OF EMISSION AND FUEL ECONOMY MEASUREMENTS FROM NEW YORK QUICK, C39 AND C39H DRIVING CYCLES FOR VEHICLES IN GROUP: ALL TESTS

Gross Vehicle Weight= __ To 14,000 lb.
__ 14,001 to 26,000 lb.
__ Over 26,000 lb.

Model Year= __ Prior to 1972
__ 1972 and later

		NEW YORK QUICK				C39				C39H			
		HC	CO	NOX	MPG	HC	CO	NOX	MPG	HC	CO	NOX	MPG
No. Of Vehicles		181				41				89			
BEFORE TUNE UP	mean	17.97	173.01	15.98	6.59	38.11	369.44	26.56	3.59	36.37	276.21	19.06	4.32
	s.d.	20.07	125.24	11.18	2.64	30.80	231.48	16.14	1.30	33.84	156.93	11.60	1.47
AFTER TUNE UP	mean	11.39	120.63	15.32	6.84	25.95	229.89	24.77	3.83	22.69	185.98	18.31	4.42
	s.d.	9.42	91.93	9.41	2.76	18.68	125.96	12.22	1.25	14.04	105.43	10.13	1.50
% CHANGE	mean	-19.05	-24.32	9.87	4.51	-18.71	-20.93	10.13	8.00	-20.97	-24.44	7.32	4.53
	s.d.	35.02	39.78	57.52	10.66	33.68	53.60	56.80	16.29	31.41	36.55	55.60	11.81

Emissions are in units of gram per mile.

Statistics for all Inspection/Maintenance tests.

The pollutant levels and fuel economy before tune-up are given on the first line. The after-tune-up levels are given on the second line.

The third line gives the average and standard deviations of the percent change in the measured levels for each vehicle as a result of tune up. This is defined as:

$$100 \times \frac{\text{(value after tune up)} - \text{(value before tune up)}}{\text{value before tune up}}$$

Note that the average percent change shown on the third line is not the same as the change in the average levels shown on lines one and two.

The Table shows that, as expected, substantial reductions in HC and CO levels resulted from tuning the engines to manufacturers specifications. Greater percentage reductions were produced for CO than for HC. This probably was a result of favoring CO reduction during tune up (see Section II.A.)

The test results for NOX were surprising. It had been expected that the decreases in HC and CO as a result of tuning would be accompanied by an increase in NOX. However, analysis of the pairs of before-tune-up and after-tune-up measurements showed that any change was not statistically significant at the 95% level. It can be concluded that the effects of tune-up on NOX emissions were negligible.

Results of the fuel economy measurements showed that, as expected, tuning to manufacturer's specifications results in improved fuel economy.

Table IV-C was prepared to summarize the effect of tune up on the vehicles tested when operating under avarage N.Y. City driving conditions. The emissions in Table IV-C are the averages of the NY Quick cycle results and the C39 cycle results from TableIV-B. To prepare Table IV-C no distinction was made between the very similar C39 and C39H cycles. Measerements from the two cycles were lumped together, their averages found and these averages where then averaged with the means of the N.Y. Quick cycle measurements.

TABLE IV-C

AVERAGES OF NEW YORK QUICK AND C39 TESTS FROM TABLE IV-B

	HC	CO	M.P.G.
BEFORE	27.44	239.31	5.33
AFTER	17.55	160.22	5.53

Emissions are in units of gm/mi.

From emissions in Table IV-C we see that when all 181 vehicles drove one mile in their "as received" conditions they emitted 5.0kg of HC and 43.4kg of CO. After tune up their emissions were reduced to 3.2kg of HC and 29.0kg of CO, a net reduction of 1.8kg of HC and 14.4kg of CO.

The data in the last column shown an average fuel economy of 5.33mpg before tune up and an average gain 0.2mpg in fuel economy from tuning. At a fuel cost of $1.30 a gallon a properly tuned vehicle would save, on the average, eight dollars and eighty cents for every thousand miles driven.

Useful statistics are generated by dividing the vehicle tests into weight and model year catagories. This facilitates extrapolating results of the present study to groups of trucks whose distributions of weight and model year differ from the group tested in the study.

Tables IV-D show statistics for vehicles in three gross-vehicles-weight ranges. As expected, fuel economy decreases with increasing weight. The intermediate weight vehicles show higher HC and CO emissions than the lighter vehicles. However, the emissions of these two pollutants were less for the heavy vehicles than for the intermediate weight vehicles. A possible explanation for this unexpected result may arise from the limitations of the dynamometer used in the study which was unable to load the heaviest vehicles to full load. Had the heavy vehicles been fully loaded their emissions would have been higher.

For reference, the results from an earlier study of heavy vehicles conducted by the Southwest Research Institute (5) are shown in Table IV-E. In the S.R.I. study a large group of trucks was driven through a test cycle and their emissions measured. The trucks were tested in "as received" condition,

TABLE IV-D-1

MEANS AND STANDARD DEVIATIONS OF EMISSION AND FUEL ECONOMY MEASUREMENTS FROM NEW YORK QUICK, C39 AND C39H DRIVING CYCLES FOR VEHICLES IN GROUP:

Gross Vehicle Weight= x To 14,000 lb.
__ 14,001 to 26,000 lb.
__ Over 26,000 lb.

Model Year= __ Prior to 1972
__ 1972 and later

		NEW YORK QUICK				C39				C39H			
		HC	CO	NOX	MPG	HC	CO	NOX	MPG	HC	CO	NOX	MPG
No. Of Vehicles		51				7				19			
BEFORE TUNE UP	mean	12.03	109.37	7.87	9.66	43.28	262.90	8.85	5.49	20.85	171.05	12.18	6.27
	s.d.	14.00	60.79	3.96	1.89	28.85	94.24	4.54	1.31	17.04	69.22	8.74	1.41
AFTER TUNE UP	mean	8.25	82.74	7.34	10.15	40.68	245.96	7.21	5.50	12.56	112.50	9.50	6.63
	s.d.	12.40	74.79	3.11	2.10	37.52	76.42	3.56	1.48	5.07	61.03	2.92	1.41
% CHANGE	mean	-18.96	-23.76	2.45	5.15	-9.00	15.46	13.93	0.49	-22.22	-29.97	-4.85	7.09
	s.d.	33.92	45.01	38.67	8.83	44.61	82.16	28.21	12.14	33.93	26.19	38.57	9.36

Emissions are in units of gram per mile.

Statistics for Inspection/Maintenance tests grouped by vehicle weight.

TABLE IV-D-2

MEANS AND STANDARD DEVIATIONS OF EMISSION AND FUEL ECONOMY MEASUREMENTS FROM NEW YORK QUICK, C39 AND C39H DRIVING CYCLES FOR VEHICLES IN GROUP:

Gross Vehicle Weight= __ To 14,000 lb.
X 14,001 to 26,000 lb.
__ Over 26,000 lb.

Model Year= __ Prior to 1972
__ 1972 and later

		NEW YORK QUICK				C39				C39H			
		HC	CO	NOX	MPG	HC	CO	NOX	MPG	HC	CO	NOX	MPG
No. Of Vehicles			77				13				40		
BEFORE TUNE UP	mean	21.06	205.36	12.59	6.26	41.72	415.20	18.42	3.81	43.33	292.38	14.20	4.31
	s.d.	22.59	148.33	5.95	1.77	43.87	313.76	8.49	1.20	35.21	155.30	6.95	0.88
AFTER TUNE UP	mean	13.44	145.99	12.80	6.41	23.08	205.98	20.01	4.16	30.39	216.46	14.34	4.33
	s.d.	9.01	99.23	5.59	1.69	12.35	152.81	7.37	1.02	16.23	112.89	6.06	0.84
% CHANGE	mean	-21.82	-22.88	21.22	3.63	-23.98	-35.99	36.51	12.72	-18.22	-20.47	18.69	1.07
	s.d.	27.62	34.36	77.17	11.96	28.77	37.00	86.83	20.42	24.81	30.67	72.51	9.96

Emissions are in units of gram per mile.

Statistics for Inspection/Maintenance tests grouped be vehicle weight.

TABLE IV-D-3

MEANS AND STANDARD DEVIATIONS OF EMISSION AND FUEL ECONOMY MEASUREMENTS FROM NEW YORK QUICK, C39 AND C39H DRIVING CYCLES FOR VEHICLES IN GROUP:

Gross Vehicle Weight= __ To 14,000 lb.
__ 14,001 to 26,000 lb.
X Over 26,000 lb.

Model Year= __ Prior to 1972
__ 1972 and later

		NEW YORK QUICK				C39				C39H			
		HC	CO	NOX	MPG	HC	CO	NOX	MPG	HC	CO	NOX	MPG
No. Of Vehicles		53				21				30			
BEFORE TUNE UP	mean	19.20	187.24	28.72	4.10	34.16	376.50	37.50	2.83	36.91	321.24	29.89	3.08
	s.d.	20.26	113.37	10.89	0.54	21.43	200.11	13.90	0.32	37.44	172.10	10.52	0.44
AFTER TUNE UP	mean	11.44	120.25	26.66	4.29	22.67	239.81	34.01	3.02	18.88	190.30	28.43	3.24
	s.d.	4.99	84.40	6.99	0.53	8.83	124.04	7.03	0.30	8.37	97.54	8.54	0.31
% CHANGE	mean	-15.11	-26.95	0.53	5.18	-18.69	-23.87	1.42	7.55	-23.80	-26.29	-0.17	7.50
	s.d.	44.76	42.35	31.24	10.37	33.51	47.43	28.97	14.08	37.76	46.92	32.91	14.42

Emissions are in units of gram per mile.

Statistics for Inspection/Maintenance tests grouped by vehicle weight.

no tune ups were performed. The S.R.I. results and the "before tune up" results of the present study are not directly comparable because of differences in driving cycles and other procedures.

Average values of HC and CO emissions found in the S.R.I. study are of the same order as the NY Quick "before tune up" results of the present study within a factor of 1.8. The S.R.I. result that HC emissions are almost the same for all three weight catagories is surprising.

TABLE IV-E

MEANS AND STANDARD DEVIATIONS OF EMISSIONS MEASUREMENTS FROM A STUDY BY THE SOUTHWEST RESEARCH INSTITUTE

G.V.W.	# VEHICLES		HC	CO	NOX
14,000 lbs. or less	38	mean	12.06	159.1	5.90
		s.d.	4.43	42.2	2.34
14,001 to 26,000 lbs.	75	mean	11.81	168.13	7.75
		s.d.	5.69	57.60	3.08
over 26,000 lbs.	20	mean	12.81	190.23	7.15
		s.d.	11.61	73.31	3.31

Units are gram/mile

Tables IV-F show statistics for vehicles grouped in two model year ranges. Model year 1972 was chosen to divide the groups in order to emphasize differences between vehicles built before and after the introduction of emissions controls. The newer vehicles showed lower emissions than the older ones. However, since the regulations governing heavy duty vehicles are less strigent than those for autos how much of this differce was the result of emissions controls on the newer vehicles and how much was just the result of their being newer is hard to determine.

In Table IV-G statistics are given for vehicles grouped be weight and model year. Enough tests were performed to provide good statistics for each group, at least for NY Quick cycle results. No statistics are given when less than five vehicles were tested.

It is commonly assumed that good general maintanance is important in control of emissions from heavy duty vehicles. A preliminary statistical analysis of this aspect of emissions control was made.

From observation of the vehicles received for testing it was found that the United Parcel Service fleet was excellently maintained. In the current atudy 52 vehicles were tested that were in the 14,001 lb. to 26,000 lb. gross-vehicle-weight range and also in the model-year-prior-to-1972 range. Four fleets were represented in this group; 11 from Consolidated Edison, 11 from Brooklyn Union Gas, 17 from New York City and 12 from U.P.S

For each of the four fleets the average of HC and CO emissions during NY Quick tests were calculated and compared with the averages for the rest of the vehicles in the group. Only for U.P.S. vehicles were the HC and CO emissions averages consistantly less than, and the fuel economy average consistantly greater than the rest of the vehicles in the group when judged at the 95% confidence level. While this does not prove that good maintaihance is, of itself, an important emissions control measure it certainly supports the idea.

Statistics on I/M tests for each fleets of trucks that participated in the study are given in Table IV-H. Statistics are not given for cases where there were results from fewer than four tests.

TABLE IV-F-1

MEANS AND STANDARD DEVIATIONS OF EMISSION AND FUEL ECONOMY MEASUREMENTS FROM NEW YORK QUICK, C39 AND C39H DRIVING CYCLES FOR VEHICLES IN GROUP:

Gross Vehicle Weight= __ To 14,000 lb.
__ 14,001 to 26,000 lb.
__ Over 26,000 lb.

Model Year= X Prior to 1972
__ 1972 and later

		NEW YORK QUICK				C39				C39H			
		HC	CO	NOX	MPG	HC	CO	NOX	MPG	HC	CO	NOX	MPG
No. Of Vehicles			95				23				49		
BEFORE TUNE UP	mean	20.89	197.98	12.99	6.79	42.86	424.91	21.75	3.77	40.60	288.67	14.33	4.57
	s.d.	22.18	136.80	8.11	2.56	37.92	255.33	14.61	1.47	35.61	158.01	8.26	1.47
AFTER TUNE UP	mean	13.82	134.12	13.41	7.09	29.13	226.57	23.03	4.11	26.28	193.54	14.20	4.82
	s.d.	11.89	103.01	8.30	2.62	23.29	129.04	13.19	1.35	17.24	114.81	7.38	1.45
% CHANGE	mean	-16.26	-29.10	18.12	5.77	-15.90	-36.22	23.26	12.65	-20.26	-27.28	12.61	6.73
	s.d.	38.69	31.21	70.54	12.14	38.52	34.34	69.54	18.40	30.78	29.59	62.20	11.61

Emissions are in units of gram per mile.

Statistics for Inspection/Maintenance tests grouped by model year.

TABLE IV-F-2

MEANS AND STANDARD DEVIATIONS OF EMISSION AND FUEL ECONOMY MEASUREMENTS FROM NEW YORK QUICK, C39 AND C39H DRIVING CYCLES FOR VEHICLES IN GROUP:

Gross Vehicle Weight= __ To 14,000 lb.
__ 14,001 to 26,000 lb.
__ Over 26,000 lb.

Model Year= __ Prior to 1972
X 1972 and later

		NEW YORK QUICK				C39				C39H			
		HC	CO	NOX	MPG	HC	CO	NOX	MPG	HC	CO	NOX	MPG
No. Of Vehicles		86				18				40			
BEFORE TUNE UP	mean	14.74	145.42	19.29	6.36	32.04	298.57	32.70	3.36	31.18	260.93	24.73	4.00
	s.d.	17.01	105.12	13.06	2.72	17.39	179.53	16.30	1.03	31.18	156.21	12.63	1.42
AFTER TUNE UP	mean	8.71	105.07	17.42	6.57	21.66	234.40	27.13	3.44	18.38	176.90	23.25	3.94
	s.d.	4.20	75.46	10.14	2.91	8.38	125.46	10.71	1.03	6.84	93.57	10.83	1.42
% CHANGE	mean	-22.14	-19.04	0.76	3.12	-22.52	-0.23	-7.62	1.70	-21.85	-20.95	0.80	1.83
	s.d.	30.39	47.12	36.65	8.61	26.40	67.75	25.14	10.39	32.85	43.79	46.18	11.63

Emissions are in units of gram per mile.

Statistics for Inspection/Maintenance tests grouped by model year.

TABLE IV-G-1

MEANS AND STANDARD DEVIATIONS OF EMISSION AND FUEL ECONOMY MEASUREMENTS FROM NEW YORK QUICK, C39 AND C39H DRIVING CYCLES FOR VEHICLES IN GROUP:

Gross Vehicle Weight= X To 14,000 lb.
__ 14,001 to 26,000 lb.
__ Over 26,000 lb.

Model Year= X Prior to 1972
__ 1972 and later

		NEW YORK QUICK				C39				C39H			
		HC	CO	NOX	MPG	HC	CO	NOX	MPG	HC	CO	NOX	MPG
No. Of Vehicles		25				5				12			
BEFORE TUNE UP	mean	15.09	122.66	7.73	9.56	45.98	279.91	7.54	5.74	22.83	165.69	11.00	6.23
	s.d.	15.99	66.68	4.32	2.35	33.20	31.36	4.41	1.39	20.40	70.56	6.95	1.59
AFTER TUNE UP	mean	11.41	102.86	7.40	10.08	48.03	256.73	6.69	5.66	11.93	120.27	9.83	6.61
	s.d.	17.05	95.17	3.97	2.58	43.31	90.67	3.95	1.76	5.53	64.73	3.17	1.40
% CHANGE	mean	-13.41	-20.32	1.87	5.55	-2.34	-9.60	-10.91	-2.11	-25.75	-25.03	4.52	7.60
	s.d.	42.55	30.60	40.07	10.64	47.67	24.17	22.93	11.67	30.16	24.87	40.50	11.03

Emissions are in units of gram per mile.

Statistics for Inspection/Maintenance tests grouped by vehicle weight and model year.

TABLE IV-G-2

MEANS AND STANDARD DEVIATIONS OF EMISSION AND FUEL ECONOMY MEASUREMENTS FROM NEW YORK QUICK, C39 AND C39H DRIVING CYCLES FOR VEHICLES IN GROUP:

Gross Vehicle Weight= X To 14,000 lb.
__ 14,001 to 26,000 lb.
__ Over 26,000 lb.

Model Year= __ Prior to 1972
X 1972 and later

		NEW YORK QUICK				C39				C39H			
		HC	CO	NOX	MPG	HC	CO	NOX	MPG	HC	CO	NOX	MPG
No. Of Vehicles		26				2				7			
BEFORE TUNE UP	mean	9.09	96.58	8.01	9.77					17.46	180.24	14.20	6.34
	s.d.	11.33	52.68	3.67	1.35					9.34	71.36	11.53	1.15
AFTER TUNE UP	mean	5.22	63.39	7.28	10.23					13.81	96.97	8.84	6.68
	s.d.	2.96	41.21	2.05	1.56					4.14	54.88	2.46	1.56
% CHANGE	mean	-24.29	-27.07	3.00	4.76					-11.16	-39.84	-23.58	6.08
	s.d.	22.11	55.94	38.06	6.87					41.14	28.20	28.59	5.32

Emissions are in units of gram per mile.

Statistics for Inspection/Maintenance tests grouped by vehicle weight and model year.

TABLE IV-G-3

MEANS AND STANDARD DEVIATIONS OF EMISSION AND FUEL ECONOMY MEASUREMENTS FROM NEW YORK QUICK, C39 AND C39H DRIVING CYCLES FOR VEHICLES IN GROUP:

Gross Vehicle Weight= __ To 14,000 lb.
X 14,001 to 26,000 lb.
__ Over 26,000 lb.

Model Year= X Prior to 1972
__ 1972 and later

		NEW YORK QUICK				C39				C39H			
		HC	CO	NOX	MPG	HC	CO	NOX	MPG	HC	CO	NOX	MPG
No. Of Vehicles		52				10				29			
BEFORE TUNE UP	mean	24.44	231.50	11.36	6.32	47.38	492.19	17.99	3.59	48.82	318.35	13.51	4.30
	s.d.	26.41	156.73	6.18	1.77	48.70	319.07	9.43	1.13	39.49	153.13	7.18	0.84
AFTER TUNE UP	mean	15.13	160.01	12.40	6.51	25.24	238.65	20.58	4.05	33.28	230.70	13.58	4.43
	s.d.	10.02	106.65	6.01	1.58	13.18	160.59	8.17	0.98	17.45	115.34	6.11	0.86
% CHANGE	mean	-21.51	-26.47	29.32	4.81	-25.20	-38.02	47.80	16.39	-18.40	-22.96	18.72	3.52
	s.d.	27.33	31.24	89.10	13.14	30.53	38.81	95.38	22.02	26.15	30.91	76.04	8.35

Emissions are in units of gram per mile.

Statistics for Inspection/Maintenance tests grouped by vehicle weight and model year.

TABLE IV-G-4

MEANS AND STANDARD DEVIATIONS OF EMISSION AND FUEL ECONOMY MEASUREMENTS FROM NEW YORK QUICK, C39 AND C39H DRIVING CYCLES FOR VEHICLES IN GROUP:

Gross Vehicle Weight= __ To 14,000 lb.
X 14,001 to 26,000 lb.
__ Over 26,000 lb.

Model Year= __ Prior to 1972
X 1972 and later

		NEW YORK QUICK				C39				C39H			
		HC	CO	NOX	MPG	HC	CO	NOX	MPG	HC	CO	NOX	MPG
No. Of Vehicles		25				3				11			
BEFORE TUNE UP	mean	14.03	150.99	14.10	6.13					28.85	223.91	16.03	4.35
	s.d.	7.52	113.66	5.25	1.79					12.22	145.89	6.24	0.98
AFTER TUNE UP	mean	9.93	116.83	13.64	6.20					23.03	180.20	16.26	4.07
	s.d.	4.96	75.48	4.60	1.93					9.78	102.43	5.77	0.77
% CHANGE	mean	-22.48	-15.41	4.37	1.87					-17.75	-14.13	18.62	-5.16
	s.d.	28.76	39.74	39.36	8.75					22.17	34.21	66.09	10.67

Emissions are in units of gram per mile.

Statistics for Inspection/Maintenance tests grouped by vehicle weight and model year.

TABLE IV-G-5

MEANS AND STANDARD DEVIATIONS OF EMISSION AND FUEL ECONOMY MEASUREMENTS FROM NEW YORK QUICK, C39 AND C39H DRIVING CYCLES FOR VEHICLES IN GROUP:

Gross Vehicle Weight= __ To 14,000 lb.
__ 14,001 to 26,000 lb.
X Over 26,000 lb.

Model Year= X Prior to 1972
__ 1972 and later

		NEW YORK QUICK				C39				C39H			
		HC	CO	NOX	MPG	HC	CO	NOX	MPG	HC	CO	NOX	MPG
No. Of Vehicles		18				8				8			
BEFORE TUNE UP	mean	18.69	205.75	23.56	4.28	35.28	431.42	35.33	2.77	37.46	365.57	22.92	2.93
	s.d.	13.12	108.04	7.75	0.63	27.17	227.80	13.04	0.34	31.16	182.37	8.94	0.52
AFTER TUNE UP	mean	13.42	105.89	24.69	4.62	22.17	192.61	36.43	3.22	23.30	173.39	22.92	3.06
	s.d.	7.50	86.20	7.72	0.53	8.81	110.92	6.84	0.28	14.63	124.12	9.20	0.61
% CHANGE	mean	-5.03	-48.88	8.34	8.84	-12.74	-50.62	13.93	17.19	-15.51	-45.79	3.37	16.66
	s.d.	57.00	24.22	23.56	11.11	43.60	26.25	37.52	12.77	45.31	27.29	27.15	16.99

Emissions are in units of gram per mile.

Statistics for Inspection/Maintenance tests grouped by vehicle weight and model year.

TABLE IV-G-6

MEANS AND STANDARD DEVIATIONS OF EMISSION AND FUEL ECONOMY MEASUREMENTS FROM NEW YORK QUICK, C39 AND C39H DRIVING CYCLES FOR VEHICLES IN GROUP:

Gross Vehicle Weight= __ To 14,000 lb.
__ 14,001 to 26,000 lb.
X Over 26,000 lb.

Model Year= __ Prior to 1972
X 1972 and later

		NEW YORK QUICK				C39				C39H			
		HC	CO	NOX	MPG	HC	CO	NOX	MPG	HC	CO	NOX	MPG
No. Of Vehicles			35				13				22		
BEFORE TUNE UP	mean	19.45	177.72	31.38	4.01	33.37	342.92	38.83	2.86	36.71	305.13	32.42	3.09
	s.d.	23.27	116.38	11.39	0.46	18.25	182.31	14.76	0.31	40.15	169.68	10.05	0.37
AFTER TUNE UP	mean	10.42	127.64	27.67	4.12	23.00	271.27	32.40	2.89	17.34	196.18	30.35	3.16
	s.d.	2.62	83.74	6.46	0.45	9.23	126.67	6.96	0.23	4.23	89.06	7.59	0.28
% CHANGE	mean	-20.29	-15.67	-3.49	3.30	-22.66	-6.04	-6.93	1.13	-26.82	-19.20	-1.46	4.17
	s.d.	36.86	45.44	34.15	9.59	26.21	50.79	19.06	11.23	35.34	50.93	35.26	12.14

Emissions are in units of gram per mile.

Statistics for Inspection/Maintenance tests grouped by vehicle weight and model year.

TABLE IV-H-1

MEANS AND STANDARD DEVIATIONS OF EMISSION AND FUEL ECONOMY MEASUREMENTS FROM NEW YORK QUICK, C39 AND C39H DRIVING CYCLES FOR VEHICLES IN GROUP: BROOKLYN UNION GAS

Gross Vehicle Weight= __ To 14,000 lb.
__ 14,001 to 26,000 lb.
__ Over 26,000 lb.

Model Year= __ Prior to 1972
__ 1972 and later

		NEW YORK QUICK				C39				C39H			
		HC	CO	NOX	MPG	HC	CO	NOX	MPG	HC	CO	NOX	MPG
No. Of Vehicles		17				0				17			
BEFORE TUNE UP	mean	31.36	226.08	11.90	5.37					50.46	308.79	14.23	3.95
	s.d.	18.02	109.24	5.39	1.15					27.96	137.01	6.37	0.78
AFTER TUNE UP	mean	24.13	181.21	12.30	5.50					40.47	246.89	14.23	4.09
	s.d.	10.77	89.86	4.80	1.25					18.52	124.55	6.76	0.89
% CHANGE	mean	-16.94	-17.17	18.00	2.53					-12.40	-18.87	5.43	3.62
	s.d.	21.40	28.22	62.42	7.98					23.69	25.37	38.64	10.59

Emissions are in units of gram per mile.

Statistics for Inspection/Maintenance tests grouped by fleet.

TABLE IV-H-2

MEANS AND STANDARD DEVIATIONS OF EMISSION AND FUEL ECONOMY MEASUREMENTS FROM NEW YORK QUICK, C39 AND C39H DRIVING CYCLES FOR VEHICLES IN GROUP: CONSOLIDATED EDISON

Gross Vehicle Weight= __ To 14,000 lb.
__ 14,001 to 26,000 lb.
__ Over 26,000 lb.

Model Year= __ Prior to 1972
__ 1972 and later

		NEW YORK QUICK				C39				C39H			
		HC	CO	NOX	MPG	HC	CO	NOX	MPG	HC	CO	NOX	MPG
No. Of Vehicles		21				14				7			
BEFORE TUNE UP	mean	30.48	321.59	13.90	5.17	56.96	491.35	19.89	3.46	53.05	421.91	13.19	3.81
	s.d.	34.43	176.77	7.76	1.56	43.36	298.62	10.73	1.07	56.36	168.98	10.74	0.71
AFTER TUNE UP	mean	17.29	233.74	14.62	5.30	36.50	279.52	20.58	3.75	21.72	308.54	11.74	3.90
	s.d.	17.95	128.48	10.00	1.32	27.54	130.17	12.22	0.81	9.03	55.92	5.47	0.89
% CHANGE	mean	-24.73	-5.62	20.42	5.24	-21.02	-13.73	14.52	12.15	-43.65	-12.47	10.41	5.95
	s.d.	44.79	63.19	103.48	18.14	41.67	70.05	72.78	20.46	27.45	32.33	84.66	18.74

Emissions are in units of gram per mile.

Statistics for Inspection/Maintenance tests grouped by fleet.

TABLE IV-H-3

MEANS AND STANDARD DEVIATIONS OF EMISSION AND FUEL ECONOMY MEASUREMENTS FROM NEW YORK QUICK, C39 AND C39H DRIVING CYCLES FOR VEHICLES IN GROUP: N.Y. CITY DEPT. OF SANITATION

Gross Vehicle Weight= __ To 14,000 lb.
__ 14,001 to 26,000 lb.
__ Over 26,000 lb.

Model Year= __ Prior to 1972
__ 1972 and later

		NEW YORK QUICK				C39				C39H			
		HC	CO	NOX	MPG	HC	CO	NOX	MPG	HC	CO	NOX	MPG
No. Of Vehicles			47				19				28		
BEFORE TUNE UP	mean	17.71	178.36	30.23	4.02	29.94	341.29	38.28	2.85	35.30	322.70	31.23	3.05
	s.d.	20.79	111.12	10.40	0.49	16.82	171.79	13.50	0.32	37.96	173.89	9.54	0.42
AFTER TUNE UP	mean	10.32	114.96	27.62	4.19	21.70	231.40	33.54	3.02	17.10	189.65	29.45	3.20
	s.d.	12.68	81.68	6.15	0.43	8.22	125.29	6.45	0.29	4.70	99.20	7.85	0.28
% CHANGE	mean	-12.70	-25.76	-1.21	5.04	-14.91	-20.26	-3.87	6.51	-24.04	-26.16	-1.93	7.46
	s.d.	46.49	44.30	31.92	10.82	32.29	48.71	20.67	14.41	38.92	48.52	33.20	14.79

Emissions are in units of gram per mile.

Statistics for Inspection/Maintenance tests grouped by fleet.

TABLE IV-H-4

MEANS AND STANDARD DEVIATIONS OF EMISSION AND FUEL ECONOMY MEASUREMENTS FROM NEW YORK QUICK, C39 AND C39H DRIVING CYCLES FOR VEHICLES IN GROUP: N.Y. CITY DEPT. OF WATER RESOURCES

Gross Vehicle Weight= __ To 14,000 lb.
__ 14,001 to 26,000 lb.
__ Over 26,000 lb.

Model Year= __ Prior to 1972
__ 1972 and later

		NEW YORK QUICK				C39				C39H			
		HC	CO	NOX	MPG	HC	CO	NOX	MPG	HC	CO	NOX	MPG
No. Of Vehicles			59				0				24		
BEFORE TUNE UP	mean	13.88	133.97	9.46	8.32					30.45	210.75	12.44	5.61
	s.d.	15.18	84.07	5.06	2.26					29.63	126.52	7.91	1.48
AFTER TUNE UP	mean	8.60	95.61	9.13	8.82					19.32	145.16	11.39	5.79
	s.d.	6.37	62.56	3.97	2.45					11.55	75.80	5.27	1.67
% CHANGE	mean	-19.98	-27.25	11.49	6.21					-20.51	-23.34	17.01	3.89
	s.d.	28.16	30.10	51.00	8.31					33.21	36.21	81.34	7.94

Emissions are in units of gram per mile.

Statistics for Inspection/Maintenance tests grouped by fleet.

TABLE IV-H-5

MEANS AND STANDARD DEVIATIONS OF EMISSION AND FUEL ECONOMY MEASUREMENTS FROM NEW YORK QUICK, C39 AND C39H DRIVING CYCLES FOR VEHICLES IN GROUP: UNITED PARCEL SERVICE

Gross Vehicle Weight= __ To 14,000 lb.
__ 14,001 to 26,000 lb.
__ Over 26,000 lb.

Model Year= __ Prior to 1972
__ 1972 and later

		NEW YORK QUICK				C39				C39H			
		HC	CO	NOX	MPG	HC	CO	NOX	MPG	HC	CO	NOX	MPG
No. Of Vehicles			25				7				8		
BEFORE TUNE UP	mean	10.85	101.72	11.05	9.30	26.19	218.11	10.22	5.69	22.48	163.69	16.69	5.71
	s.d.	4.84	61.63	5.29	1.91	9.70	97.24	7.25	1.13	7.96	45.52	5.81	1.17
AFTER TUNE UP	mean	7.47	63.08	10.77	9.41	17.79	127.19	12.47	5.90	17.26	89.92	15.11	5.64
	s.d.	3.03	44.96	4.71	2.06	2.82	61.69	7.29	1.17	4.48	30.29	4.79	1.06
% CHANGE	mean	-25.02	-37.78	9.39	1.50	-25.31	-38.12	38.46	4.65	-19.87	-44.89	0.21	-0.59
	s.d.	26.00	27.90	63.80	9.35	23.06	29.11	81.88	12.55	15.22	11.06	50.82	8.94

Emissions are in units of gram per mile.

Statistics for Inspection/Maintenance tests grouped by fleet.

TABLE IV-H-6

MEANS AND STANDARD DEVIATIONS OF EMISSION AND FUEL ECONOMY MEASUREMENTS FROM NEW YORK QUICK, C39 AND C39H DRIVING CYCLES FOR VEHICLES IN GROUP: UNITED STATES POSTAL SERVICE

Gross Vehicle Weight= __ To 14,000 lb.
__ 14,001 to 26,000 lb.
__ Over 26,000 lb.

Model Year= __ Prior to 1972
__ 1972 and later

		NEW YORK QUICK				C39				C39H			
		HC	CO	NOX	MPG	HC	CO	NOX	MPG	HC	CO	NOX	MPG
No. Of Vehicles			4				0				0		
BEFORE TUNE UP	mean	17.88	265.44	17.04	4.72								
	s.d.	11.70	200.25	5.39	0.60								
AFTER TUNE UP	mean	7.54	141.40	16.36	4.90								
	s.d.	3.03	37.78	1.75	0.22								
% CHANGE	mean	-52.08	-20.87	6.37	4.94								
	s.d.	15.51	65.53	46.65	13.90								

Emissions are in units of gram per mile.

Statistics for Inspection/Maintenance tests grouped by fleet.

IV.B. Result Of The Retrofit Study.
IV.B.1 Screening

A goal of the study was to identify the best non-catalytic emissions controls by screening and testing commerically available device.

Extensive screening and preliminary testing had already been accomplished in an earlier study of both catalytic and non-catalytic device (2). The present study incorporates the results of the previous study wherever possible.

A list of non-catalytic devices that were screened is given in Table IV-I Factors that were considered include emissions reductions, effects on safety, driveability and fuel economy, ease of installation and maintainance and cost, including installation and maintance costs.

Some devices were identified by screening as unsuitable. Preliminary test showed others to be unacceptable. Summary descriptions of these units are given at the end of this section. The preliminary test results, if any, can be found in Appendix III.

Screening and initial testing produced three candidates for further investigation in this study: exhaust gas recirculation devices, air bleeds and lean mixture carburetors.

Exhaust gas recirculation devices:

Exhaust gas recirculation is a well-known control technique for oxides of nitrogen. NOX is formed by high temperature oxidation of nitrogen during combustion. EGR reduces peak combustion temperature by introducing a quantity of basically non-reactive gas (exhaust) into the combustion chamber. There are undesirable thermodynamic consequences of EGR, such as lowering peak cycle temperature, which reduces engine efficiency and thus fuel economy.

Two EGR systems tested in this program are the DANA "Retronox" and the STP systems. The two systems have much in common. Both use an externally mounted aluminum body valve to control EGR both route the exhaust into the manifold via the PCV line, and both make use of two additional control approaches, air bleed and vacuum spark advance modification.

TABLE IV-I

NON-CATALYTIC DEVICES SCREENED

Device Name	Description
Adaks Vacuum Breaker	Air bleed with carburetor spacer plate
Air Jet/Ball-Matic	Air bleed to PCV line
A.Q.P. Pure Power	Spark advance, capacitor discharge ignition system
Clear Air International	Air bleed to PCV line
Care System	Modified PCV system with air bleed
Echlin	Spark advance plus air bleed
Gas Atomizer/Econoneedle	Air bleed mixture screw
G-R Valve	Air bleed to PCV line
Hydrocatalyst	Screen under carburetor
M.S.D.	Electronic ignition system
Patco	Chemical injection
Paton	Heated air bleed to intake manifold
Pollution Master	Air bleed to intake & exhaust manifolds
Retronox	EGR plus air bleed, timing mod.
Rochester, Motorcraft and Holly carburetors	Lean mixture carburetors
Smogmaster	Air bleed to PCV line
STP-EGR	EGR plus air bleed, timing mod.
STP-Air Computer	Air bleed to PCV line

In both systems, manifold vacuum is the signal which controls EGR valve operation. In the DANA system, ported manifold vacuum above a certain point (about 3- inches Hg) opens the valve and allow exhaust gas to flow. Thus EGR is blocked out during low vacuum (acceleration) modes, and since ported vacuum is used, there is no EGR during idle. The STP valve, in addition to controlling EGR, also controls filtered bleed air from the air cleaner. During idle and low cruise modes, both exhaust gas and air flow into the intake manifold. Low vacuum modes, such as acceleration and high speed cruising, close the air bleed and allow full EGR flow. Upon decelerating, the EGR is closed and bleed air alone flows through the valve.

In the DANA system, the air bleed function is accomplished through the use of an increased-flow PCV valve replacement. Both systems use vacuum delay valves (VDV's) to delay the onset of distributor vacuum advance as an HC control measure. On the DANA system, the VDV also delays EGR valve opening on sudden changes in vacuum.

Air bleeds:

The air bleed-type device operates by admitting extra air to lean out the air/fuel mixture during certain modes of operation, thus reducing CO concentrations. Of the many air bleeds screened, those which gave the best result were vacuum operated; the amount of air bled to the intake manifold is directly related to manifold vacuum. This means that the lean-out occurs during the characteristically high vacuum modes of idle and deceleration. During low vacuum modes, such as high speed cruising and acceleration, the valve is closed.

The bleed air can be brought into the intake manifold in one of two ways. The way common to most of the devices was by tapping into the rubber PCV hose near where crankcase vapors enter the intake manifold. This method is undesirable for two reasons; 1) it can lead to malfunctioning of the PCV valve or allow emission of crankcase vapors, and 2) it may lead (on some engine models) to an uneven air/fuel mixture distribution to the cylinders.

The second method is to use the carburetor spacer plate. This plate, usually of one-half inch aluminim, is installed between the carburetor and the intake manifold. This arrangement assures adequate mixing of the bleed air, but entails a more involved installation procedure. Longer carburetor mounting studs may be required, and choke and throttle linkages adjusted for the raised, carburetor. Nevertheless, the spacer plate must be considered the preferred method of air bleed installation on the basis of observed emission reductions.

One device which emerged early in the program and was the only air bleed-type device to receive full test treatment, was the ADAKS Vacuum Breaker. This device features a piston-in-oil damped bleed valve, a replaceable foam-type air filter, and an aluminum spacer plate.

Five pre-adjusted ADAKS devices were supplied by the manufacturer. Emissions data indicated that these pre-set versions are not as effective as device properly adjusted using an exhaust gas analyzer. Actual physical deterioration of the ADAKS device is expected to be negligible. The manufacturer recommends periodic replacement of the air filter; they never needed replacement in our study. Other maintenance should include checking the hose for leaks, checking the oil level in the valve and having the bleed setting checked by a mechanic skilled in the use of the CO/HC analyzer. A one-year maintenance interval is reasonable. The manufacturer estimated the cost of the device, including installation, to be under $100. Cost will vary somewhat due to the different adaptor plates required on various engine.

Lean mixture carburetors:

The 1973 California HD Vehicle Emission Standards called for emission reductions estimated at 67% for CO and 47% for HC and NOX compared to uncontrolled vehicles. These standards became national in 1974. Despite the large percentage reduction indicated, heavy-duty engine manufacturers were able to attain the new CO standard almost entirely through carburetor modifications.

The newer carburetors, hereafter referred to as lean carburetors, are not very different in outward appearance from the devices they replace. The fact that they can be easily installed by a mechanic of average skill level makes it a prime candidate as a retrofit device.

The main difference in a lean carburetor is the quality control level in recent carburetor production. (7) Whereas the air/fuel ratio tolerance used to be in the neighborhood of 10%, engine manufacturers, under pressure to meet emission standards, are now asking for 3% tolerances. Most carburetors manufactered today are individually flow tested. With greater confidence in air/fuel ratios, carburetors can be designed much leaner without fear of straving the engine.

Lean carburetors, depending on the specific model, may differ in other ways. Idle mixture limiter caps, pre-set at the factory to optimum air/fuel ratio or permitting a small range of adjustment, prevent, to some degree, excessive enrichment at idle. Power enrichment and accelerator pump circuits may be modified. Idle stop solenoids prevent dieseling on engine shut-off. Automatic chokes are designed to open sooner.

Three manufacturer's examples of lean carburetors were tested in this program. They are the Rochester Carburetors for General Motors trucks, the Motorcraft for Ford trucks, and the Holley for International trucks.

Deterioration of lean carburetors is nor expected to be an important consideration, except as a result of improper maintenance, especially the removal of idle limiter caps. Enriching the idle mixture is the mechanic's traditional cure-all for a poorly running engine.

Some deterioration in vehicle driveability, notably acceleration and cold-start performance, may occur with lean carburetors. This effect was not of such a degree as to cause any adverse driver comments during this program.

Availability of devices is limited to those engine families for which a carburetor redesign took place. Many engines, of course, have been dropped from production. The most popular HD engines, however, are still being produced and are therefore candidates for lean carburetor retrofit.

Prices of the carburetors vary from about $50.00 to above $125.00

IV.B.2 Results - Exhaust Gas Recirculation Devices.

Exhuast Gas Recirculation devices were promising candidates for a retrofit program and were specified as one of the controls to be tested in the study.

Preliminary testing was done on the DANA Retronox and the STP EGR devices. These devices were manufactured in response to an anticipated requirement for retrofit of older autos with NOX controls that was expected to be enforced in California(8). However, the requirement was never put into effect, possibly because too low a price limit, $35 installed, had been set for the devices. By the time the study was ready to start serious testing of EGR devices they were no longer being manufactured for retrofit and were unavailable.

Results from preliminary test of the DANA device will be discussed. These were installed on three trucks. Emissions and fuel economy in tuned up conditions were measured immediately before and after installation. The vehicles were then returned to service. They were occasionally recalled and retested for a period up to a year and a half.

Graphs of the measured levels of HC, CO, NOX and fuel economy are given in Appendix II. The graphs show the level with the device installed. For comparison, the level immediately prior to installation is shown by a dashed line.

Caution must be used in interpreting the dashed line as a constant level against which later measurements can be compared. It has been found that emission levels from vehicles can vary substantially with time depending on the general condition of the vehicle. Therefore variations of emission levels probable have more to do with the service and maintainance histories of the vehicles than with the durability of the control device.

DANA claimed, on the basis of tests on a single auto, that reductions of 19% in HC, 47% in CO and 65% in NOX could be achieved. The preliminary test results for heavy duty vehicles indicate that CO levels were reduced up to 50% and NOX up to 40%. Changes in HC levels were minor and there was a small improvement in fuel economy.

Unlike RETROFIT tests on other devices all the DANA tests were run using the 72H driving cycle. (9)Had testing been continued the New York Quick and the C39 would have been used.

Both the STP and the DANA systems, which were approved for sale in California's light-duty vehicle retrofit program, showed vulnerable points in HD vehicle application. The VDV's in both systems had a tendency to become clogged with dirt, thus cutting off all vacuum advance and, in the case of the Retronox, stopping EGR function as well. The corrugated metal hose supplied with the DANA kit, good in its tendency to keep the EGR valve cool by dissipating heat, can crack if bent too often in installation.

The hose supplied with the STP kit was clearly inadequate for EGR work. Several of these had to be replaced. Installing EGR systems was complex and time consuming. STP claimed installation of their device in autos took about fifteen minutes. However, each model of heavy duty vehicles required a unique installation procedure and took much longer.

No adverse driveability effects were found as long as the devices were operating properly. Out-of-adjustment devices did produce drivability problems. This indicates that adequate maintanance of EGR devices in heavy duty vehicles is important and that maintanance costs may be increased.

IV.B.3 Results - Air Bleeds.

Results of HC, CO NOX and fuel economy measurements for eleven vehicles with the ADAKS device are given in Appendix II. Levels with and without the device are shown. The "without" values were measured with the air inlet to the device plugged, making it inoperative.

Experience with HD vehicle emissions suggests they are strong dependent on the general condition of the vehicle and its engine, As a result it should be expected that periodic testing of in-service vehicles would show considerable variation in emission levels from test to test. This assumption is supported by the results in Appendix III which show large variations in levels both with and without the device.

Figures 4-A through 4-J show plots of the percent change in emissions and fuel economy achieved by ADAKS in ten vehicles. Reductions in HC and CO varied widely from test to test. Also shown in the figures are the means and standard deviations of the percent changes.

The following Table summerizes the data for ten vehicles tested with ADAKS:

TABLE IV-J

PERCENT CHENGE IN POLLUTANT LEVEL AND FUEL ECONOMY PRODUCED BY ADAKS

POLLUTANT	HC (GRAMS PER MILE)	CO (GRAMS PER MILE)	NOX (GRAMS PER MILE)	FUEL ECONOMY M.P.G.
Mean % change	-2.40	-44.74	8.74	2.34
Standard error of the mean	8.04	6.62	3.80	1.82

The results in Table can be compared with results of tests performed on a different group of vehicles in the Grant study. In that study their Table 9 reporting tests on 7 vehicles shows roughly the same changes in CO and fuel economy. They reported substantially larger reductions in HC and NOX possibly due to the large scatter in their results and also in the present results for these two pollutants.

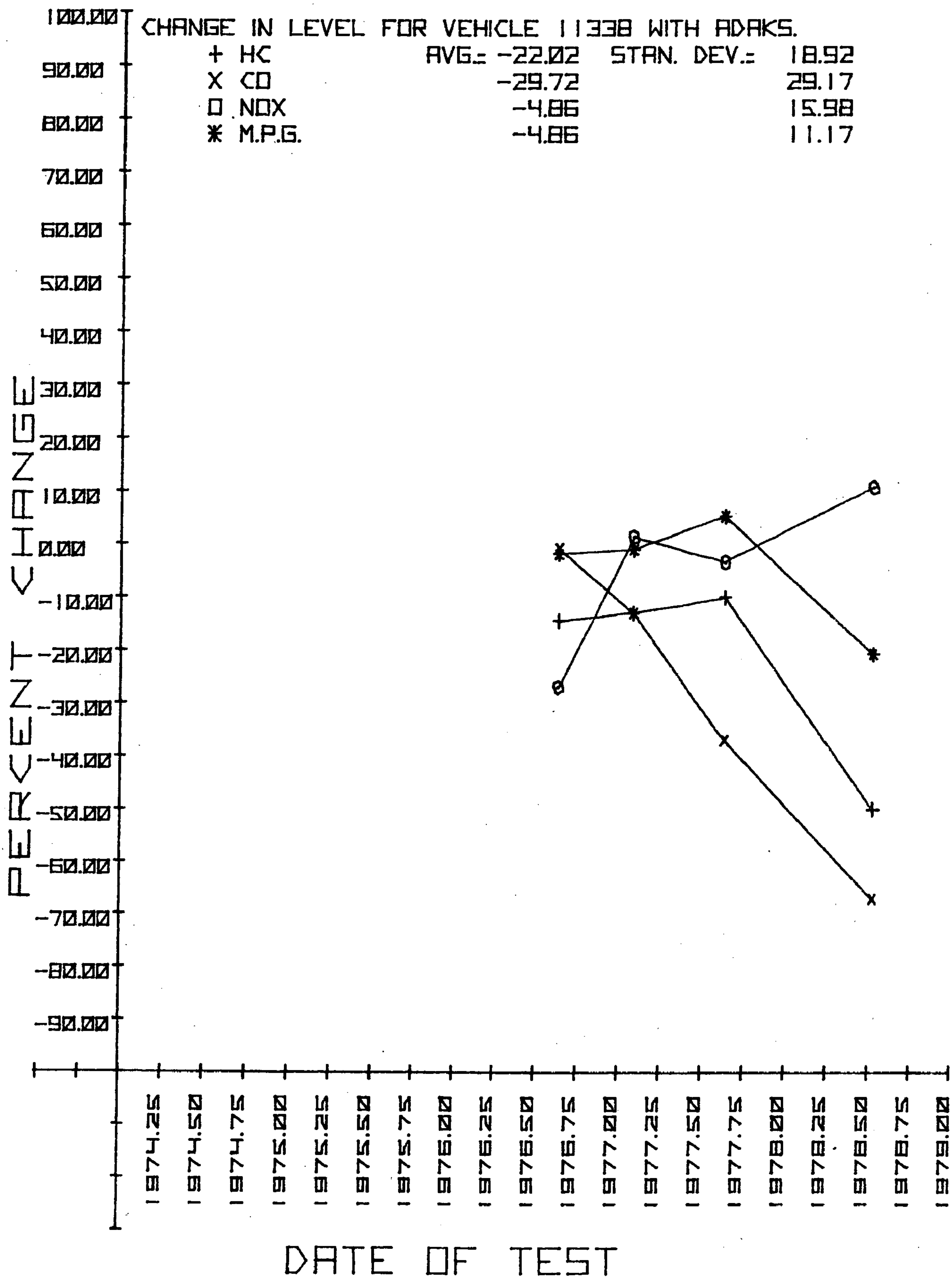

Fig. 4-A Percent change in emissions and fuel economy produced by ADAKS (compared with level measured with device disconnected).

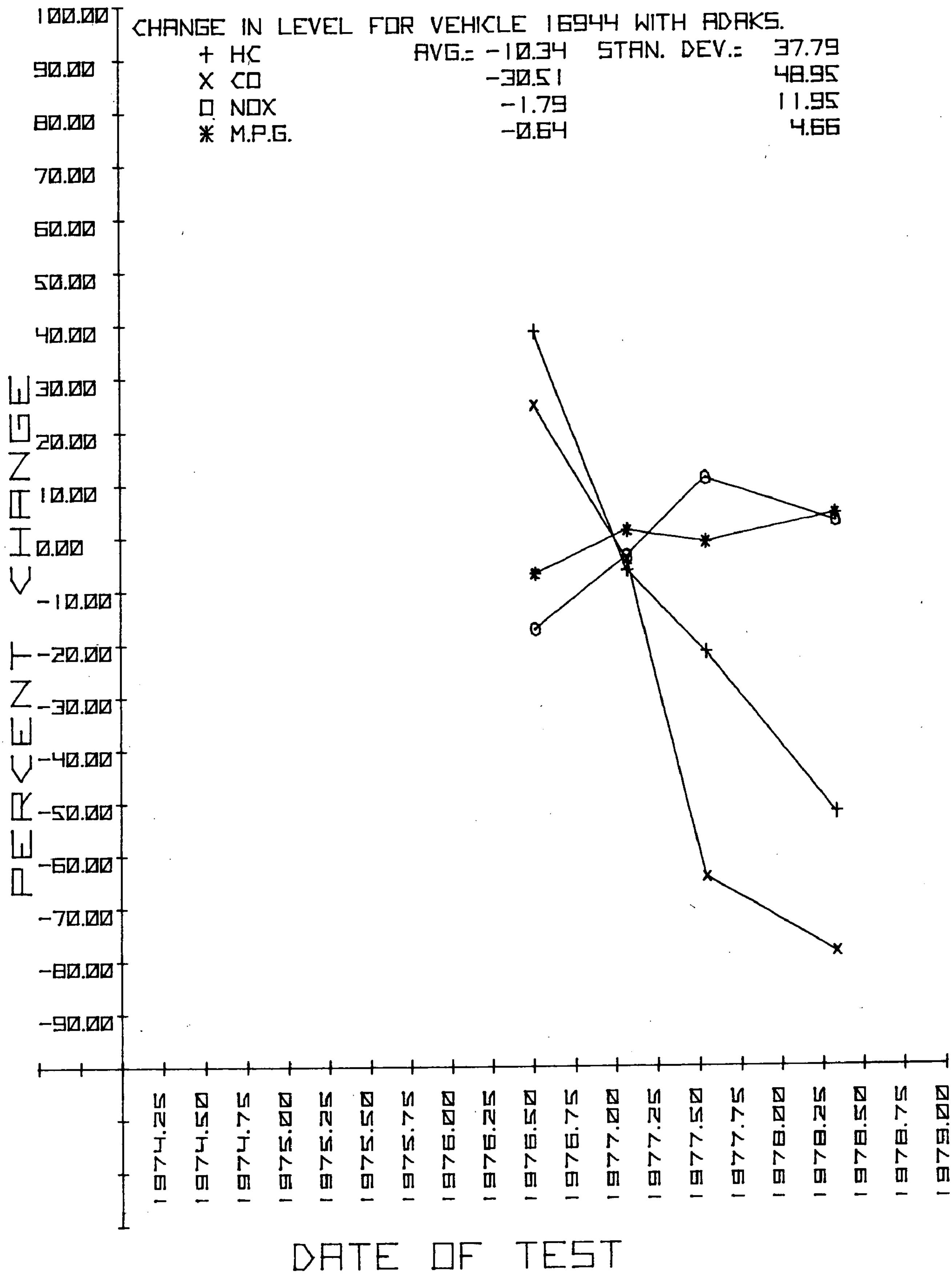

Fig. 4-B Percent change in emissions and fuel economy produced by ADAKS (compared with level measured with device disconnected).

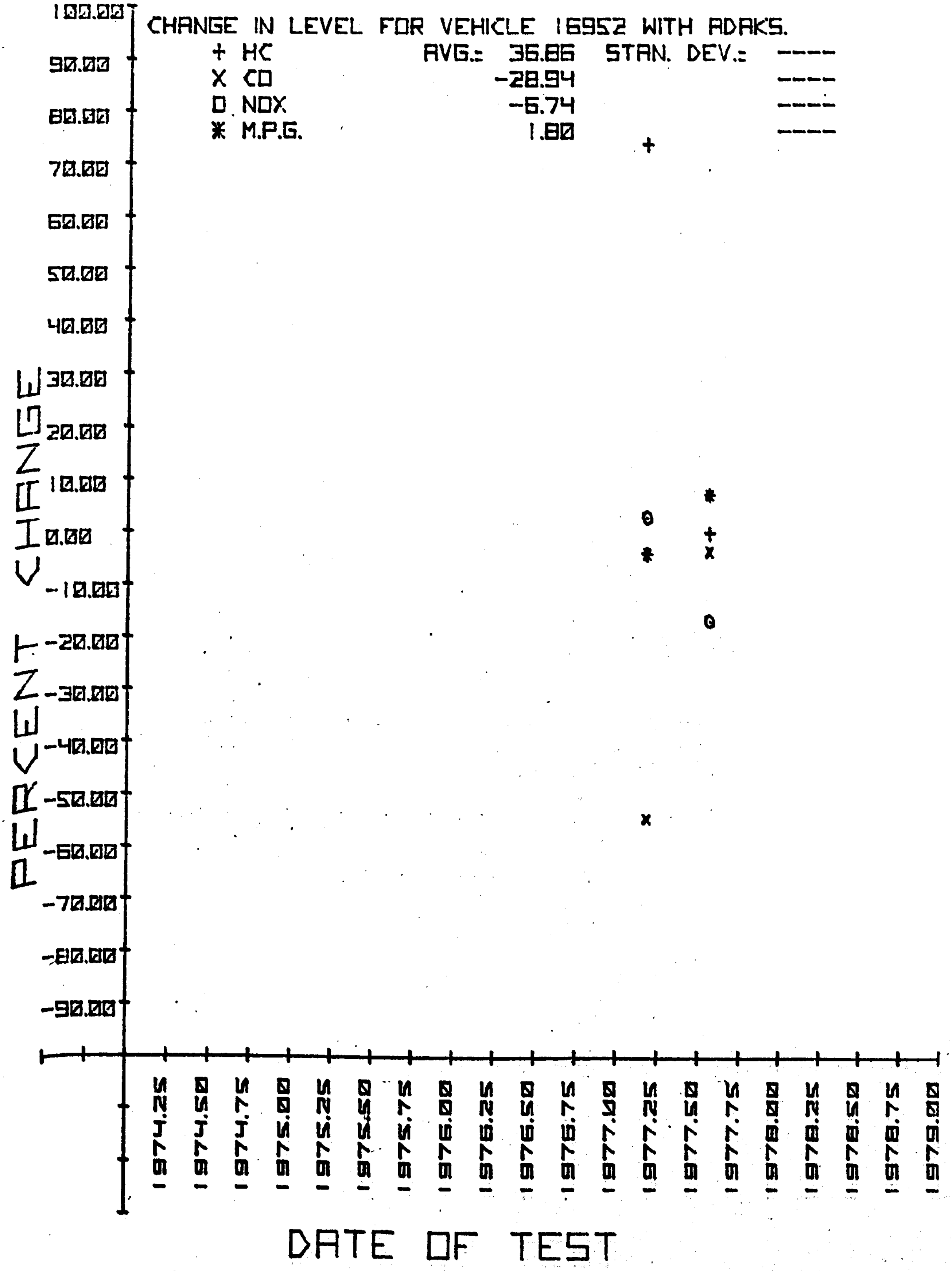

Fig. 4-C Percent change in emissions and fuel economy produced by ADAKS (compared with level measured with device disconnected).

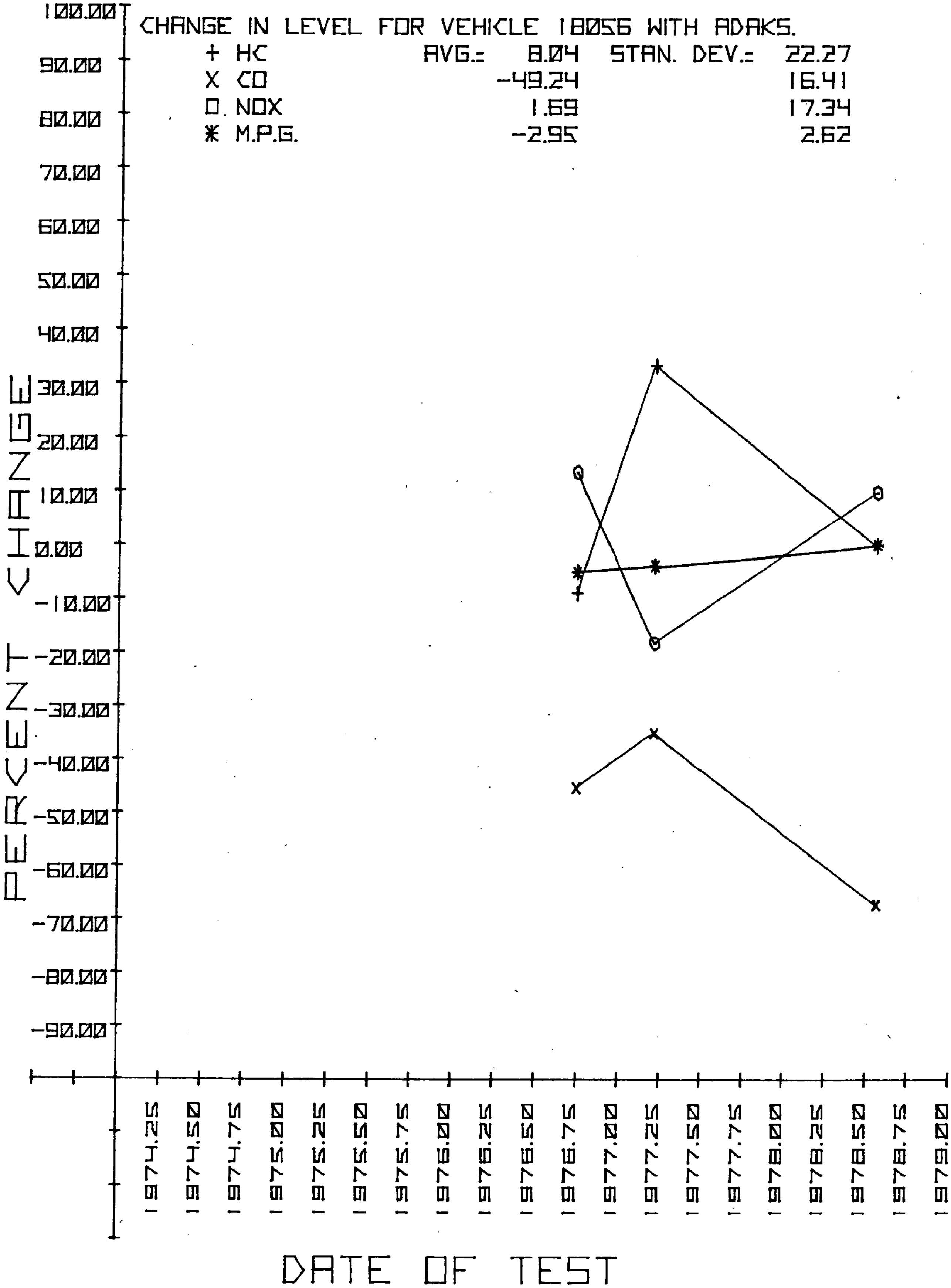

Fig. 4-D Percent change in emissions and fuel economy produced by ADAKS (compared with level measured with device disconnected).

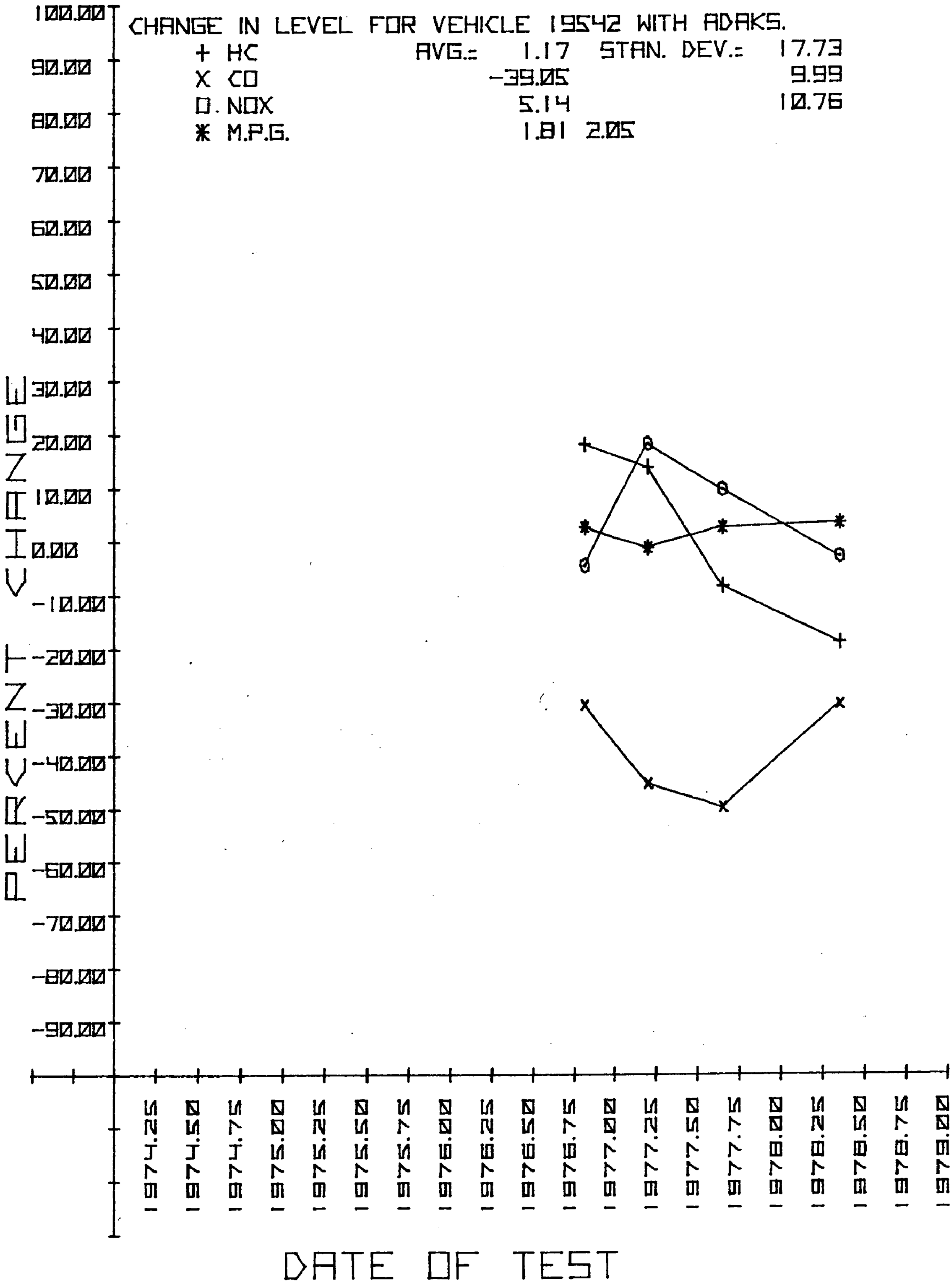

Fig. 4-E Percent in emissions and fuel economy produced by ADAKS (compared with level measured with device disconnected).

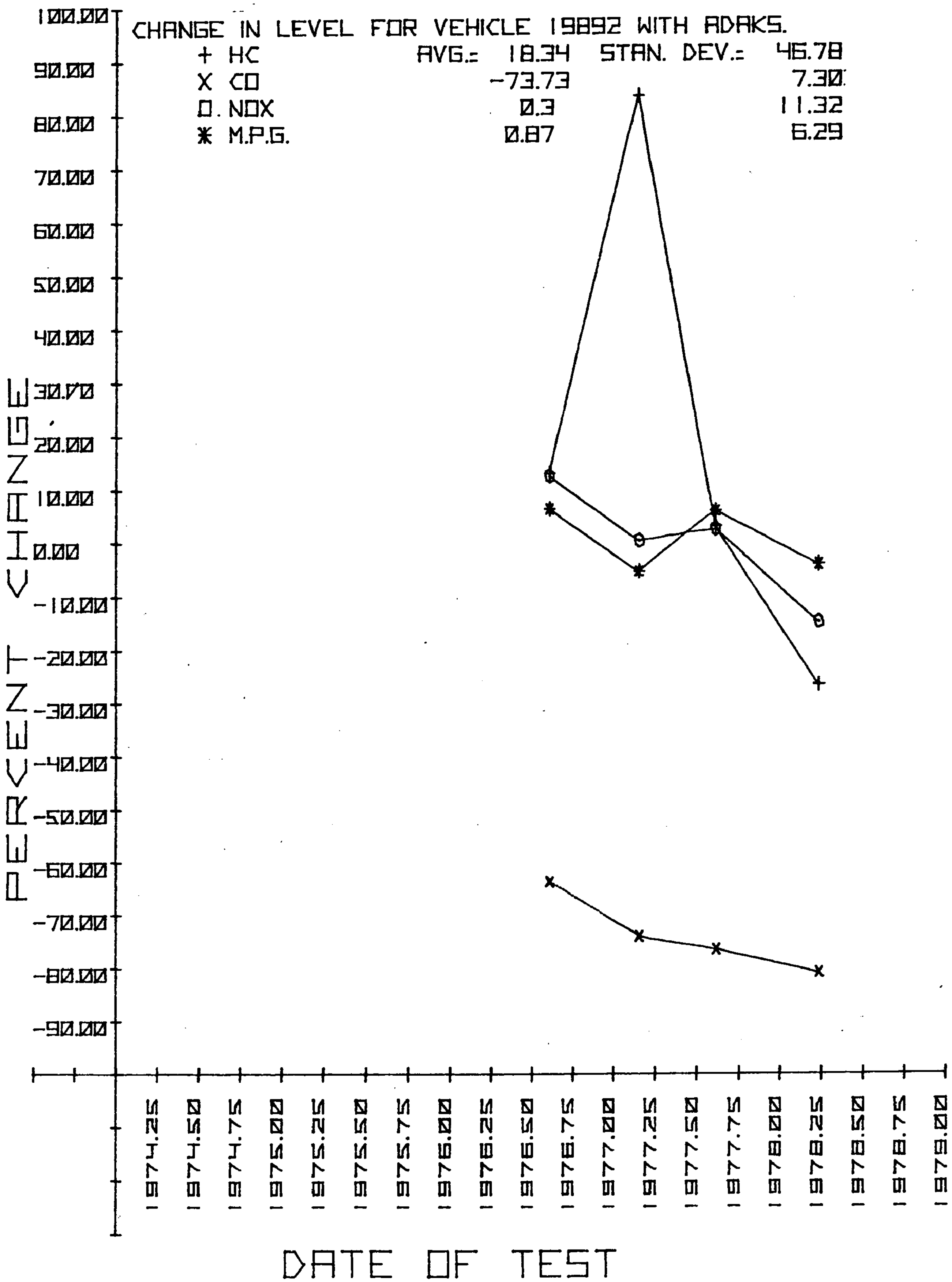

Fig. 4-F Percent change in emissions and fuel economy produced by ADAKS (compared with level measured with device disconnected).

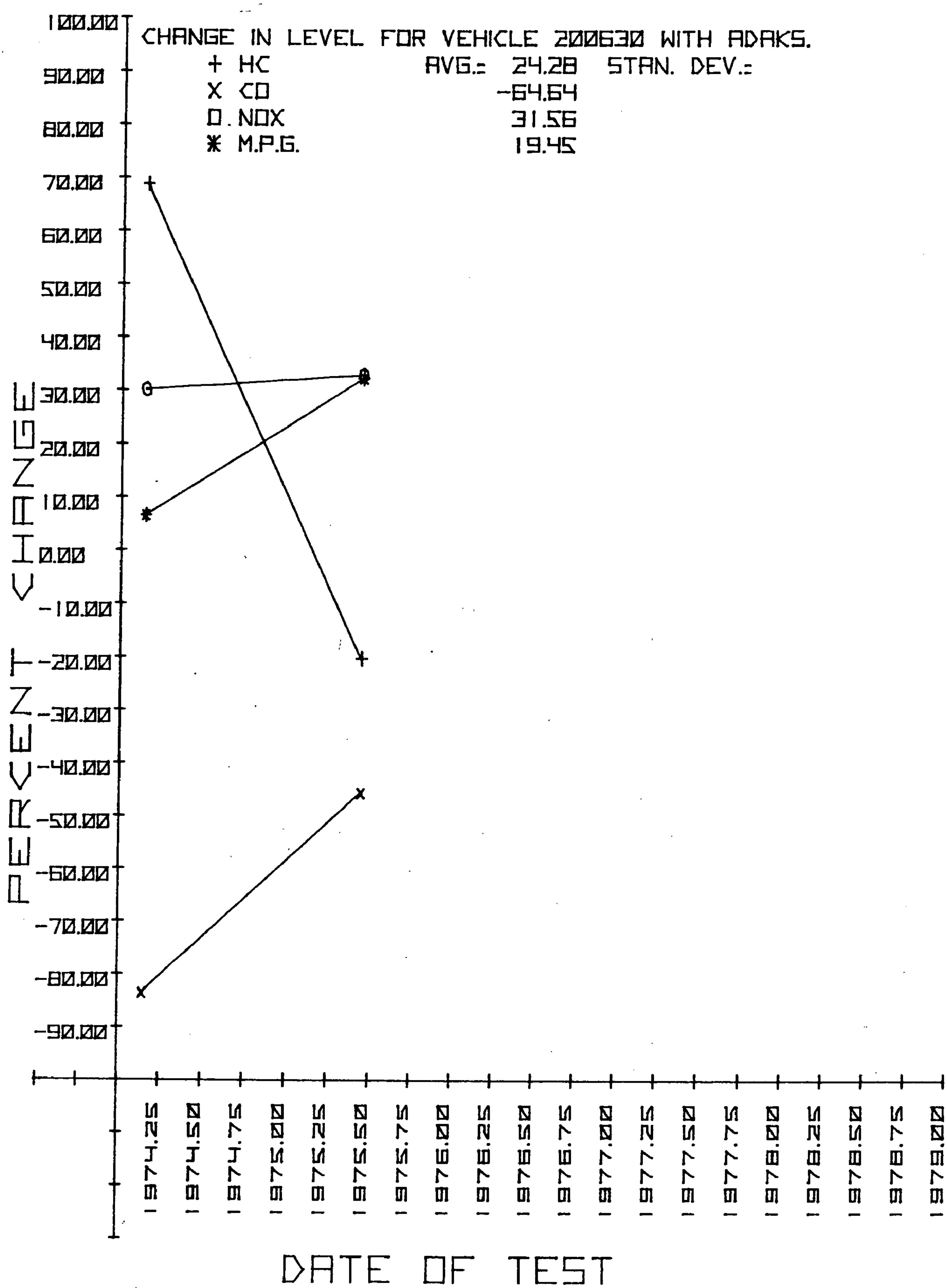

Fig. 4-G Percent change in emissions and fuel economy produced by ADAKS (compared with level measured with device disconnected).

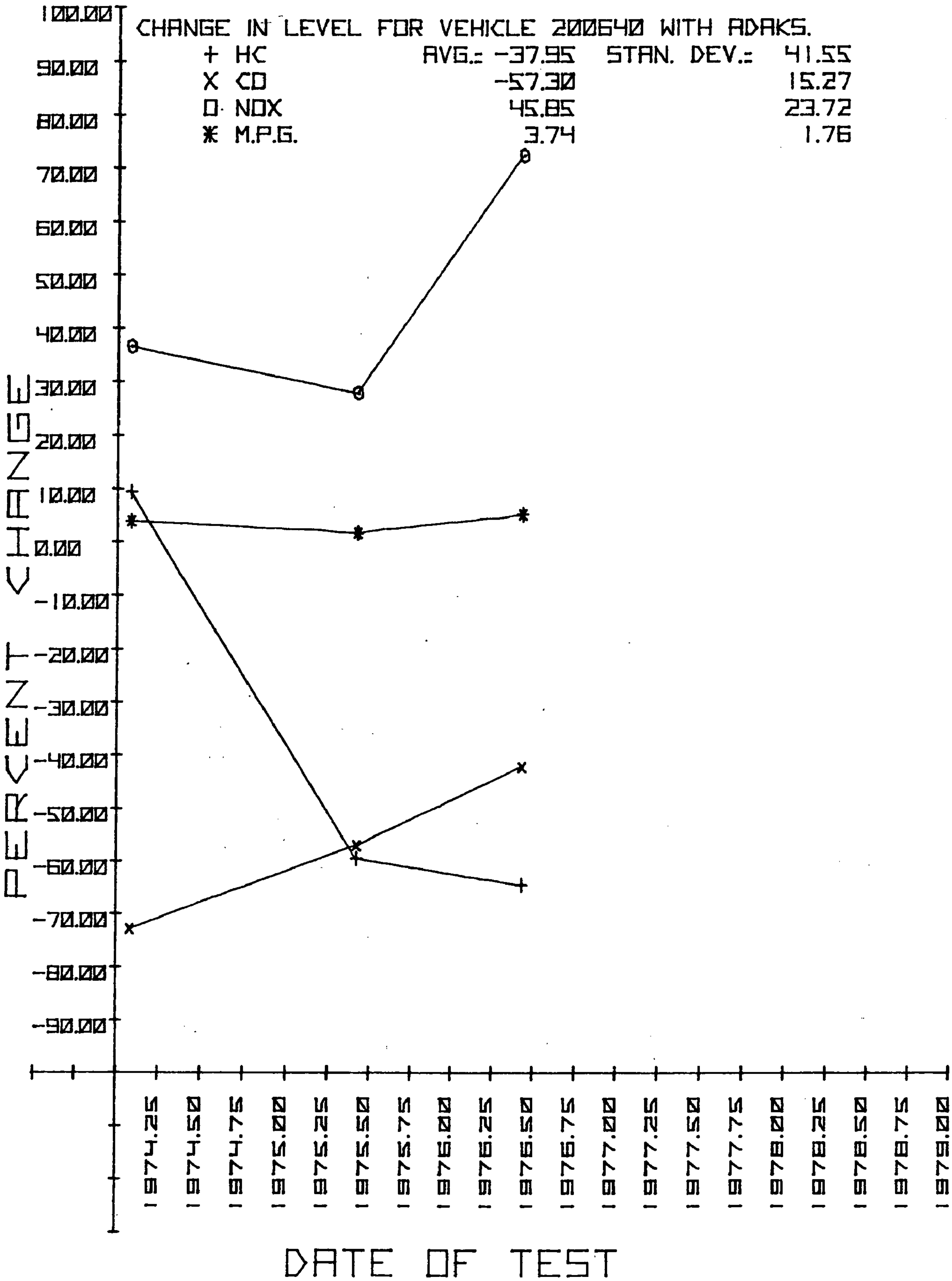

Fig. 4-H Percent change in emissions and fuel economy produced by ADAKS (compared with level measured with device disconnected).

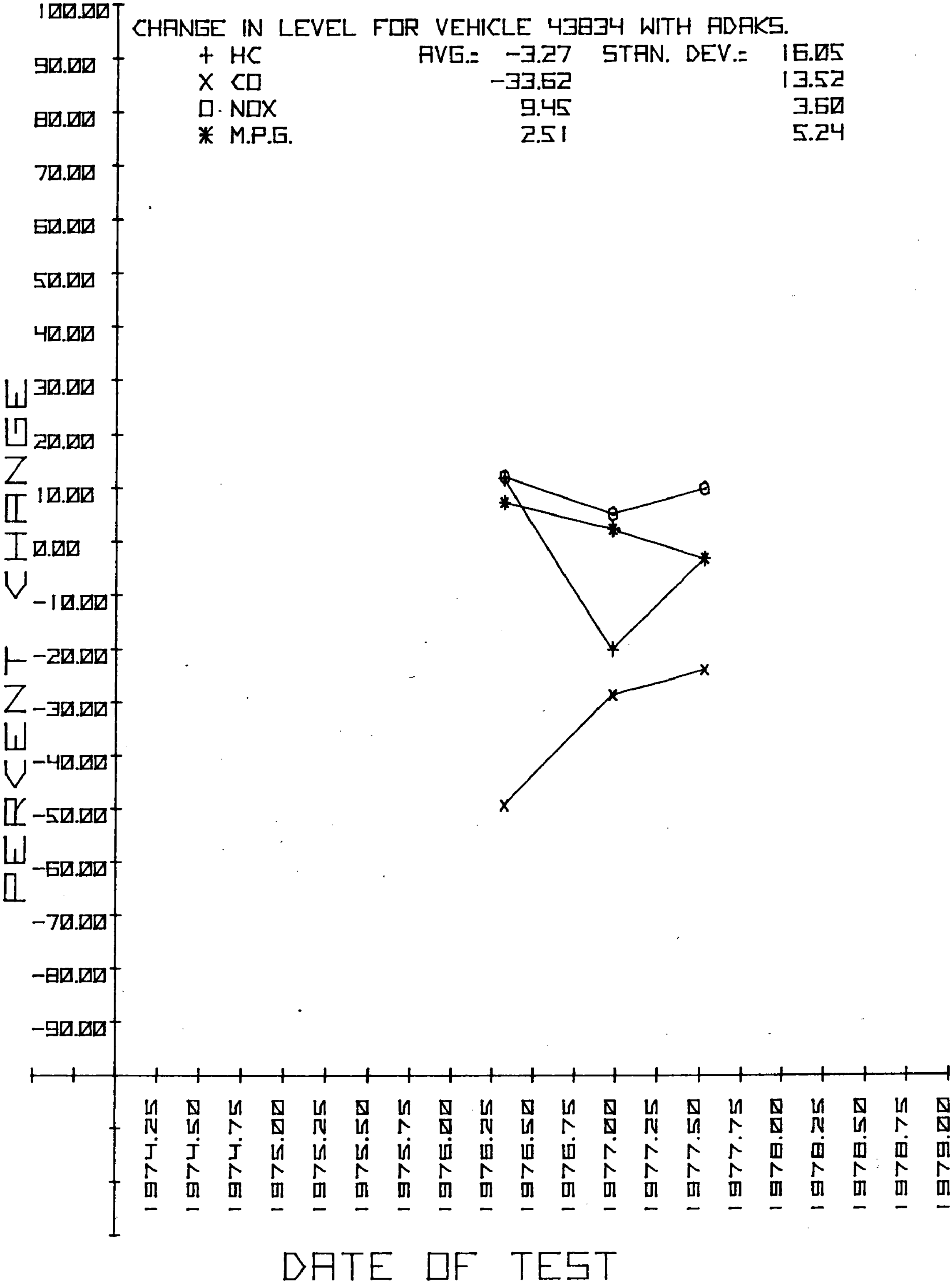

Fig. 4-I Percent change in emissions and fuel economy produced by ADAKS (compared with level measured with device disconnected).

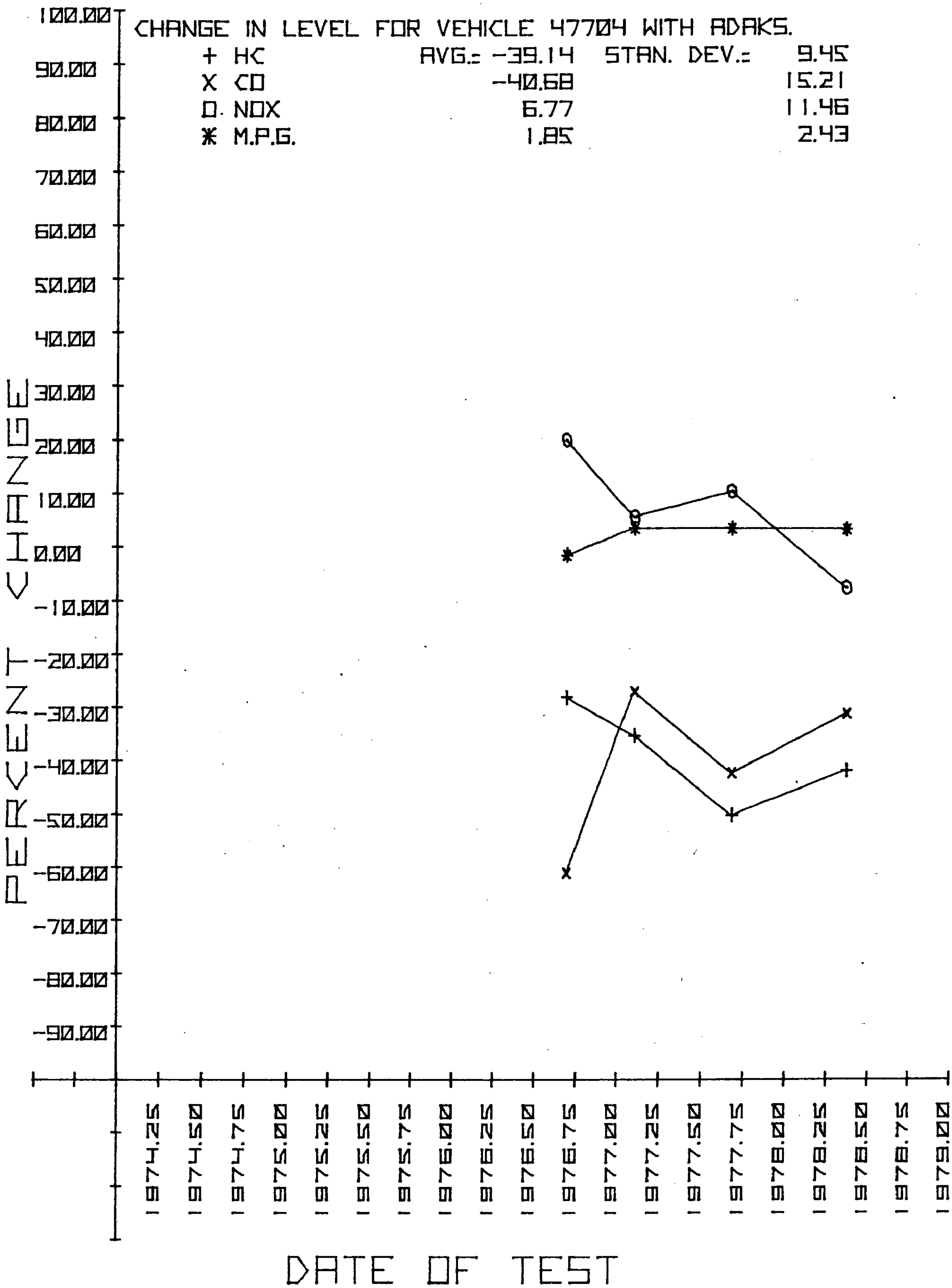

Fig. 4-J Percent change in emissions and fuel economy produced by ADAKS (compared with level measured with device disconnected).

IV.B.4 Results - Lean Mixture Carburetors.

The significant improvements in the emissions levels and fuel economy of light duty vehicles that results from improved carburetors suggest that similar improvements would result from retrofitting older HD vehicles with new carburetors.

Tests were made on two 1971 vehicles, a 1970 vehicle and a 1959 vehicle. Other vehicles were tested but the results could not be used. One of the vehicles became unavailable for further testing after retrofit. For another vehicle ignition system malfunctions invalidated the test data. Data from all carburator retrofit tests are contained in Appendix III.

Vehicles in the carburetor retrofit study were tuned up and their HC, CO, NOX and fuel economy levels were measured. They were then retrofitted with the most modern carburetors that matched the engine and were again tested. The vehicles were returned to service and were periodically retested.

Graphs of the NY Quick cycle results are given in Appendix II. A dashed line on each plot shows the level immediately prior to retrofit. Caution should be used in interpreting the dashed line representing a single measurement, as a constant level against which all later level can be compared.

The percent change in emissions level, produced by lean carburator (l.c.) retrofit, defined as

$$100 \times \frac{(\text{level after l.c. retrofit} - \text{level before l.c. retrofit})}{\text{level before l.c. retrofit}}$$

are shown in Table IV-K. In the table results from tests on 4 vehicles in the present study (nos. 10704, 10715, 19899 and 47720) are grouped with results from tests on 11 vehicles made during the Grant study

A mean decrease of emissions levels is shown for all three pollutants. However, the standard errors of the mean are large: 5.6 for HC, 9.0 for CO and 6.3 for NOX. Only for CO is the mean percentage reduction statistically significant at a 95% level of confidence.

The 4 vehicle in the current study showed a modest average increase in fuel economy of 3.6% after retrofit. While this was not significant at the 95% level the previous study on 11 vehicles also reported a "small" increase in fuel economy.

The small size of the average reductions in emission shown in Table IV-K does not mean that lean carburetors are inadequate for HD retrofit. As discussed in the CONCLUSIONS section, the small reductions result from limitations in the study rather than limitations of lean carburetors as control devices.

TABLE IV-K

INITIAL CHANGE IN EMISSIONS UPON INSTALLATION OF A LEAN MIXTURE CARBURETOR

OWNER'S I.D. No.	MODEL YEAR	PERCENT CHANGE HC	CO	NOX
47720	1959	13.5	2.6	-6.9
252-284	1969	-24.7	-33.1	6.0
4200	1961	8.6	7.6	-8.4
19899	1970	23.9	69.5	-22.7
25D369	1970	-0.2	5.9	-26.0
10704	1971	-11.5	-51.4	23.7
10715	1971	3.7	-19.8	1.1
4160	1971	-3.5	-11.2	-25.1
4177	1971	-26.4	-56.0	-18.7
4205	1971	-23.4	-42.8	1.4
4206	1971	-20.3	-30.4	22.2
4215	1971	-42.4	-70.5	63.1
4220	1971	38.1	1.5	-21.9
4418	1972	-11.1	-48.4	-14.4
4633	1972	-21.2	-25.4	-22.5
	Mean	-6.5	-20.1	-3.3
	s.d.	-21.5	-34.8	24.5

IV.B.5 Description Of Devices Screened.

Herein are brief descriptions of those devices tested in the screening phase.

BALL-MATIC (also marketed as "AIR JET")

This device is representative of a series of small, air bleed type devices which are inserted into the PCV line between the PCV valve and the intake manifold. The device contains a non-adjustable ball check valve which is normally open but which closes under high manifold vacuum conditions, the exact opposite of vacuum-opening type devices. The flow of air is so high under low vacuum conditions that misfire may occur at high speeds. These devices may also allow crankcase emissions.

AIR QUALITY PRODUCTS - "PURE POWER"

The Pure Power exhaust emission control system is a capacitive discharge electronic ignition system. The system monitors engine revolutions and computes correct spark timing signals to control emissions and raises the sparking voltage to improve combustion effectiveness at all engine speeds.

CLEAR AIR INTERNATIONAL

This is a vacuum-operated air bleed which feeds into the PCV line. Valve spring tension is adjustable and installation requires the use of an exhaust analyzer.

C.A.R.E. SYSTEM

This system replaces the vehicle's crankcase ventilation system and provides heating of crankcase vent air plus additional bleed air. Air enters the crankcase via an air tube containing a flow valve (replacing the vehicle's PCV valve) and a filter. Upon exiting the crankcase, the air passes through a copper tube clamped to the exhaust manifold where it is heated. The air enters the intake manifold. Additional bleed air is introduced through a separate variable orifice and filter.

ECHLIN

This system combines air bleed and V.S.A.D. functions. The air bleed is referred to as an "ultra-sonic generator" which is alleged to enhance the combustion process. A carburetor spacer plate is enclosed, as is a plug for the distributor vacuum line.

GAS ATOMIZER (also marketed as ECONONEEDLE)

These devices replace the carburetor idle fuel adjusting screws. The device consists of a needle screw with an bleed hole drilled through the center. It is claimed that this carburetor modification for lean air-to-fuel mixture in idle and deceleration modes results in reduced fuel consumption and exhaust emissions.

G-R VALVE

Refer to "BALL MATIC" description.

HYDROCATALYST

This device consists of two fine mesh wire cloths of deep dish configuration installed in a carburetor mounting gasket. The top (upstream) wire is coated with cadmium and the bottom (downstream) wire cloth is coated with nickel. The object of this devices is, through the alleged catalytic on the carbureted mixture of gasoline and air, to precondition the mixture for more efficient ignition, therby cleaning up existing carbon deposits in the combustion chamber of the engine and reduce exhaust emission.

M.S.D. (Multiple Spark Discharge) IGNITION SYSTEM

This electronic ignition system provides a series of capacitive discharge pulses in place of single discharge of conventional C.D. or inductive systems. The vehicle's original contact breaker points provide the timing signal.

PATCO POWER-PACK

This device is a chemical fuel vaporizer which, according to the manufacturer, increase gas mileage and power while reducing pollution and maintenance due to carbon foul-up. It consists of a 9-inch long cylindrical container, filled with an unknown chemical, which mounts to a fender well or other suitable location in the engine compartment. This unit ties into the PCV line by means of a connecting hose and "T" fitting, which are provided in the Kit.

PATON SYSTEM

This is a heated air bleed system. A small heat exchanger is installed in the vehicle exhaust pipe. Air from the carburetor air cleaner is drawn through this heat exchanger and into the PCV line.

POLLUTION MASTER

This system consists of two parts. The"crankcase scavenger" is a PCV valve replacement which acts as an air bleed. The "exhaust scavenger" is a check valve which is a check valve which allows secondary air to be drawn into the exhaust manifold by venturi action.

SMOGMASTER

This device is a vacuum-operated air bleed valve which vents filtered air into the PCV line. The device must be adjusted using an exhaust gas analyzer.

STP AIR COMPUTER

This device is a vacuum-operated air bleed valve. The valve is operated by a signal from the distributor vacuum advance line. A vacuum delay valve damps the action of the bleed valve, which vents into the PCV line.

V. CONCLUSIONS

V.A. Conclusions From The Inspection/Maintenance Study.

An obligatory I/M schedule is required for a HD vehicle retrofit program to insure that:

1. devices are installed
2. they are properly installed
3. they are properly maintained.

I/M to assure that HD vehicles are properly tuned and maintained is in itself an effective control strategy. Averages over 181 pairs of tests indicate that tune up achieves:

1. 36% reduction in HC emissions
2. 33% reduction in CO emissions
3. almost 4% gain in fuel economy.

There is evidence that there are lower emissions after tune up from vehicles that are routinely well maintained than from vehicles that are not. The gain in fuel economy represents a savings of $8.80 for every 1,000 miles driven if gasoline is $1.30 a gallon.

Data collected in the study can provide valuable information on relations between vehicle condition and pollutant emissions. It is hoped that investigators concerned with these topics will take advantage of the DATA TAPE discussed in Appendix I and the test data printouts in Appendix III.

V.B. Conclusions From The Retrofit Study.

Catalytic And Non-Catalytic Controls.

Non-catalytic devices can achieve considerable reductions in pollutant emissions. However, extensive studies at the Mobile Systems Laboratory show that catalytic converters have greater promise for HD retrofit than non-catalytic devices.

Catalytic converters are discussed in a separate report. (6)

Durability Of Non-Catalytic Devices.

In order to collect data on retrofitted vehicles in in-service condition the vehicles were deliberately not tuned up when they were periodically retested. This accounts for the erratic variations in emissions from test to test as seen, for example, in the plots of retrofit measurements in Appendix II. Since these variations mask any gradual deterioration in the performance of the retrofit devices the goal of determining the deterioration in performance of the devices could not be met.

Even if the vehicles were tuned before retesting it is unlikely that variations would be reduced sufficiently to allow deterioration to be determined because device deterioration would still be masked by vehicle deterioration. Vehicle deterioration depends on the quality of maintenance received by the vehicle. Maintenance quality varies from fleet to fleet and can vary from vehicle to vehicle within a fleet. The only way to control this factor is for the testing laboratory to assume responsibility for all maintenance and repairs on the vehicles. This would be impractical for in-service fleets.

It appears that deterioration in emissions reductions and fuel economy, if any, of non-catalytic devices cannot be determined by periodic testing of in-service vehicles.

The durability of the devices tested in the study appeared good. No evidence of physical deterioration was observed in properly installed devices.

V.B.I. Conclusions On EGR Devices.

EGR devices are effective in reducing CO and NOX emissions. Test results also indicated a slight improvement in fuel economy and little change in HC emissions.

The devices were no longer available as HD retrofits during the study. However, EGR devices were still used as original equipment on autos and the state of the art has progressed since the tests made in the study.

Experience with installing EGR retrofits on HD vehicles showed it to be a more costly and time consuming process than retrofitting autos. Unless EGR devices are properly maintained and adjusted they have a potential for causing drivability programs in HD vehicles. These two factors weight against EGR devices as first choice for a HD retrofit program.

V.B.2 Conclusions On Air Bleed Devices

The test results on air bleed devices indicate they are effective CO controls, relatively ineffective HC controls and slightly increase NOX emissions. They produce only a slight gain in fuel economy, a disappointing result since the ADAKS device was sold as a fuel savings retrofit for autos.

Installation was simple and no maintenance or drivability problems were found. Within its limitations the air bleed might be considered as part of a retrofit program for older HD vehicles. For newer vehicles improvements in original equipments carburetors and other changes have already accomplished most of the improvement that could be expected from an air bleed retrofit.

V.B.3 Conclusions On Lean Mixture Carburetors.

The wide range of results from carburetor retrofit shown in Table IV-K requires explanation. Retrofit produced large decreases in HC, CO and NOX emissions in vehicles 4177 and 4633 yet produced large increases in HC and NOX emissions in vehicle 19899. The latter result seem to contradict the general observation that carburetor retrofit is an effective emissions control method.

It is probable that the best results in the Table IV-K are typical of the improvements obtainable with lean mixture carburetor retrofit. Some of the increases in emissions observed in the Table undoubtedly result from the procedure used to adjust the retrofitted carburetors. These were adjusted to minimize emissions at idle and fast idle. However, this does not guarantee that the mixture is not too rich under the load conditions of the driving cycle.

Another probable reason for high emissions was the lack of data on matching retrofit carburetors to HD engines. Matching was no problem where a "California" carburetor existed to match an engine that had been in production for a number of years.

However, matching old engines for which improved replacement carburetors were not available involved subjective judgements. This might have resulted in a mismatch over part of the engines' operating range.

The data indicates that lean mixture carburetors are effective retrofit devices for older, rich mixture HD engines. On newer vehicles the effect of carburetor retrofit would be much less pronounced. The variability in effectiveness in reducing emissions make the universal use of lean carburetor retrofit inadvisable except as part of a more comprehensive control strategy.

A lean carburetor retrofit program would require a preliminary study on criteria for selecting and adjusting the carburetors.

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(4) Norman H. Nie et. al., SPSS Statistical Package For The Social Sciences, 2'nd edition, McGraw Hill Book Co., New York. 1975

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(8) Bulletin of the California Air Resources Board. May, 1973

(9) This light duty vehicle driving cycle is described in the Federal Register, Part II,Vol.35 pp.17311, 17312. November 10, 1970.

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16. ABSTRACT

To collect baseline information for heavy duty vehicle Inspection/Maintenance programs, a large fleet of in-service gasoline powered vehicles were chassis dynometer tested for HC, CO and NOx emissions and fuel economy in as-received condition and again after being tuned to their manufacturers' specifications. Computer analysis of the changes produced by tuning are presented and discussed.

To investigate the suitability of commercially available non-catalytic emissions control devices for heavy-duty-vehicle retrofit programs over fifteen such devices were screened. Exhaust gas recirculation devices, air bleeds and lean mixture carburetors were selected as promising candidates for retrofitting. These devices were installed on in-service heavy duty vehicles. Emissions and fuel economy were tested immediately after installation. The vehicles were recalled and retested periodically to monitor changes in devices effectiveness with use and time. Test results are evaluated to determine in applicability of the devices to a heavy du retrofit program.

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