75-21 JJM

Summary Report on the Evaluation of Light Duty Diesel Vehicles

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Technology Assessment and Evaluation Branch
Emission Control Technology Division
Office of Mobile Source Air Pollution Control
Environmental Protection Agency

CONTENTS

Background

The Environmental Protection Agency receives information about many systems which appear to offer potential for emission reduction or fuel economy improvement compared to conventional engines and vehicles. EPA's Emission Control Technology Division is interested in evaluating all such systems, because of the obvious benefits to the Nation from the identification of systems that can reduce emissions, improve economy, or both. EPA invites developers of such systems to provide complete technical data on the system's principle of operation, together with available test data on the system. In those cases for which review by EPA technical staff suggests that the data available show promise, attempts are made to schedule tests at the EPA Emissions Laboratory at Ann Arbor, Michigan. The results of all such test projects are set forth in a series of Technology Assessment and Evaluation Reports, of which this report is one.

The conclusions drawn from the EPA evaluation tests are necessarily of limited applicability. A complete evaluation of the effectiveness of an emission control system in achieving performance improvements on the many different types of vehicles that are in actual use requires a much larger sample of test vehicles than is economically feasible in the evaluation test projects conducted by EPA. For promising systems it is necessary that more extensive test programs be carried out.

The conclusions from the EPA evaluation test can be considered to be quantitatively valid only for the specific test car used; however, it is reasonable to extrapolate the results from the EPA test to other types of vehicles in a directional or qualitative manner i.e., to suggest that similar results are likely to be achieved on other types of vehicles.

The Diesel engine has long been recognized as an inherently low HC and CO emissions engine with excellent fuel economy advantages. This engine has been accepted by the heavy duty motor carrier and railroad locomotive industries for many years as the most efficient power source available for transporting goods over long distances. It has not yet been accepted, or rejected, for light duty use in the United States since inadequate numbers have been made available to determine the degree of public acceptance. Until 1974, only one imported model, the Mercedes Benz, was available to the general public and this had limited sales since it was only available in a premium priced vehicle. In 1971 EPA obtained both a 2.2 litre gasoline and a 2.2 litre Diesel powered Mercedes Benz for comparative evaluation studies at the Southwest Research Institute. This comparative test pointed out substantial differences in both emissions and fuel economy between the two vehicles which were identical except for their respective power plants. This intensified the interest of EPA in the Diesel as a light duty power plant. Since the automotive industry in the United States has not produced anything besides the conventional gasoline engine for personal transportation vehicles, it was necessary to obtain additional Diesel powered test vehicles from abroad.

Several EPA test reports have previously been published which portray the history of in-house data developed from light duty Diesel automobiles and a Diesel-powered pick-up truck. These tests are referenced as follows:

ECTD Report #	Title	Date
72-18	Interim Report on Testing of a Mercedes-Benz Diesel Sedan	March 1972
73-6	Final Report: Exhaust Emissions from a Mercedes-Benz Diesel Sedan	July 1972
73-19	Exhaust Emissions from Three Diesel Powered Passenger Cars	March 1973
73-26	Effects of FID Oven and Sample Line Temperature on the Measurement of Hydrocarbon Emissions from Diesel Engines	May 1973
74-1	Emissions from a Pick-Up Truck Retrofitted with a Nissan Diesel Engine	July 1973
75-10	Emissions from a Mercedes-Benz Diesel Car Equipped with a Turbocharger	October 1974

The summary of data from the above reports and additional vehicle tests are covered in this report.

Vehicle Descriptions

This report summarizes the testing of eleven different Diesel powered light duty vehicles:

1. Mercedes-Benz 220D (1971)
2. Mercedes-Benz 220D (1971) with and without turbocharger
3. Mercedes-Benz 220D (1972) stock and with modified fuel injection
4. Mercedes-Benz 240D (1975)
5. Mercedes-Benz 300D (1975)
6. Peugeot 504D (1973)
7. Peugeot 504D (1974 w/1975 Fuel Injection)
8. Peugeot 204D (1974)
9. Opel Rekord 2100D (1973)
10. Nissan 220C (1973)
11. Ford-Nissan CN-6-33 (pick-up truck)

All Mercedes vehicles used the Daimler-Benz prechamber combustion system which is shown in figure 1. All other vehicles used a version of the Ricardo Comet swirl chamber combustion system which is shown in figure 2. More detailed specifications on each vehicle can be found on the vehicle description sheets in Appendix A of the report. A brief description of each vehicle follows:

Mercedes-Benz Vehicles - All Mercedes-Benz models tested were versions of the 3500 pound inertia weight (IW), 4-door sedan. The first three vehicles were equipped with 2.2 litre, four cylinder engines rated at 60-65 horsepower.

The first 1971 vehicle was a car loaned to EPA by Mercedes-Benz of North America (MBNA) and initially tested by SwRI. The second 1971 vehicle was owned by a private citizen and was loaned to EPA for tests before and after the installation of a turbocharger. Neither 1971 vehicle incorporated any technology for the control of gaseous emissions. The 1972 vehicle was also provided by MBNA and was tested in two configurations:

1. As produced
2. With a modified injection system to reduce unburned hydrocarbons and odor.

A detailed description of the injection system modification to eliminate secondary injections is attached to the vehicle description table in Appendix A. Basically the modification involved installing "Reverse Flow Damping Valves" (RFDV) between the injection pump and the fuel injectors.

The engine in the 240D vehicle has a larger displacement (2.4 litre) and is a newer (1975 model year) version of the 220D. Reverse flow damping valves are standard equipment on this vehicle as well as on the five-cylinder 300D. The 300D is the same basic engine and vehicle with one additional cylinder added. The 240D is rated at 65 horsepower and the 300D is rated at 77 horsepower.

Peugeot Vehicles - All three Peugeot vehicles were loaned to EPA by Peugeot. The first vehicle tested, the 3000-Pound IW 504D, was a 1973 model equipped with a 65 horsepower, 2.1 litre engine. The second 504D vehicle, a 1974 model, nearly identical to the first, had been modified for lower hydrocarbon emissions. The third Peugeot vehicle, the 204D, was a 2500-pound IW sub-compact vehicle equipped with a transverse mounted 1.4 litre, four cylinder, aluminum alloy Diesel engine with cast iron sleeves, rated at 51 horsepower at 5000 rpm. This engine is the highest speed automotive Diesel engine in the world. No gaseous emission control technology was employed.

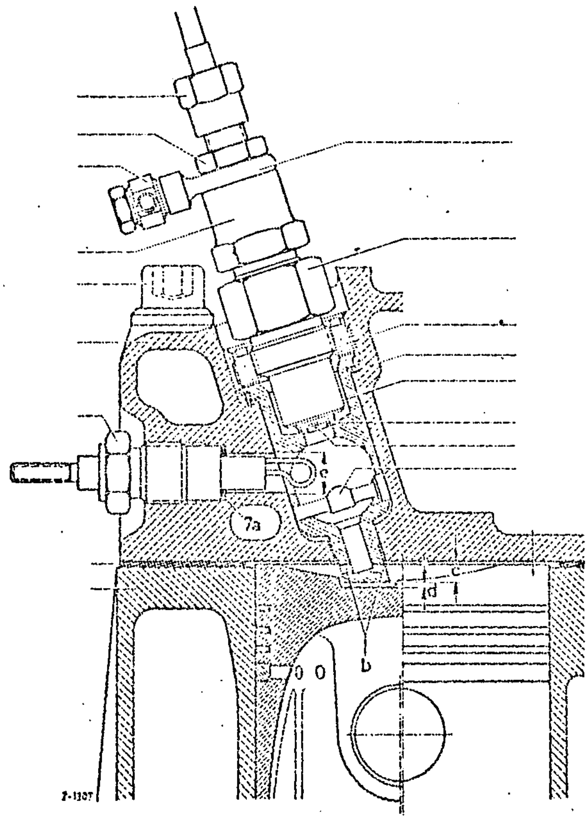

Figure 1 - Pre-Combustion Chamber

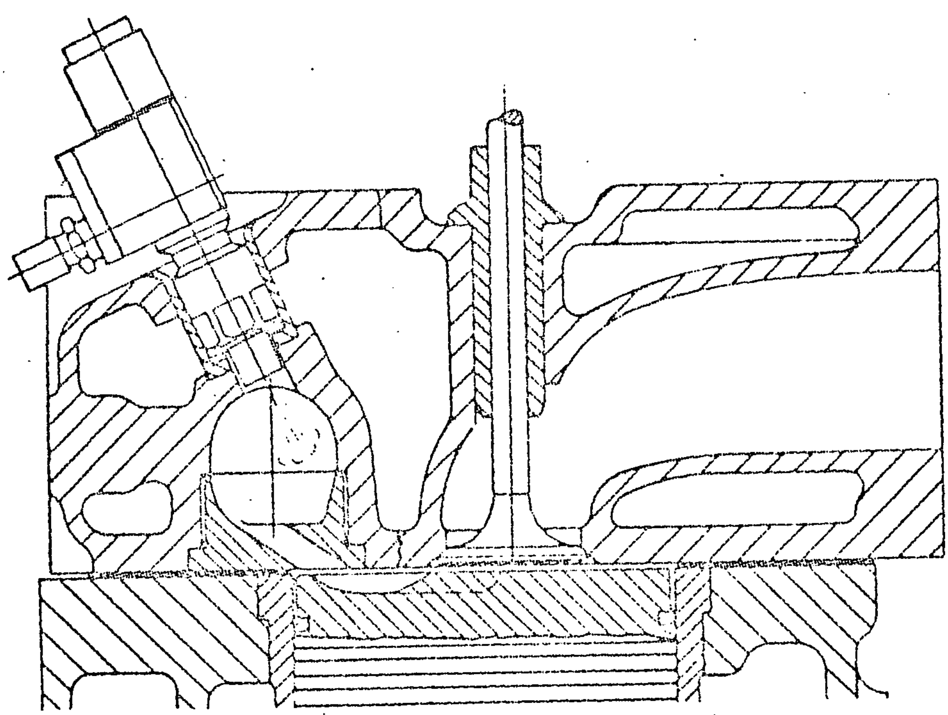

FIGURE 2 RICARDO COMET Vb INDIRECT INJECTION COMBUSTION SYSTEM PROPOSED FOR LIGHT-DUTY PASSENGER CARS

Opel Vehicle - The Opel Rekord 2100D was supplied courtesy of General Motors Corporation. It was manufactured by GM's European subsidiary Adam Opel AG. The 68 horsepower four cylinder, 2.1 litre engine was designed to be built off of the tooling for the 1.9 litre gasoline engine. No emission control system was employed. The 3000-pound IW Rekord 4-door sedan was similar in size to the Mercedes and Peugeot 504 vehicles.

Datsun-Nissan Vehicle - The Datsun-Nissan 220C was another 3500-pound IW, 4-door sedan vehicle powered by a 4 cylinder, 2.2 litre engine of 70 horsepower. The vehicle was provided courtesy of Nissan. No emission control system was incorporated.

Ford-Nissan Vehicle - The Nissan powered Ford pick-up truck was the only six cylinder vehicle tested and it was the heaviest at 4500 pounds IW. The engine installation had been done by S&S Equipment Sales, a Chicago based firm. The engine is a 92 horsepower six cylinder version of the four cylinder engine used in the Nissan 220C.

Gasoline engine data from a stratified charge PROCO Capri and a standard Capri were used in the tables of data for comparative purposes when applicable. Vehicles are described on the Test Vehicle Description sheets in Appendix A.

Test Procedures

To obtain a comprehensive evaluation of the Diesel as a light duty power plant, eleven different types of tests were performed:

1. 1975 Federal Test Procedure (FTP) for HC, CO, NOx emissions and urban cycle fuel economy from light duty vehicles.

2. Highway Cycle tests for emissions and fuel economy during non-urban driving.

3. Heavy Duty gaseous test procedure (13-mode) for mapping HC, CO, NOx emissions and specific fuel consumption.

4. Heavy Duty Smoke test

5. Light Duty Smoke test

6. Odor tests

7. Oxygenates testing (during 1975 FTP vehicle operation)

8. Noise tests

9. Particulate emission tests

10. Hydrocarbon distribution tests

11. Acceleration performance tests

Table 1 - Tests Performed

	75 FTP	Highway Cycle	13 Mode	HD Smoke	LD Smoke	Odor	Oxygenates	Noise	Particulate	HC Dist.	Acceleration
1. Mercedes-Benz 220D (1971)-SwRI	x		x	x		x	x				x
2. Mercedes-Benz 220D (1971) w/&w/o turbo	x	x									x
3. Mercedes-Benz 220D (1972) w/&w/o RFDV	x	x	x	x	x	x	x	x	x	x	x
4. Mercedes-Benz 240D (1975)	x	x									x
5. Mercedes-Benz 300D (1975)	x	x									x
6. Peugeot 504D (1973)	x		x	x	x	x	x	x	x	x	x
7. Peugeot 504D (1974)	x	x									
8. Peugeot 204D (1974)	x	x									x
9. Opel Rekord 2100D (1973)	x		x	x	x	x	x	x	x	x	
10. Datsun-Nissan 220C (1973)	x		x	x	x	x	x	x	x	x	
11. Ford-Nissan CN-6-33	x										
Testing Location — Test performed by	EPA/TAEB and SwRI	EPA/TAEB	SwRI	SwRI	SwRI	SwRI	SwRI	SwRI	EPA/ORD and Dow Chemical	SwRI	EPA/TAEB and Manufacturers Data

Table one identifies which tests each of the test vehicles was subjected to up to the present time.

The specific test procedures and analysis systems used for each emissions category are described in the following subsections. In every case possible, recognized procedures published in the Federal regulations were employed. Instruments, sampling and analysis, and other facilities adhere strictly to these methods without exception. Where Federal procedure, or chassis versions of Federal procedures, do not exist, existing procedures for Heavy Duty Diesel vehicles were modified or adapted as necessary for purposes of this project. The Diesel cars were tested with number 2 Diesel fuel (DF2).

1. Gaseous Emissions - 1975 Light Duty Vehicle FTP

The cold start 1975 FTP was the basic gaseous transient procedure used. It is essentially the same for both gasoline and Diesel. Hydrocarbon values were obtained by both the bag method, prescribed for gasoline engines, and continuous hot analysis. The Federal test procedures for gaseous emissions and fuel economy were followed without exception.

2. Highway Cycle Testing

The EPA Highway cycle test for light duty vehicles simulates a hot start 10.2 mile trip in a non-urban area. Average cycle speed is high at 48 mph. The fuel economy a vehicle achieves on this test is nearly the optimum that could be expected from normal long distance travel.

3. Gaseous Emissions - 1974 Heavy Duty Vehicle

The 1974 Heavy Duty gaseous emissions test, known as the 13-mode test, is a stationary engine test. The 39-minute long chassis procedure is a speed-load map of 13 modes, at 3 min per mode. In addition to CO and NO by NDIR (according to SAE recommended practice J-177), and HC by heated FIA (according the SAE recommended practice J-215), air rate must be measured continuously (according to SAE recommended practice J-244). A Flo-Tron system was used to measure the net fuel consumption of the engine, which, in turn, enabled the use of manufacturer's curves for inlet fuel rate and engine flywheel horsepower to set power points.

The four Diesel and one stratified charge engines investigated had rated speeds of 4000 to 4500 rpm and nominal peak torque speeds of 2400 rpm. For the 13-mode test, the intermediate speed is defined as peak torque or 60 percent of rated, whichever is higher. The procedure starts with low idle, then 2, 25, 50, 75, and 100 percent load at intermediate speed followed by low idle. Then speed is increased to rated at 100 percent load with decrease to 75, 50, 25, and 2 percent. Another idle is then run.

The major difference between the engine test used for certification and the chassis alternative is the procedure used to determine the engine operating points at 25, 50, and 75 percent of power and the actual power output at 100 percent. The engine procedure uses measured power output at the flywheel to determiné the cycle weighted power for division into the product of emission concentration times gas mass flow rate to get brake specific emission rate. For engines installed in a chassis, there is no convenient way to measure power output at the flywheel. But, it is convenient to measure the net fuel rate to the engine which can be used to determine power, given suitable curves from the manufacturer.

For most of the cars subjected to this test, a curve of fuel rate versus flywheel power output, from no load to maximum power output at rated and intermediate speed was available. The procedure was to measure maximum fuel rate by operating at maximum power output at each specified speed. The flywheel power output for the maximum fuel rate was read from the available curve. The part load power fuel rate settings were then obtained from the curve at 75, 50, and 25 percent of the maximum chassis dynamometer power reading. The vehicle was then operated at these fuel rates during the test and the power used in the calculations was than read or determined by the fuel-power curves.

In a few instances, such part load curves were not available making it necessary to define the maximum flywheel power from full load performance curves which were available. A straight line relationship was then drawn between the full load fuel rate and the no load fuel rate on a plot of fuel flow vs. load for each of the two test speeds. The flow corresponding to the 25, 50, and 75 percent load points was taken from this curve as previously discussed. This practice, required for the Nissan Diesel car, assumes fuel rate and power output to be a linear relationship which for most Diesel engines, both Light and Heavy Duty, is a reasonable approximation.

4. Smoke - Heavy Duty Vehicle FTP

The Federal Heavy Duty smoke test consists of an initial engine acceleration from 150-250 rpm above the low idle speed to 85-90 percent of rated engine speed in 5.0 $\pm$ 1.5 seconds, a second acceleration from peak torque speed (or 60 percent of rated speed, whichever is higher) to 95-100 percent of rated speed in 10.0 $\pm$ 2.0 seconds, and (following this second acceleration) a full-power lugdown from 95-100 percent of rated speed to the particular intermediate engine speed (peak torque speed or 60 percent of rated speed) in 35.0 $\pm$ 5 seconds. Three of these sequences constitute one smoke test. The U.S. EPA light extinction meter is used to record smoke opacity.

The average smoke opacity from the 15 highest-valued one-half second intervals of the two accelerations determine the "a" factor, and the average opacity from the five highest-valued one-half second intervals of the lugdown mode determines the "b" factor. The maximum values allowed for "a" and "b" factors of 1970 through 1973 certification engines were 40 and 20-percent opacity, respectively. For 1974, the "a" factor was reduced to 20-percent opacity and "b" factor was reduced to 15-percent opacity. The new peak or "c" factor, which is the average of the three highest one-half second intervals per cycle, is determined from the "a" and "b" chart readings. The three cycle "c" values are then averaged to determine the "c" factor for the test.

5. Smoke - 1975 Light Duty Vehicle FTP

There currently is no recognized U.S. smoke test procedure for light duty passenger car exhaust. Although the Heavy Duty schedule can be used with the light duty vehicle by a chassis dynamometer version of the test, it is uncertain whether this test is indeed representative of the way the smaller, higher speed Diesels operate. The smoke opacity was recorded therefore, during operation of the vehicle over the LA-4 transient driving schedule used for the Federal light duty gaseous emissions test. The U.S. EPA light extinction smoke meter was connected at the end of the tailpipe and continuously recorded smoke opacity throughout the test cycle. Smoke tests were conducted independently of the emissions tests.

6. Odor - Light Duty Vehicle

(a) Diesel Odor Analytical System

As one result of approximately five years of research, sponsored under the CAPE-7 project of CRC APRAC, A. D. Little developed a prototype liquid chromatograph for use in predicting Diesel exhaust odor. Called DOAS for Diesel odor analytical system, the system provides two results, one being an indication of the oxygenate fraction called LCO for liquid chromatograph oxygenates, and the other called LCA for liquid chromatograph aromatics. These were found by earlier research by ADL to represent the major odorants in Diesel exhaust. The ADL studies had shown a correlation of the TIA (total intensity of aroma) to sensory measurements by the ADL odor panel. TIA is equal to $1 + \log_{10}$ LCO, where LCO is expressed in $\mu g/\ell$ of the exhaust gas fraction.

Both LCO and LCA are expressed in micro-grams per litre of exhaust using either the test fuel or a reference component for calibration. The LCO is, by virtue of its use to express TIA, considered the most important indication of Diesel exhaust by this method.

DOAS values and odor ratings with the trained odor panel were obtained simultaneously on all the vehicles in this project. The DOAS does not measure odor, but measures a class of odorants and it was intended and developed specifically for use with Diesel exhaust. Its application to exhaust from gasoline engines had never previously been attempted. To obtain DOAS samples requires each test mode to be extended. Double the running time, from a nominal three minutes to six minutes, was needed to allow a full five minutes of trapping. The first minute is to achieve a stable operating speed and load. Panel evaluation is normally during the third minute of the run.

The sampling system used a multi-opening stainless steel probe, as is normal practice for HC measurement from Heavy Duty Diesel engines. The sample was then transferred to the oven via a 9.5mm (3/8 inch) diameter stainless steel line 0.75m (30 inches) long covered by tubular exterior electrical heating sleeves to maintain 190°C (375°F) sample gas temperature. Between the probe and sample transfer line, a high temperature bellows type stainless steel valve was placed for leak check purposes. Inside the oven, the sample passed through a fiberglass filter, then into a metal bellows pump mounted inside the oven.

Once the sample passes through the trap, the sample goes through a drierite column, a glass tube flowmeter, and then into a dry gas volume meter. The dessicant prevents troublesome water from condensing in the flowmeter and gas meter. The flowmeter allows monitoring of gas flow, by visual observation, during the test while the gas meter measures the total flow of gas during the last run.

(b) Diesel Odor Evaluation by Trained Panel

The EPA (PHS) quality-intensity (Q/I) or Turk kit method of evaluation of dilute samples of Diesel exhaust odor was employed to express odor judgements by the trained ten-person SwRI odor panel. The reference standards used are blends of chemical compounds selected for their stability and similarity to Diesel odor characteristics. The kit includes an overall "D" or composite odor graded in steps of 1 through 12, 12 being strongest. The "D" odor is made of four sub-odors or qualities. These comprise burnt-smoky "B", oily "O", aromatic "A", and pungent "P" qualities. Horizontal exhaust at bumper height from a city bus was found in field studies to be diluted to a minimum reasonable level of 100:1 before being experienced by an observer. Since no similar dilution data were available for light duty vehicles, the 100:1 dilution was retained in this program for consistency recognizing that it is probably low for these smaller engines and particularly for the throttled gasoline engines.

Both steady state and transient vehicle operation were simulated for odor evaluation. The steady state runs were made at three power levels, normally zero, one-half, and full power at a high and at an intermediate speed. The seventh condition was low idle for a well warmed-up engine. For the four Diesels, one-half load was defined as a fuel rate midway between the fuel rates at full and no load. These seven conditions were performed in random order so as to replicate each condition three times for a total of 21 runs.

The odor measurement procedures applied to the Diesel powered cars were based on the extensive previous work with Diesel exhaust odor measurement from larger size vehicles. One important change was made, however, and that was to operate the cars more nearly as they might on the road. This meant changing the engine speeds from rated and intermediate, as defined for the 13-mode test, to lower speeds. High speed was defined as the engine rpm corresponding to 90.1 km/hr (56 mph) level road load. In practice, the level road load, defined for a specific car test weight was set in the dynamometer 80.5 km/hr (50 mph) and then the car increased in speed to 90.1 km/hr (56 mph). Most of the cars were, in high gear or high range of the transmission, operating at approximatley 3000 engine rpm at 90.1 km/hr (56 mph). The intermediate speed was then defined as 60 percent of this speed, which was a nominal 1800 rpm for most cars.

Operation of the Ford Capri gasoline car posed some special concerns in that it was the first gasoline powered vehicle evaluated by the trained SwRI odor panel. The carbon monoxide in gasoline engine exhaust, relative to that from Diesels, is substantially greater and required special pre-evaluation examination to determine panelist exposure level. Since the current OSHA limit is 50 ppm CO per eight hour working day, there is no concern about exposing odor panelists to CO levels at or below this level in the dilute exhaust. For very brief exposures and a minimal number of occurrences in a given working day, the range of 400 to 500 ppm CO in air (one-hour or less exposure) has been considered the limit.

The basic philosophy was to characterize odor over a range of loads and speeds that could be encountered and over a wide enough range to cover steep uphill plus moderate trailer towing as well as the moderate load and no load conditions.

7. Oxygenates - 1975 Light Duty Vehicles

In addition to the usual HC, CO, NOx measurements, raw exhaust samples were continuously taken and collected in reagents for wet chemical analysis. These samples were withdrawn in the stainless steel pipe section connecting the exhaust dilution point (below the CVS filter box) and the inlet of the

CVS heat exchanger. Multiopening stainless steel probes were used, one probe for the aldehyde-formaldehyde bubbler in series, one for the pair of acrolein bubblers in series, one for each of the three odor trapping systems for the Diesel odor analytical system (DOAS).

These probes were located adjacent to the probe used to obtain the continuous HC sample. All sample lines and interfaces were heated as required to maintain sample integrity for Diesels. Alehydes, formaldehyde and acrolein samples were maintained at 71°C (160°F). This is the same temperature used with raw exhaust samples to prevent condensation of water and loss of water soluble oxygenates.

In the case of wet collected traps, the entire 23-minute (bags 1 and 2) and the third bag 505 sec portion of the 1975 FTP were taken in a single collector (bubbler on trap). This was necessary to obtain sufficient sample for analysis and preclude the problem of switching after the first 505 seconds of the run (cold start bag). The chromatropic acid method for formaldehyde, 3-methyl-2-benzothiazolone hydrazone (MBTH) method for aliphatic aldehydes, and the 4-hexlresorcinal method for acrolein, all of which are wet chemical methods, were employed.

8. Vehicle Noise

This series of tests was intended to determine the maximum interior and exterior sound levels, in dBA scale, during idle and various driving modes. SAE J986a, Sound Level for Passenger Cars and Light Trucks, describes a test procedure that formed the basis for measurement and vehicle operation. A General Radio Type 1933 Precision Sound Level Analyzer, General Radio Type 1562-A Sound Level Calibrator, and General Radio Wind Screen.

(a) Acceleration Drive-By

Acceleration drive-by measurements were made at 15.24m (50 feet). Each vehicle approached a line 7.6m (25 feet) before a line through the microphone normal to the vehicle path and accelerated, using the lowest transmission gear or range such that the front of the vehicle reached or passed a line 7.6m (25 feet) beyond the microphone line when maximum rated engine speed was reached. The sound level reported was that of the loudest side of the vehicle. Tests were made with all windows fully closed and the vehicle accessories such as heater, air conditioner, or defroster (radio excluded) in operation at their highest apparent noise level.

Interior sound level determinations were the same as exterior except that the microphone was located 6 inches to the right side of the driver's right ear. All other test procedures were as presented in J986a.

(b) Constant Speed Drive-By

The constant speed drive-by measurements were also made at a distance of 15.24m (50 feet). The vehicle was in high gear and driven smoothly at 48.3 km (30 mph) ± 5 percent.

Interior sound level determinations were made in the same manner as during the accel test. The sound level reported for this test was obtained in the manner outlined in the acceleration test already described.

(c) Idle

This test included sound level measurements at 3.05m (10 ft) distances from the front, rear, left (street side) and right (curb side) of the vehicle. The vehicle was parked and engine allowed to run an manufacturer's recommended low idle speed with transmission in neutral for at least one minute. Accessory items such as air conditioner or heater and defroster were not operated during this test. Interior measurements were also obtained at the same single point used in drive-by tests.

9. Particulate Emission Tests - 1975 and 1972 LDV-FTP and 60 miles per hour (96.6 Km/hr)

A Clayton CT-200-0 chassis dynamometer with a variable inertia flywheel assembly was used in all tests conducted under this program. In these tests, the vehicle was operated under approximately 60 mph road-load cruise conditions and under cyclic conditions of the Federal Test Procedure.

Exhaust particles were collected after air dilution of the exhaust in a large dilution tube. The entire exhaust stream was diluted. Air dilution and cooling of the exhaust was accomplished by a dilution tube 16 inches in diameter and 27 feet in length constructed of extruded polyvinyl chloride (PVC) pipe in several sections with butt joints which were taped during assemply prior to each run. The diluent air coming into the tube was filtered by means of a Dri-Pak Series 110 Class II PIN 114-110-020 untreated cotton filter assembly. This filter assembly is 24" x 24" and has 36 filter socks which extend to 36 inches in length. This filter will pass particles 0.3 micron in size and smaller. Pressure drop at 600 cfm flow rate is minimal.

Exhaust was delivered to the tube via a tailpipe extension which was brought into the bottom of the tube downstream of the filter assembly. The extension was bent 90 degrees inside the tube, thus allowing the introduction of the exhaust stream parallel to the tube axis. Within the dilution tube, along the perpendicular plane of the end of the exhaust extension was a mixing baffle which has an 8-inch center hole and was attached to the inside diameter of the tube. The baffle presented a restriction to the incoming dilution air in the same plane as the end of the exhaust extension and provided a turbulent mixing zone of exhaust gas and dilution air.

The particulate sampling zone is located at the exhaust end of the dilution tube. Two sample probes were both connected to 142 mm holders fitted with 0.3 micron Gelman Type A glass fiber filter pads and vacuum pumps. A flow meter was used to monitor and regulate the flow through the filters. Sample probes sized to deliver an isokinetic sample from the dilution tube were used. The average mass from the two filters was used in determining total mass particulates sized greater than 0.3 microns. Heavy particulates which fall out in the tunnel are not considered of immediate concern since these would not normally be airborne in a normal environment.

10. Hydrocarbon Distribution - 1975 LDV-FTP

The classification of exhaust hydrocarbons by different molecular weight categories were measured. Such analyses requires a sample of concentrated exhaust for analysis by gas liquid chromatograph (GLC). The type column (length and packing) has been essentially standardized to the use of a 3.05m x 3.18mm (10 ft x 1/8 inch) 5 percent Dexil 300 on 60/80 AW/DMCS Chromosorb G columns in which the sample is eluted by a carrier gas, nitrogen, while the column temperature is slowly raised, temperature programmed from 100°C to 350°C at 10°C/min after 5 minutes of isothermal operation at 100°C.

The ADL Diesel odor analysis system (DOAS) which was used requires a non-aqueous, concentrated sample of organic exhaust products for analysis. Chromosorb 102 will absorb oxygenates and unburned fuel at slightly elevated temperatures, permitting the water vapor to pass through the column. The trap can be capped off and is reported reasonably stable for several days. During this time, the absorbed organic matter can be extracted by eluting with a pre-purified solvent, cyclohexane. A small amount of this extract is then used in the DOAS and a small amount of the remainder in injected into the Varian Model 1740 GC used for hydrocarbon analysis.

The resulting chromatogram is then analyzed for peak height, area and elution time. These values are then compared to calibration standards from which a quantitative and qualitative indication of hydrocarbon distribution may be determined. The only change to usual laboratory practice for these measurements was the use of the DOAS sample. The DOAS sample was taken during the running of an entire 1975 LD FTP. This sample, taken at a continuous rate from the CVS diluted exhaust, was felt to represent as well as any other sample technique, the type HC usually emitted by Diesels in transient operation.

11. Acceleration Tests

Zero to sixty miles per hour acceleration runs on the road were made for some of the vehicles. All times were recorded based on the vehicles speedometer reading with two test engineers aboard. Tests were conducted on a flat, level, paved highway. A stop watch was used to measure the time of acceleration. Where data were not available, manufacturers data or published test results were used in the evaluation.

Test Results

Exhaust emissions data from EPA, Dow and SwRI are summarized in Tables 2-9. Analysis of these data showed the following:

1. LDV Gaseous Emissions and Fuel Economy

As shown in table 2, the 1972 Mercedes 220D, the Nissan 220C and the Opel 2100D all were able to meet the levels of the 1977 statutory standards (.41 HC, 3.4 CO, 2.0 NOx). The 1975 FTP tests illustrated an inherent low emission capability of the Diesel powered car.

The two 1971 Mercedes-Benz cars had 16,500 and 88,000 miles respectively and the latter was tested three years after the first car. The magnitude in mass emissions of the two cars was not significantly different. Although the HC level of the 1971 cars was about twice the 1977 statutory level of 0.41 gm/mi, this was improved with the 1972 model to 0.34 gm/mi. Then, with the addition of Reverse Flow Dampening Valves (RFDV) to the high pressure fuel distribution lines of the 1972 model car, HC was further reduced to 0.26 gm/mi by controlling secondary injections. The RFDV strategy was then adapted in production for the 1975 Mercedes 2.4 and 3.0 litre models yielding HC levels on the order of 0.13 to 0.16 gm/mi, CO on the order to 1.03 to 1.43 gm/mi and NOx on the order of 1.42 to 1.55 gm/mile. These significant improvements were obtained with only minor adjustments to the fuel injection system. In the case of the Peugeot 504D, HC control was improved by 74% and CO by 47% merely by finer tuning of the high pressure fuel system (changes in the fuel nozzle and delivery valve retraction volume). Neither the Opel nor the Datsun Diesel cars are marketed in the U.S. nor are the engines developed for low emissions. Both of these vehicles, as received and tested however, produced emission levels well below the stringent 1977 statutory levels. These were all 3000 to 3500 pound IW test vehicles. The heavier, 4500 pound IW, Ford truck which was tested by EPA with a retrofitted Diesel engine, the Chrysler-Nissan CN 6-33, was high in HC but met the 1977 NOx statutory standards without any refinements or adjustments to the engine or fuel system. In the single example of turbo-charging, the full load fuel setting was unchanged and turbo effectiveness was experienced primarily during light load accelerations with the 3500 pound IW Mercedes. Addition of the turbo had no significant influence on emissions during the FTP. The only light weight car tested, the Peugeot 204D, had high HC and CO emissions compared to the heavier cars but this is probably due to secondary injections and an untuned fuel injection system.

Table 2

1975 LDV - FTP Emissions and Fuel Economy

Vehicle	Inertia Weight	Model	HC gm/mi	HC gm/Km	CO gm/mi	CO gm/Km	NOx gm/mi	NOx gm/Km	Weighted 1975 MPG	Litre/ 100 Km	# of Tests
Mercedes-Benz	3500#	1971 220D (SwRI 1972 FTP)	0.87	(0.54)	1.62	(1.00)	1.83	(1.13)			5
	3500#	1971 220D (w/o turbocharger)	0.87	(0.54)	2.66	(1.65)	1.61	(1.00)	24.7	(9.51)	2
	3500#	1971 220D (with turbocharger)	0.98	(0.61)	2.67	(1.66)	1.66	(1.03)	24.5	(9.59)	2
	3500#	1972 220D	0.34	(0.21)	1.39	(0.86)	1.54	(0.95)	24.3	(9.67)	15
	3500#	1972 220D (modified)*	0.26	(0.16)	1.11	(0.69)	1.42	(0.88)	26.5	(8.87)	18
	3500#	1975 240D 2.4 1	0.13	(0.08)	1.03	(0.64)	1.42	(0.88)	25.2	(9.33)	1
	3500#	1975 300D	0.22	(0.14)	1.43	(0.89)	1.55	(0.96)	23.9	(9.83)	1
Peugeot	3000#	1973 504D (pre-SwRI)	3.29	(2.04)	3.66	(2.27)	1.06	(0.66)	24.2	(9.71)	10
	3000#	1973 504D (post SwRI)*	1.88	(1.17)	2.47	(1.53)	1.03	(0.64)	25.7	(9.14)	6
	3000#	1974 504D	0.94	(0.58)	1.93	(1.20)	1.45	(0.90)	24.0	(9.79)	7
	3500#	1975 504D	0.51	(0.32)	1.51	(0.94)	0.95	(0.59)	26.7	(8.80)	2
	2500#	1974 204D	1.60	(0.99)	2.75	(1.70)	0.69	(0.43)	33.0	(7.12)	1
Opel-Rekord	3000#	1973 2100D (pre-GM)	0.53	(0.33)	1.30	(0.81)	1.41	(0.87)	24.3	(9.67)	23
	3000#	1973 2100D (post GM)*	0.39	(0.24)	1.05	(0.65)	1.31	(0.81)	25.4	(9.25)	6
Datsun-Nissan	3500#	1973 220C*	0.31	(0.19)	1.35	(0.84)	1.47	(0.91)	25.9	(9.07)	6
Ford-Nissan	4500#	Ford F250 w/Nissan CN6-33	1.70	(1.05)	3.81	(2.36)	1.71	(1.06)	21.4	(10.98)	3
Uncontrolled Gasoline baseline	3500# Ave	Typical	8.70	(5.39)	87.00	(53.94)	3.50	(2.17)	14.1	(16.67)	
1975 Interim Standards			1.5		15.0		3.1				
1975 California			0.9		9.0		2.0				
1977 Interim Standards			0.41		3.4		2.0				
1978 Statutory Standards			0.41		3.4		0.4				

* Average of SwRI and EPA tests.

Table 2 also shows urban cycle fuel economy and fuel consumption from 2500 to 4500 pound inertia weight Diesels and Figure 3 compares these to gasoline powered cars. Urban fuel economy (MPG) from these vehicles was about 1.8 times that of typical gasoline powered vehicles of equal IW class. Table 3 shows the non-urban or highway fuel economy and fuel consumption from Mercedes-Benz and Peugeot models. Highway Cycle fuel economy, about the best which can be expected for long distance trips, ranged from 30 to 35 miles per gallon for the Diesel cars as compared against 19 miles per gallon for the typical uncontrolled gasoline car of 3500 inertia weight. The small Peugeot 204D gave 41 MPG on the highway cycle. Figure 3a shows a comparison to gasoline cars.

Assessment of fuel economy from Diesel fueled vehicles for comparative analyses with gasoline fueled vehicles should take into consideration the difference in available energy from the two fuels. Average DF2 fuel has a heat content of 137,500 BTU/gallon where gasoline has 124,500 BTU/gallon - 10% more available energy per gallon of fuel. To correct for this, fuel economy (MPG) of the Diesel x 0.91 will provide the corrected value for an absolute comparison. However, it should be noted that considerably less energy is required at the refinery to make DF2 fuel. The true efficiency advantage of DF2 fueled cars probably lies somewhere in between the observed and corrected values for fuel economy.

HC emissions are roughly one fourth, CO one tenth and NOx one fifth that of the uncontrolled gasoline car when tested on the highway cycle. It is interesting to note the low HC and CO from the Peugeot 504D (modified) as compared against the Mercedes-Benz which had lower HC and CO levels when tested on the urban cycle.

Table 4 shows the oxygenates (formaldehyde, aliphatic aldehydes, acrolein) were proportional to total HC's. As HC was lowest for the Mercedes so were the oxygenates. As HC was the highest for the Peugeot (of the four Diesels tested), so were the oxygenates. As compared against the 1974 Mercedes uncontrolled gasoline 2.2 litre vehicle, oxygenates were roughly one half of the gasoline engine (except for the Peugeot where aldehydes were about 75% higher, formaldehydes and acroleins about the same as the gasoline). The LDV Diesel engine, therefore, should not present any major problems in this category of pollutants except for possibly some contribution to the exhaust odor quality.

2. <u>Heavy Duty Vehicle Gaseous</u>

Using a chassis version of the 1974 Federal Diesel Heavy Duty (HD) 13-mode procedure, all four of the Diesel passenger cars were substantially below the most stringent CO level of 25 gm/bhp-hr specified by California for 1977 as is shown in table 5. Combined HC and NO_2 for the four Diesels ranged from 3.9 to 7.0 gm/bhp-hr. The tight HC and NO_2 standard set by California for 1977 is 5 gm/bhp-hr. HC from the Peugeot was about 10 times higher than the other Diesel cars, but fuel injection modifications should correct this condition.

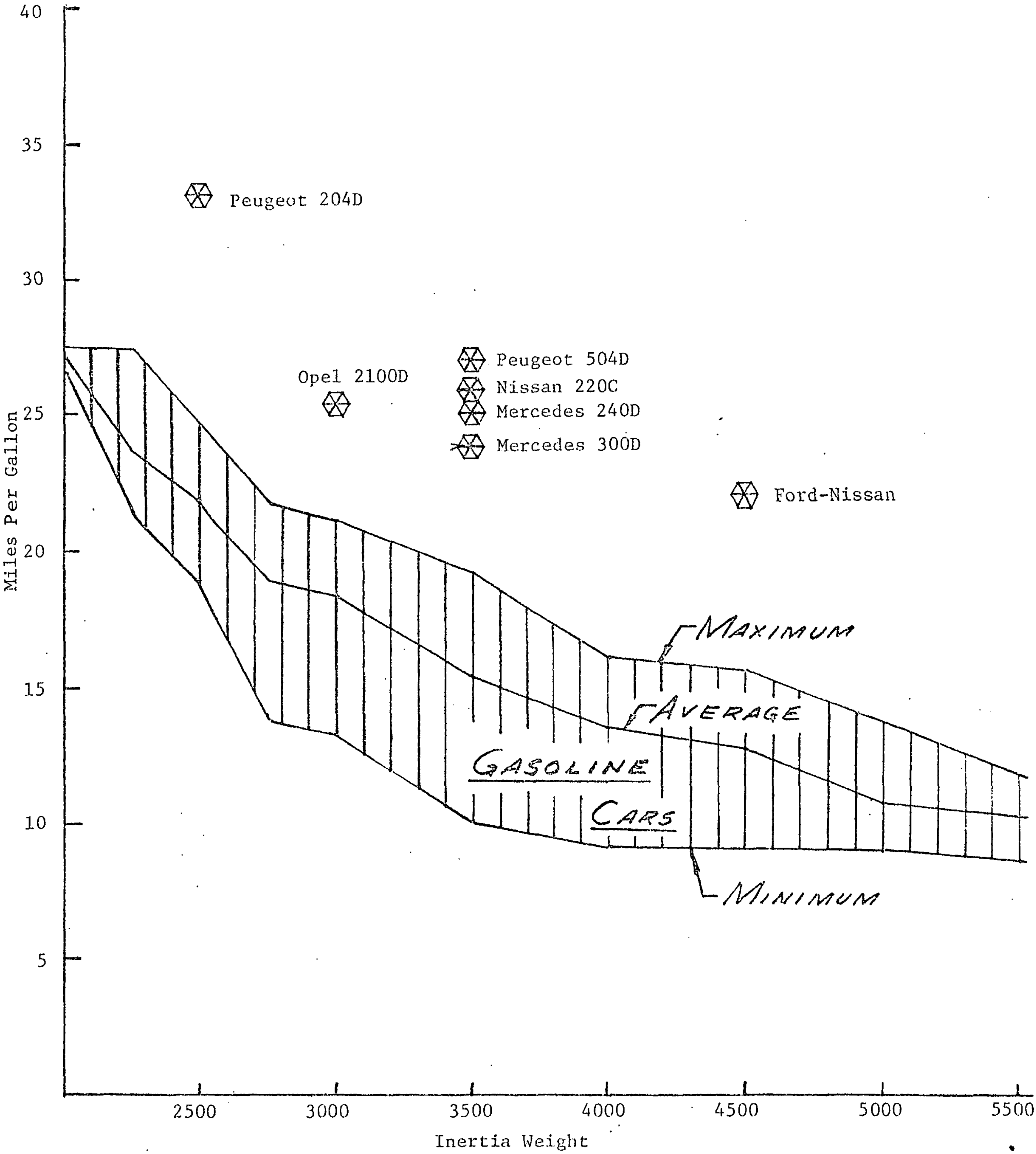

Figure 3 - Diesel vs. 1975 Gasoline Urban MPG

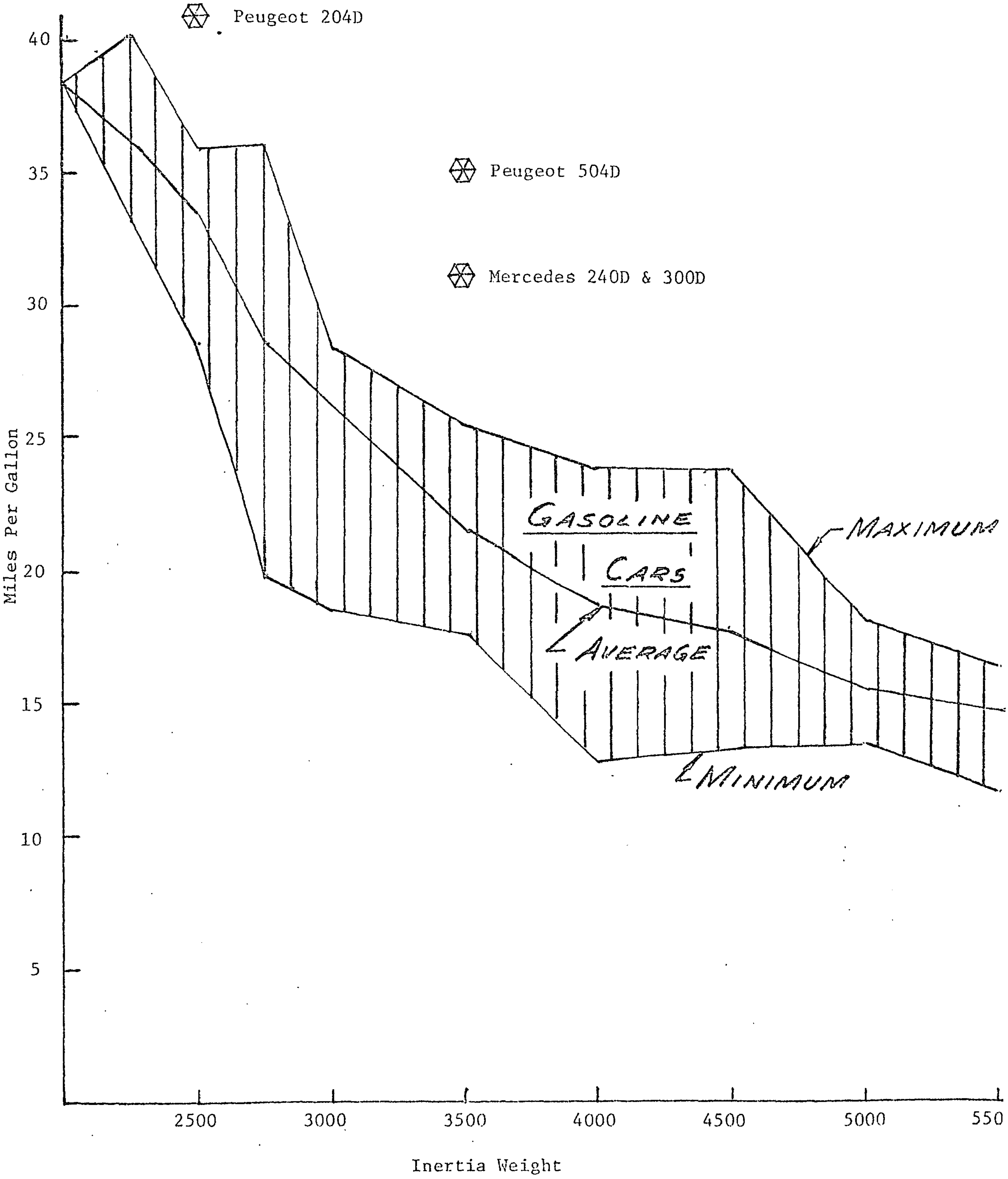

Figure 3a - Diesel vs. 1975 Gasoline Highway MPG

Table 3

Highway Driving Cycle
Emissions and Fuel Economy

Vehicle	Inertia Weight	HC gm/mi	HC gm/Km	CO gm/mi	CO gm/Km	NOx gm/mi	NOx gm/Km	Fuel Economy mpg	(Consumption) litre/100 Km	# Tests
Mercedes Benz										
1971 220D	3500#									
Natural Aspirated		0.68	(0.42)	2.45	(1.52)	1.60	(0.99)	33.8	(6.95)	1
Turbo-Charged		0.79	(0.49)	2.31	(1.44)	1.59	(0.99)	33.3	(7.06)	2
1972 220D Modified - RFDV	3500#			0.74	(0.46)	1.34	(0.83)	32.4	(7.25)	1
1975 240D	3500#							30.3	(7.75)	1
1975 240D - 300	3500#							31.4	(7.5)	1
Peugeot										
1973 504D	3000#			1.63	(1.01)	0.85	(0.53)	36.7	(6.4)	1
1974 504D (modified)	3000#	0.26	(0.16)	0.86	(0.53)	1.28	(0.79)	31.6	(7.44)	4
1975 504D	3500#							34.5	(6.80)	2
1974 204D	2500#	1.07	(0.66)	1.56	(0.97)	0.57	(0.35)	40.9	(5.75)	1
Uncontrolled Gasoline Baseline*	3500#	2.51	(1.56)	26.1	(16.2)	7.45	(4.62)	19.3	(12.2)	8

* EPA Inspection/Maintenance Evaluation Program - 8 Cars operating in the City of Detroit.

Table 4

Oxygenates for 1975 LDV FTP

Emission Category	Mercedes 220D		Opel Rekord 2100D		Peugeot 504D		Datsun-Nissan 220C		Mercedes 220 Gasoline*	
	gm/mi	gm/Km	gm/mi	gm/Km	gm/mi	gm/Km	gm/mi	gm/Km	gm/mi	gm/Km
Aldehydes	0.026	(0.016)	0.035	(0.022)	0.130	(0.082)	0.047	(0.029)	0.075	(0.046)
Formaldehyde	0.016	(0.010)	0.029	(0.018)	0.074	(0.046)	0.034	(0.021)	0.082	(0.052)
Acrolein	0.019	(0.012)	0.032	(0.020)	0.076	(0.047)	0.039	(0.024)	0.060	(0.037)

* SwRI June 1971 Data (Report AR 813)

Table 5

Average 13 Mode Emissions
(Chassis Alternative of HDV-Test

Vehicle	Gaseous Emissions: HC gm/BHP-HR	HC gm/Kw-Hr	CO gm/BHP-HR	CO gm/KW-Hr	NOx gm/BHP-HR	NOx gm/KW-Hr	HC+NOx gm/BHP-HR	HC+NOx gm/Kw-HR	Fuel Consumption lb/BHP-HR	Fuel Consumption gm/Kw-Hr
Mercedes 220D	0.330	(0.443)	3.73	(5.01)	5.04	(6.77)	5.37	(7.21)	0.719	(437)
Opel Record 2100D	0.561	(0.753)	3.81	(5.12)	3.29	(4.42)	3.85	(5.17)	0.665	(404)
Peugeot 504D	4.264	(5.723)	5.34	(7.29)	2.76	(3.71)	7.03	(9.44)	0.663	(403)
Datsun Nissan 220C	0.327	(0.439)	3.72	(4.99)	3.60	(4.83)	3.93	(5.27)	0.565	(343)
Ford PROCO Capri	2.810	(3.769)	56.38	(75.62)	4.27	(5.73)	7.08	(9.50)	0.563	(342)
HDV Emission Standards										
1974 Statutory			40	(54)			16	(21)		
1975 California			30	(40)			10	(13)		
1977 California			25	(33)			5	(7)		

3. Smoke

Several types of smoke tests were performed. The chassis version of the Federal HD smoke test resulted in smoke from the four Diesel cars well below the 1974 limits for truck and bus engines. For the Diesel engine to be considered a viable automobile power plant, the goal should be no visible smoke which is equivalent to no more than 3 to 4 percent opacity by the EPA light extinction meter method of measurement. As shown in Table 6, the acceleration ("a") and the lug-down ("b") factors ranged from 3.3 to 5.4 and from 2.7 to 7.4 percent opacity respectively. The Mercedes and the Peugeot, both now in use and marketed in this country, emitted the lowest smoke of the four by this test. Both were at or below 4% opacity in the acceleration and lug down modes with about 5% peak ("c") factors. Using the chassis version of the HD test as a reference procedure, smoke does not appear to be a problem for the LD Diesel in passenger cars unless gasoline exhaust smoke levels must be duplicated.

Smoke from the four Diesel cars was also recorded continuously on strip charts during the 1975 LD-FTP. The results are summarized in Table 7 and strip chart recordings of four LDV Diesel cars are included as Figure 4 thru Figure 8. Analysis of the strip charts revealed that the same four Diesels responded somewhat differently during this transient test. The Mercedes, which produced low "a" and "b" factors on the HD procedure, emitted smoke on the order of 10 percent during the idle periods of the LA-4 driving schedule. None of the four Diesels could consistently produce exhaust smoke as low as the gasoline fueled vehicles although some showed promise as far as having practically an invisible exhaust. The average overall percent opacity of three of the Diesels ranged from 2.3 to 3.3% as compared against 0.5% for a gasoline fueled car. The Mercedes Diesel exhaust averaged 6% opacity.

4. Noise

Both exterior and interior noise measurements were made on the four Diesel cars according to the SAE J986a acceleration tests and the results are shown in Table8. Some Diesels were higher and some lower than the reference gasoline vehicle. Exterior idle measurements indicate engine compartment noise to be definately higher from the Diesel. The Diesels were also 3 to 5 dBA higher during the 30 mph drive-by runs. The differences are apparently due to the engine although specific survey data for the various noise sources in each car were not performed. These noise measurements do demonstrate however, that the Diesel cars are not necessarily noisy or noisier than the conventional gasoline powered cars.

Table 6

Exhaust Smoke Opacity Values from a Chassis Version of the HDV Test Procedure

Vehicle	Accel "a" factor	Lug "b" factor	Peak "c" factor
Mercedes 220D	3.3%	2.7%	5.1%
Opel Record 2100D	5.4%	7.4%	8.2%
Peugeot 504D	3.7%	4.0%	5.4%
Datsun-Nissan 220C	4.8%	5.7%	6.1%
HDV Smoke Opacity Standards			
1970 Statutory	40%	20%	NR*
1974 Statutory	20%	15%	50%

* Not regulated

Table 7

Smoke Opacity Values from the Smoke Traces
During the LA-4 1975 LDV FTP

	Ford PROCO Capri	Mercedes 220D	Opel Record 2100D	Peugeot 504D	Datsun Nissan 220C
Cold Start (Peak %)	1.3	26.0	75.2	28.3	37.0
Cold Idle (Avg. %)	0.4	5.0	1.8	0.8	1.0
Accel (Peak %)	0.8	19.0	22.0	12.2	6.2
Idle (125 sec. Avg. %)	0.1	10.0	2.7	0.9	0.5
Accel to 56 MPH (Peak %)	2.0	8.0	8.3	14.2	13.0
Hot Start (Peak %)	1.6	22.0	62.0	27.5	1.0
Hot Idle (Avg. %)	0.4	2.0	1.2	1.0	0.5
Accel (Peak %)	0.6	10.0	1.2	2.8	2.7
Idle (Avg. %)	0.3	30.0	7.0	0.8	0.4
Accel to 56 MPH (Peak %)	1.0	8.0	8.2	7.0	7.7
Avg. % (1st 505 sec.)	0.8	7.0	3.0	3.0	4.0
Avg. % (Balance 23 min.)	0.5	6.0	1.8	2.0	2.7
Avg. % (505 sec. Hot Start)	0.4	6.0	2.3	2.0	3.0
Estimated Avg. % Overall	0.5	6.1	2.3	2.3	3.3

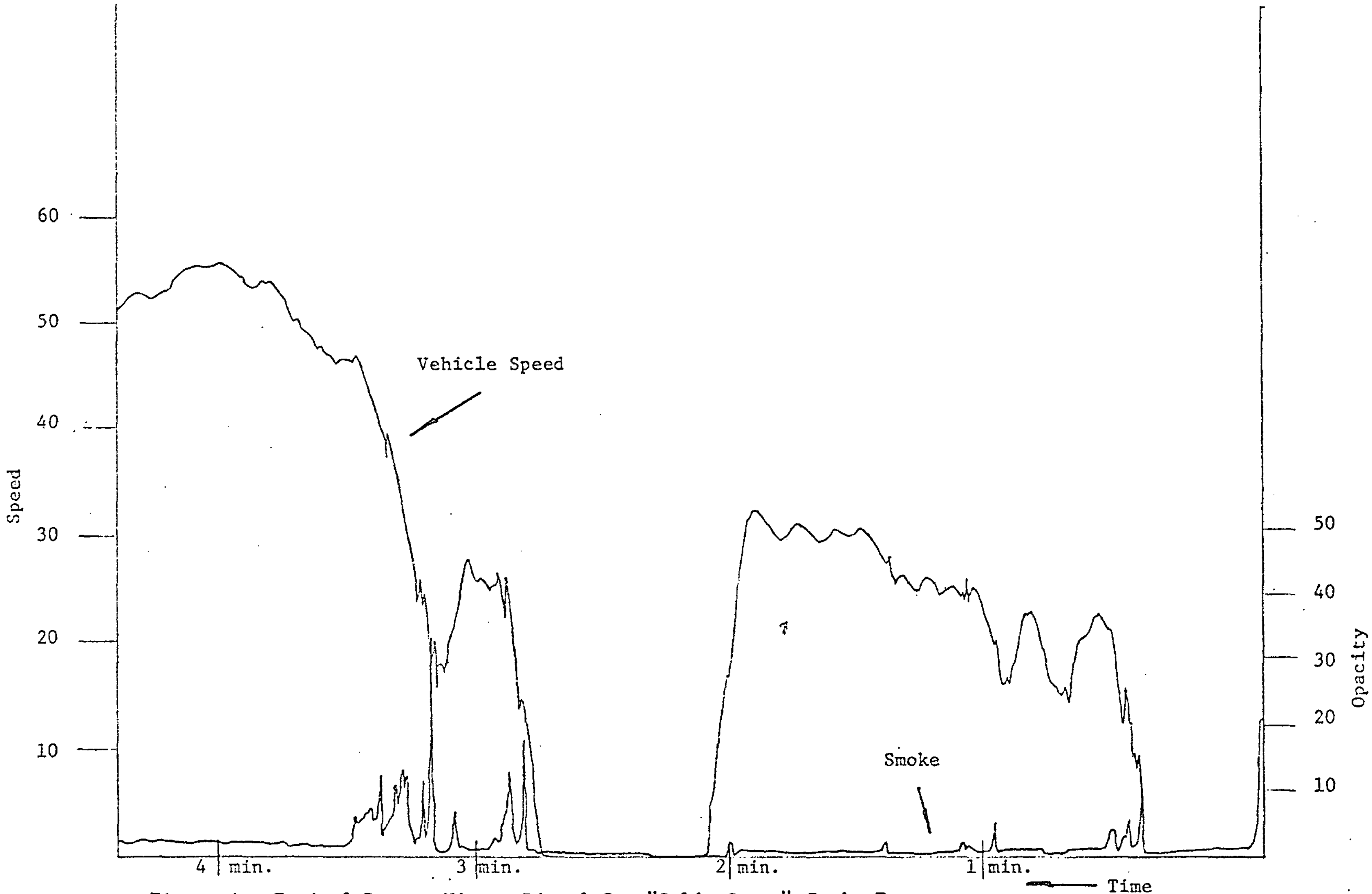

Figure 4 Typical Datsun-Nissan Diesel Car "Cold -Start" Smoke Trace
(First 300 seconds of 1975 FTP)

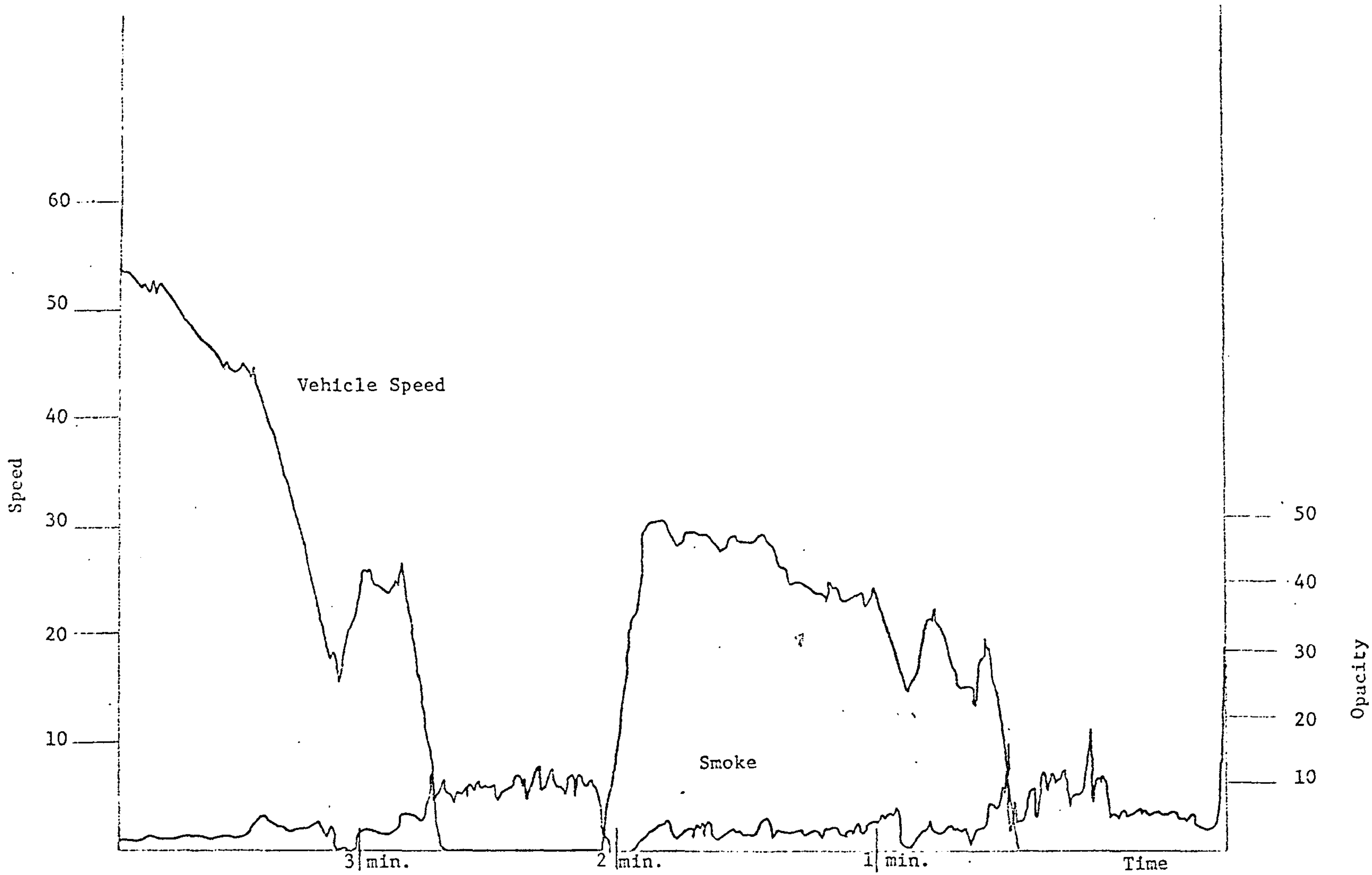

Figure 5 Typical Mercedes 220D Diesel car "Cold-Start" Smoke Trace
(First 300 Seconds of 1975 FTP)

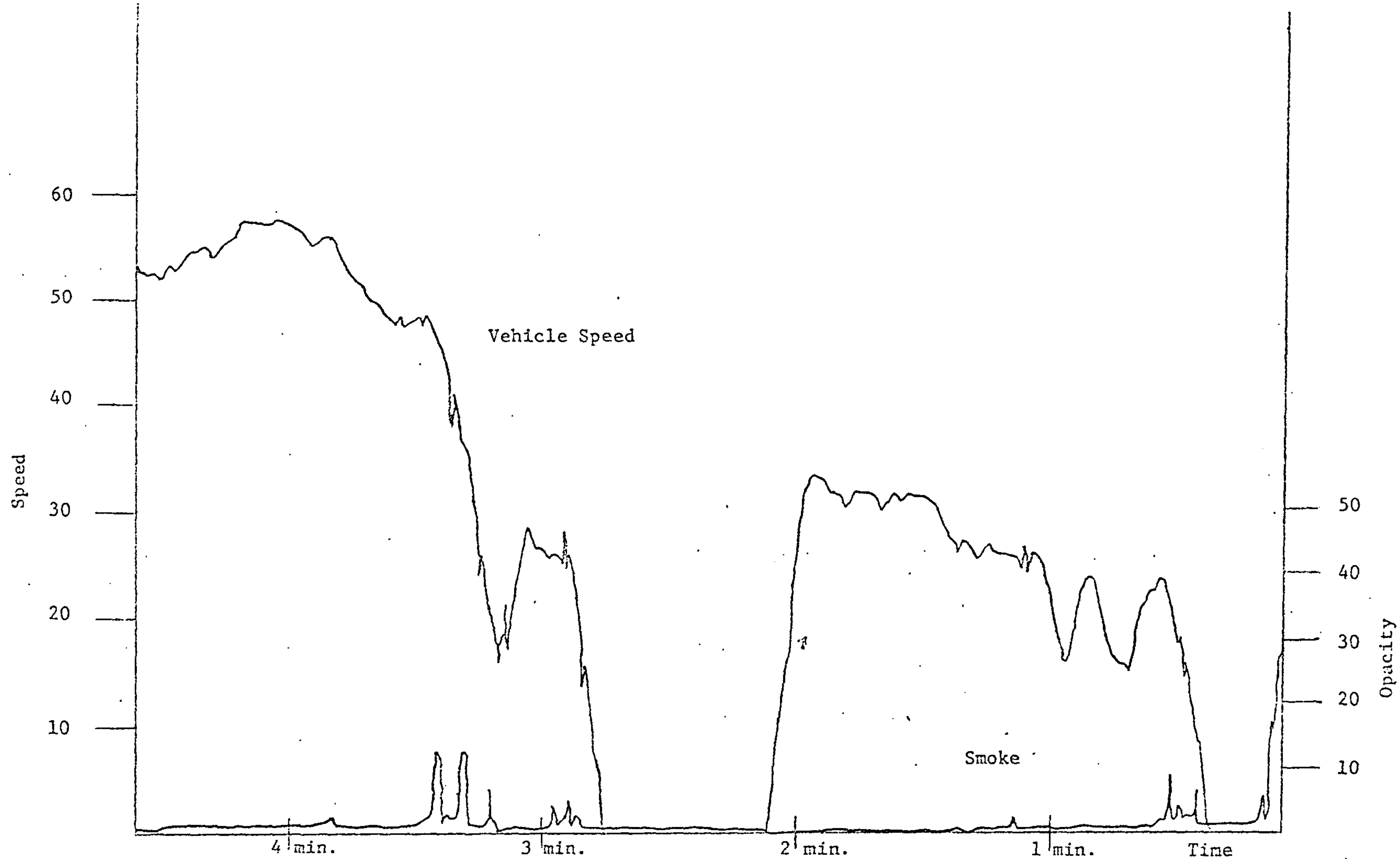

Figure 6 Typical Peugeot 504D Diesel Car "Cold-Start" Smoke Trace
(First 300 Seconds of 1975 FTP)

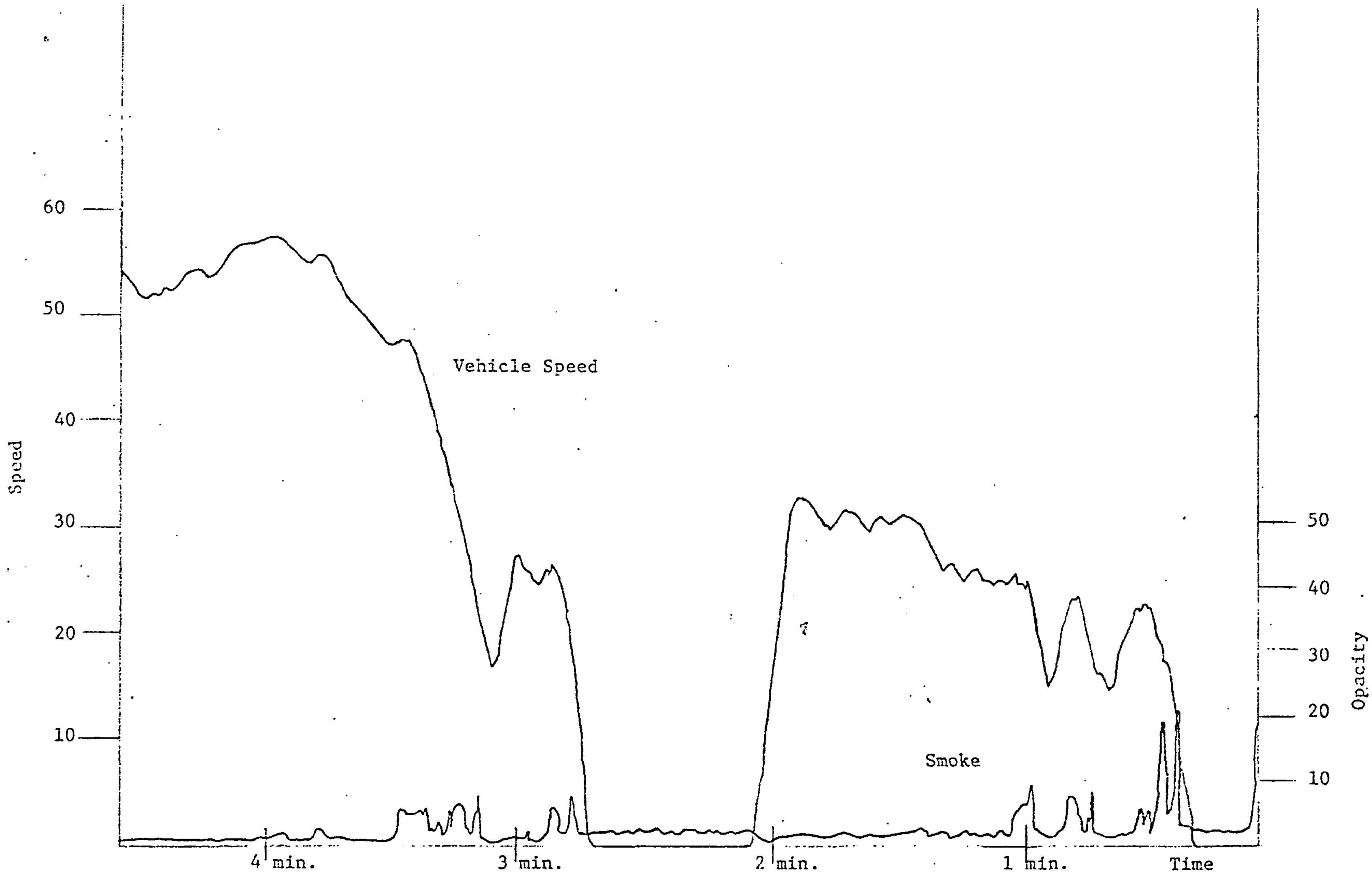

Figure 7 Typical Opel Rekord Diesel Car "Cold-Start" Smoke Trace
(First 300 Seconds of 1975 FTP)

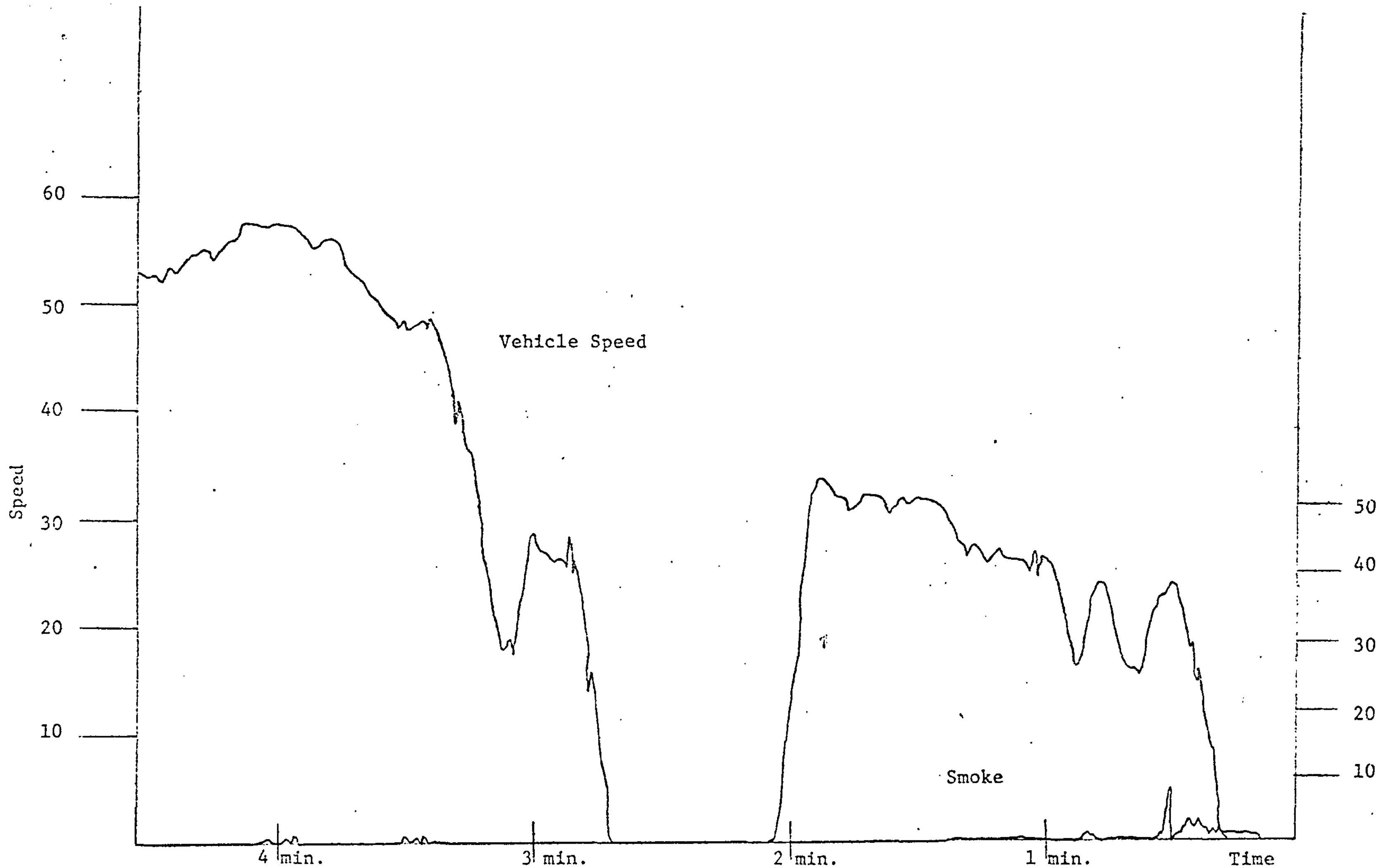

Figure 8 Typical Ford Capri PROCO "Cold-Start" Smoke Trace
(First 300 Seconds of 1975 FTP)

Table 8

Noise (DBA Scale)

		STD Capri	PROCO Capri	Mercedes 220D	Peugeot 504D	Opel 2100D	Nissan 220C
SAE J986A	Exterior	73	76	77	70.8	67.5	74.8
Accel Driveby	Interior	81.5	83	74.3	78.5	73.5	83.3
30 mi./hr.	Exterior	58.1	58.5	62	61.3	62.5	63.3
Driveby	Interior	65.8	70.5	63.5	66.5	69	69.5
Idle	Exterior	63	63.5	66	68	72	79.0
	Interior	54	66	51.5	52.3	53.3	66.8

5. Hydrocarbon Distribution

The HC distribution analysis covered only the mid-distillate, higher boiling range, fuels and is expressed in terms of mole percent. As shown in Table 9, over 60 mole percent of the hydrocarbons in the exhaust were between C_{14} through C_{17} and only 4 mole percent of the HC below C_{12}. HC's in the exhaust are not completely unburned fuel but apparently not sufficiently affected by variations in the Diesel engines to give markedly different HC distributions. This analysis only serves to compare HC distribution in the Diesel exhaust to the gasoline engine exhaust where 100 mole percent of the HC's are below C_{12}.

6. Odor

The four Diesel cars were subjected to a ten mode odor test sequence of which each mode was replicated several times in random order on two different days. The trained odor panel, using the EPA Q/I Diesel odor kit, analyzed the samples at the nominal 100:1 dilution level common to the HD bus horizontal bumper height exhaust. Insufficient information was available to select dilution ratios more appropriate for light duty Diesel or gasoline powered cars. The results are shown in Table 10 for the four Diesels. The Peugeot 504D (uncontrolled for HC emissions) had higher exhaust odor intensity than the other vehicles, about 2 "D"* intensity units above the nominal 3.2 "D" unit of the Mercedes.

The CRC CAPE-7 Diesel Odor Analysis System (DOAS) was also employed as instrumental technique for prediction of Diesel odor intensity. It was found that for the four Diesels the "D" equivalent value was approximately equivalent to 3.2 (TIA)-2, where TIA is the Total Intensity of Aroma and is the principle outcome of the odor instrument. The DOAS, does require long sampling time making it unsuitable for determining transient mode and ambient odor conditions. More development work needs to be done to improve the flexibility of the instrument for these purposes. The instrument has the promise however, of extending the use of the human panel and thereby of allowing increased research in Diesel odor. No health concerns have been established for Diesel exhaust odor, but aesthetic considerations continue to show cause for concern. Until these are qualified or otherwise resolved, the question of Diesel odor will continue to influence any decision by the industry to consider the Diesel for passenger car applications. Continuing research in this category should be encouraged.

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* The "D" unit of odor intensity is the Diesel odor quality and may be considered a composite of the four component qualities: "B" Burnt, "O" Oily, "P" Pungent and "A" Aromatic.

Table 9

1975 LDV-FTP-Gas Chromatograph
Hydrocarbon Distribution
(mole%)

HC Distribution	Mercedes 220D	Opel Record 2100D	Peugeot 504D	Datsun-Nissan 220C	Uncontrolled Gasoline
$<C_{12}$	3.6	3.4	3.7	3.8	100.0
$C_{12} - C_{13}$	14.0	14.2	14.1	14.2	--
$C_{14} - C_{15}$	36.8	36.6	37.2	36.5	--
$C_{16} - C_{17}$	27.1	26.3	27.3	26.7	--
$C_{18} - C_{19}$	16.8	16.9	16.6	17.0	--
C_{20} +	1.7	1.6	1.1	1.8	--

7. Particulate Emission Results

As shown on Table 11, total particulates collected during the 1975-LD-FTP from the four Diesel cars averaged between 0.30 and 0.62 gm/mile. This compares against total particulate matter from a typical engine with leaded fuel of 0.25 gm/mile and from a typical 1975 prototype without lead in the fuel of 0.05 gm/mile. The dominant constituent in Diesel exhaust is carbonaceous material which constitutes from 60 to 75% of the particulate mass.

Preliminary analysis of the particulate filter samples (EPA/ORD) from the Datsun-Nissan and the Opel Rekord indicate that sulfur compound emissions were relatively low and did not appear to be sulfate. Preliminary analysis of sulfate samples generated in-house from the Peugeot 504 Diesel car showed sulfates to be on the order of 0.01 g/mi. Sulfate levels from gasoline catalyst equipped cars are in the range of 0.03 to 0.05 g/mi and from a non catalyst car of 0.001-0.003 g/mi. The form of sulfur emission is of considerable interest and it is possible that sulfur-bearing fuel components are emitted with the heavy organics. It is also possible that some of the SO_2 in the exhaust is absorbed on the carbon particles and is consequently retained in the particulate matter. Improved procedures for analysis of particulates is under development at both ORD and ECTD. More work is required, however, to properly qualify the chemical toxicity and resulting health effects from exhaust gas particulate matter. This applies to all types of automotive exhaust.

8. Acceleration Time from 0-60 mph

Table 12 shows acceleration performance for those Diesel cars either as tested by EPA, as provided in manufacturers data or as extracted from technical publications. For the 3500 pound inertia weight class of Diesel cars (all Mercedes Benz) with power to weight ratios of about 35 HP/Ton, acceleration times varied from 23 seconds (1975 model) to 30 seconds (1971 model). This acceleration time is cut down to 19 seconds for this class of cars either by light turbocharging or by increasing the power to weight ratio by around 20 percent as has been done with the 300D. Other Diesel vehicles with slightly higher power to weight ratios of 43 HP/Ton had acceleration times ranging from 21 to 23 seconds. Acceleration times from 0-60 mph on all Diesel cars tested are considerably higher than the nominal 15 second times for the acceleration performance of popular sub-compact gasoline cars which have power to weight ratios in the order of around 60 HP/Ton.

Table 10

Average Odor Panel Ratings (100:1 Dilution) vs DOAS Ratings

	Standard Capri		Ford PROCO Capri		Mercedes 220D		Opel 2100D		Peugeot 504D		Datsun/Nissan 220C	
	"D"	TIA	"D"	TIA	"D"	TIA	"D"	TIA	"D"	TIA	"D"	TIA
Intermediate Speed												
No load	2.7	1.9	0.8	0.8	2.6	1.6	3.5	1.7	6.0	2.2	3.1	1.6
1/2 load	3.0	2.2	0.8	0.7	2.6	1.6	4.2	1.9	4.1	2.1	2.9	1.7
Full load	3.4	2.2	1.0	0.6	3.4	1.7	3.7	1.9	4.7	2.1	3.8	1.8
High Speed												
No load	2.2	2.0	0.8	0.8	2.6	1.6	3.3	1.8	6.0	2.1	2.3	1.5
1/2 load	3.5	2.2	1.1	0.6	3.1	1.6	4.5	2.0	4.7	2.1	3.4	1.7
Full load	3.3	2.1	1.3	1.2	3.9	1.9	4.0	2.1	5.6	2.5	4.4	1.8
Idle Speed												
No load	3.3	1.9	0.7	0.6	3.1	1.6	3.3	1.7	4.8	1.9	2.8	1.5
Idle/Accel												
0-20 MPH	1.0	N/A	1.0	N/A	4.0	N/A	5.0	N/A	5.6	N/A	3.7	N/A
Accel												
20-50 MPH	3.1	N/A	3.1	N/A	3.4	N/A	3.8	N/A	6.0	N/A	5.3	N/A
Decel												
50-25 MPH	0.8	N/A	0.8	N/A	3.7	N/A	3.4	N/A	5.5	N/A	5.0	N/A
Arithmetic Average												
Six Steady States	3.0	2.1	1.0	0.8	3.0	1.7	3.9	1.9	5.2	2.2	3.2	1.7
Idle	3.3	1.9	0.7	0.6	3.1	1.6	3.3	1.7	4.8	1.9	2.8	1.5
Three Transients	2.9	--	1.6	--	3.7	--	4.1	--	5.7	--	4.6	--
All ten conditions	3.0	--	1.1	--	3.2	--	3.9	--	5.3	--	3.6	--

Table 11

Particulate Emission Test Results

	1975 FTP gm/mi	1975 FTP (gm/Km)	1972 FTP (Hot Start) gm/mi	1972 FTP (Hot Start) (gm/km)	60 MPH Steady State gm/mi	60 MPH Steady State (gm/km)	Dominant * Constituent
Mercedes 220D	0.62	(0.38)	0.57	(0.35)	0.25	(0.16)	75%C
Opel Record 2100D	0.33	(0.20)	0.253	(0.14)	0.20	(0.12)	72%C
Peugeot 504D	0.54	(0.33)	0.40	(0.25)	0.16	(0.10)	58%C
Datsun-Nissan 220C	0.30	(0.19)	0.30	(0.19)	---	--	73%C
Ford PROCO Capri w/thermal reactor and catalyst	0.10	(0.06)	0.06	(0.04)	0.06	(0.04)	18%C
Typical 1975 Prototype gasoline w/o Pb	0.05	(0.03)	0.02	(0.01)	0.03	(0.02)	51%C
Typical Engine with leaded fuel	.25	(0.15)	--	--	--	--	35%PB

* Particulate analyzed for : Fe, Ni, Cu, Al, Ca, Mg, Mn, Cr, Sn, Ti, Pb, C, H, N

Table 12

Acceleration Performance Test

Vehicle	Inertia Weight Pounds	Power/Weight Ratio H.P./Ton (I.W.)	Acceleration Time (sec.) 0-60 mph
Diesel Cars			
1. Mercedes Benz 220D (1971) SwRI	3500	35	28*
2. Mercedes Benz 220D (1971)	3500	35	29.8
3. Same with Turbo Charger	3500	35	21.9
4. Mercedes Benz 220D (1972)	3500	35	24
5. Same with RFDV	3500	35	24
6. Mercedes Benz 240D (1975)	3500	37	22.6*
7. Mercedes Benz 300D (1975)	3500	44	19
8. Peugeot 504D (1973)	3000	43	23*
9. Peugeot 504D (1974)	3000	43	23*
10. Peugeot 204D (1974)	2500	41	26.5*
11. Opel Rekord 2100D (1973)	3000	43	21**
12. Datsun-Nissan 220C (1973)	3500	37	
13. Ford Nissan CN6-33	4500	41	
Sub-Compact Gasoline Cars			
1. Chevrolet Vega	2500	63	12.4**
2. Dodge Colt	2250	83.5	14.1**
3. Datsun B210	2000	70	16.7**
4. Fiat	2000	66	15.3**
5. Honda Civic	1750	66	14.1**

* Manufacturer's data
** Published test results

Conclusions

1. Using current technology the LDV Diesel powered vehicle can meet the stringent 1977 statutory standards for HC (0.4 gm/mile), CO (3.4 gm/mile) and NOx (2 gm/mile) without add-on type controls such as catalysts, EGR or air injection.

2. Fuel economy or fuel consumption is superior to the gasoline engine by a factor of almost 2:1 in miles per gallon or 50 percent in fuel consumed for a fixed distance of travel. Fuel economy for a 3500 pound sedan is between 24 to 26 miles per gallon for urban driving and between 30 to 37 miles per gallon for highway driving with low power to weight LDV Diesel cars.

3. Oxygenates (Formaldehyde, alphatic aldehydes, acrolein) are proportional to total HC's and should not present any major problems except for some contribution to exhaust odor quality.

4. Exhaust smoke from the LDV Diesel should not be a major problem and exhaust smoke should be below the threshold of visibility for most operating modes. Further development is required to preclude visible smoke on a cold start, at idle and at part load acceleration for some power plants.

5. The LDV Diesel is not necessarily as noisy or noisier than equivalent sub-compact gasoline powered vehicles. Where exterior noise is higher with the Diesel, interior noise was generally lower. If exterior idle noise is an aesthetic problem, anechoic techniques could be used by the car makers. Fuel injection modifications might also be studied to alleviate the problem.

6. Odor may not be an inherent problem since some of the test cars were controlled to odor levels far below that of older Diesel bus engines that have caused public complaint. More work in the odor area is necessary to firmly determine the tailpipe levels that would be publicly acceptable.

7. Particulate emissions are higher than from a non-leaded gasoline fueled engine of equivalent size. The dominant constituent in the Diesel exhaust is carbon and particulate traps may be required if these carbonaceous materials are shown to be a hazard to health. Diesel fuel oils have up to 10 times the sulfur content of gasoline fuel. Preliminary analysis indicates that sulfate levels from the Diesel may also be proportionate to the elemental sulfur in the fuel and produce up to 10 times the sulfate of uncontrolled gasoline cars or about 1/3 to 1/5 that of catalyst cars.

8. Acceleration performance of the current LDV Diesel powered cars is not as good as typical gasoline engine powered cars. The solution to this problem can be approached either by supercharging or by increased engine displacement. The supercharging approach offers the potential of improved performance without adversely affecting fuel economy during normal driving conditions. The Diesel is especially well suited for supercharged operation since high temperatures and pressures do not cause the magnitude of combustion problems as occur in conventional gasoline engines.

Appendix A

Test Vehicle Description

TEST VEHICLE DESCRIPTION

Chassis model year/make - 1971 Mercedes-Benz 220D
Emission control system - None

Engine

type	I4, 4 cycle, Diesel Pre-chamber, OHV
bore x stroke	3.43 in. x 3.64 in. (87.1 mm x 92.5 mm)
displacement	134 CID (2200 cc)
compression ratio	21.0:1
maximum power @ rpm	60 bhp @ 4000 with and without turbocharger
fuel metering	high pressure, in-line pump
fuel requirement	DF2

Drive Train

transmission type	4 speed manual
final drive ratio	3.92:1

Chassis

type	front engine, rear wheel drive, unit body
tire size	175R x 14
curb weight	3040 pounds (1380 Kg)
inertia weight	3500 lbs.
passenger capacity	5
odometer	88,000 miles

Emission Control System

basic type	none
durability accumulated on system	88,000 miles on basic engine, low mileage on turbocharger

TEST VEHICLE DESCRIPTION

Chassis model year/make - 220D - 1972 Mercedes Benz
Emission control system - None

Engine

type . . . . I4, 4 cycle - Diesel Pre-chamber, OHV
bore x stroke . . . . 3.43 in. x 3.64 in. (87.1 mm x 92.5 mm)
displacement . . . . 134 CID/2200 cc
compression ratio 21:1
maximum power @ rpm . . . . 65 bhp (48.5 Kw) @ 4200 RPM
fuel metering . . . . high pressure, in-line type pump
fuel requirement DF2

Drive Train

transmission type . . . . 4 speed automatic
final drive ratio 3.92:1

Chassis

type . . . . 4 door sedan, front engine, rear drive
tire size . . . . 6.95 x 14
curb weight . . . . 2990 pound/(1356 Kg)
inertia weight . . . . 3500 pounds
passenger capacity . . . . 5 passenger

Emission Control System

basic type . . . . none
durability accumulated on system . 8000 mi. (12,850 Km)

TEST VEHICLE DESCRIPTION

Chassis model year/make - 220D - 1972 Mercedes Benz
Emission control system - Reverse Flow Dampening Valves*

Engine

type	I4-4 cycle - Diesel Pre-chamber, OHV
bore x stroke	3.43 in. x 3.64 in. (87.1mm x 92.5mm)
displacement	134 CID/2200cc)
compression ratio	21:1
maximum power @ rpm	65 bhp/(48.5Kw)/@ 4200 RPM
fuel metering	high pressure, in-line type pump
fuel requirement	DF2

Drive Train

transmission type	4 speed automatic
final drive ratio	3.92:1

Chassis

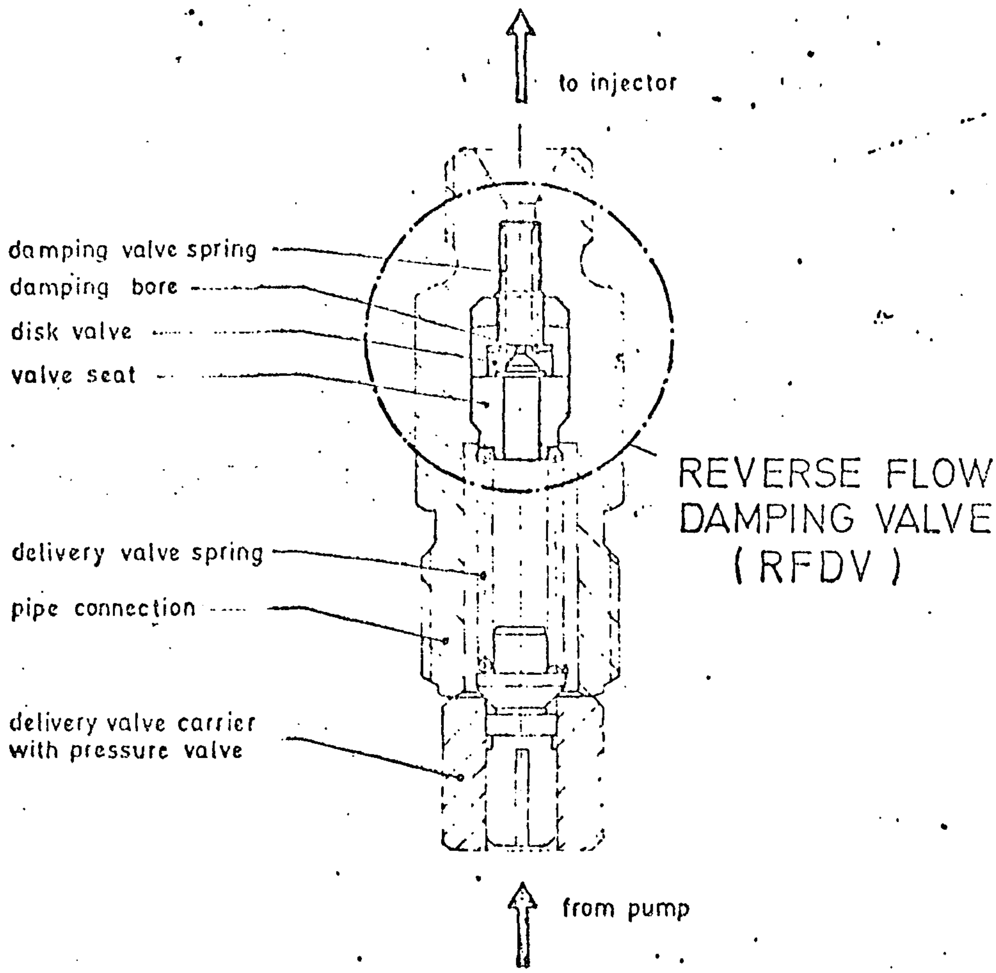
type	4 door sedan, front engine, rear drive
tire size	6.95 x 14
curb weight	2990 lb/(1356 Kg)
inertia weight	3500 lb
passenger capacity	5 passenger

Emission Control System

basic type	Engine Modification
additional features	RFDV (reverse Flow Dampening Valve)*
durability	8561 mi/(13,774 Km)

*See Attached

KP 1123



DAIMLER-BENZ A.G. Versuch
Stuttgart-Untertürkheim

2:1

REVERSE FLOW DAMPING VALVE (RFDV)

FIG. 2

2/..

FIG. 1

Brief description of Reverse Flow Damping Valve (RFDV)

1. Design

The RFD-Valves are embodied into the connectors of the injection pump as an integral part. Each connector has its own RFDV. The total number of the valves hence corresponds to the number of cylinders of the engine. From the outside the connectors with RFDV can be differentiated from those without RFDV by their slightly larger height (an additional 8.5 mm in case of the M-type pump, and 7 mm in case of the MW-type pump).

The RFDV consists of a spring loaded disk valve with a damping bore of o.6 mm diameter in the center of the valve not influencing main fuel flow towards the nozzles. The unit is permanently fixed and cannot be removed from the pipe connectors.

2. Function and effect

The RFD-Valves permit the desired fuel flow in the direction of the nozzle. The damping bore serves to damp any pressure waves in the opposite direction, i.e. from nozzles towards the pump, such as those generated after the termination of the main injection by the pumping effect of the injection needles in the nozzles. This prevents any reflection of the pressure waves at the pump, their return-travel towards the nozzles, and thus avoids any erratic injection occurring after the main injection. Such erratic injections would induce a large increase of hydrocarbon emissions in the exhaust.

3. Inspection and maintenance

Looking through the pipe connector in the direction of flow, a connector without RFDV shows a fairly large inner diameter, whereas one with RFDV only has the small damping bore visible as a minute source of light.

For purposes of inspection one should look through the pipe connector in order to verify that the small bore is open and unobstructed. Prior to this inspection fuel has to be blown out of the connector. If the damping bore is not clearly visible, then a new connector has to be installed. The faulty connector should be scrapped. Under no circumstances should any repair measures be conducted with a faulty RFDV. Similarly, there should be no tampering with an RFDV.

Attachment
Section of pipe connector with RFDV, type KP 1123

TEST VEHICLE DESCRIPTION

Chassis model year/make - 240D - 1974 Mercedes Benz
Emission control system - Engine Modification (RFDV)

Engine

type	I4, 4-cycle, Diesel Pre-chamber, OHV
bore x stroke	3.58 in. x 3.64 in. (91.0 mm x 92.5 mm)
displacement	146.5 CID (2400 cc)
compression ratio	21:1
maximum power @ rpm	62 bhp @ 4000 RPM
fuel metering	high pressure, in-line pump
fuel requirement	DF2

Drive Train

transmission type	4 speed automatic
final drive ratio	3.69:1

Chassis

type	4 door sedan, front engine, rear drive
tire size	175 SR 14
curb weight	3300 pound (1500 Kg)
inertia weight	3500 pound
passenger capacity	5

Emission Control System

basic type	Engine Modification
additional features	RFDV (Reverse Flow Dampening Valve)
durability accumulated on system .	4000 mile (6440 Km)

TEST VEHICLE DESCRIPTION

Chassis model year/make - 300D Mercedes Benz
Emission control system - Engine Modification (RFDV)

Engine

type	I5, 4 cycle, Diesel Pre-chamber, OHV
bore x stroke	3.58 in. x 3.64 in. (91.0 mm x 92.5 mm)
displacement	183 CID (3000 cc)
compression ratio	21:1
maximum power @ rpm	77 @ 4000 RPM
fuel metering	high pressure, in-line pump
fuel requirement	DF2

Drive Train

transmission type	4 speed automatic
final drive ratio	3.46:1

Chassis

type	4 door sedan, front engine, rear drive
tire size	175 SR 14
curb weight	3380 pound (1535 Kg)
inertia weight	3500 pound
passenger capacity	5

Emission Control System

basic type	Engine Modification
additional features	RFDV (Reverse Flow Dampening Valve), all speed mechanical governor
durability accumulated on system .	4000 miles (6440 Km)

TEST VEHICLE DESCRIPTION

Chassis model year/make - 1973 Peugeot 504D
Emission control system - None

Engine

type	I4-4 cycle Diesel - Swirl Chamber - OHV
bore x stroke	3.53 in x 3.27 in/(89.7 mm x 83.1 mm)
displacement	129 CID (2111 cc)
compression ratio	22:1
maximum power @ rpm	65 bhp/48.5 Kw @ 4500 RPM
fuel metering	high pressure, in-line type pump
fuel requirement	DF2

Drive Train

transmission type	manual - 4 speed
final drive ratio	3.89:1

Chassis

type	4 door sedan, front engine, rear drive
tire size	175 SR 14
curb weight	2791 lb (1266 Kg)
inertia weight	3000 pounds
passenger capacity	5 passenger

Emission Control System

basic type	none

TEST VEHICLE DESCRIPTION

Chassis model year/make - 1974 Peugeot 504D
Emission control system - Engine Modification

Engine

type . . . . I4-4 cycle Diesel-Swirl Chamber- OHV
bore x stroke . . . . 3.53 in x 3.27 in/(89.7mm x 83.1mm)
displacement . . . . I29 CID (2111cc)
compression ratio 22:1
maximum power @ rpm . . . . 65 bhp/(48.5 Kw) @ 4500 RPM
fuel metering . . . . high pressure, distributor type pump
fuel requirement DF2

Drive Train

transmission type . . . . manual - 4 speed
final drive ratio 3.89:1

Chassis

type . . . . 4 door sedan, front engine, rear drive
tire size . . . . 175 SR 14
curb weight . . . . 2791 lb (1266 Kg)
inertia weight . . . . 3000 lb
passenger capacity . . . . 5 passenger

Emission Control System

basic type . . . . Engine modification
additional features . . . . Deferred Injection (see attached)
durability accumulated on system. . . 4841 mi/(7790 Km)

OPERATING PRINCIPLE OF THE DEFERRED INJECTION DEVICE

BASIC PRINCIPLE

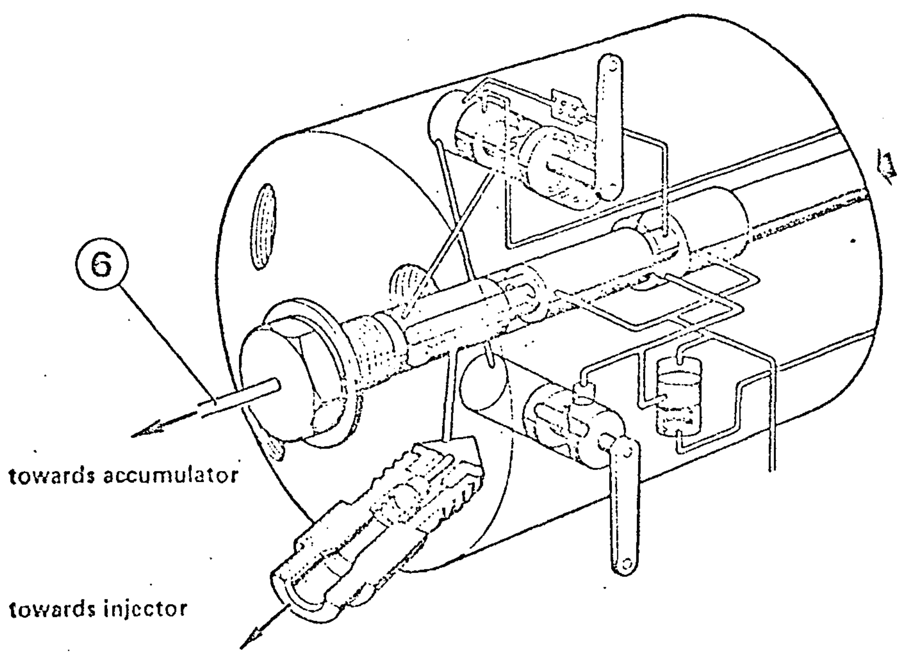
In order to reduce the amount of noise when idling, the injection rate has been modified for this stage in such a way that the same amount of fuel is injected but over a longer period of time.

Therefore, the ignition delay being constant, when the fuel ignites during injection, the amount already in the cylinder is less and the combustion is therefore progressive.

Because the injection period lengthens as the volume of the fuel delivered by the pump increases, to obtain a prolonged injection period, maximum pump delivery must be obtained.

The deferred injection system is therefore designed to increase the injection period, to provoke the maximum pump output at idling speed and, at each injection, to take off the excess fuel, through the accumulator.

INSTALLATION



An additional duct (6) is inserted in the hydraulic head in such a way that at each phase of injection one of the injector ducts and the outlet to the accumulator are aligned.

Fuel is therefore delivered at the same time to :

- the injector
- the accumulator.

TEST VEHICLE DESCRIPTION

Chassis model year/make - 1974 Peugeot 204D
Emission control system - None

Engine

type . . . . I4, 4 cycle, Diesel, Swirl Chamber, OHV
bore x stroke . . . . 3.12 in x 2.84 in (78mm x 71mm)
displacement . . . . 82.8 CID (1357cc)
compression ratio 23.3:1
maximum power @ rpm . . . . 51 bhp @ 5000 RPM (SAE) (38Kw @ 5000 RPM)
fuel metering . . . . high pressure, distribution pump
fuel requirement DF2

Drive Train

transmission type . . . . 4 speed manual
final drive ratio 4.06

Chassis

type . . . . front engine, front wheel drive
tire size . . . . 145 R x 14
curb weight . . . . 2116 lbs. (960 Kg)
inertia weight . . . . 2500 lbs.
passenger capacity 5

Emission Control System

basic type . . . . None
3100 miles (5000 Km)

TEST VEHICLE DESCRIPTION

Chassis model year/make - 1973 Datsun Nissan 220C
Emission control system - None

Engine

type	I4-4 cycle, Diesel Swirl Chamber
bore x stroke	3.47 in x 3.90 in/(88.1 mm x 99.1 mm)
displacement	133 CID/(2170 cc)
compression ratio	22:1
maximum power @ rpm	70 bhp/(52.2 Kw) @ 4000 RPM
fuel metering	high pressure, in-line type pump
fuel requirement	DF2

Drive Train

transmission type	Manual
final drive ratio	3.91 (Approximate)

Chassis

type	4 door sedan
tire size	175 SR 14
curb weight	3000 lbs./(1415 Kg)
inertia weight	3500 lbs.
passenger capacity	5 passenger

Emission Control System

basic type	None
durability	5440 mi./(8754 Km)

TEST VEHICLE DESCRIPTION

Chassis model year/make - 2100D - Opel Record
Emission control system - None

Engine

type	I4-4 cycle - Diesel-Swirl Chamber
bore x stroke	3.47 in. x 3.34 in./(88.2 mm x 84.8 mm)
displacement	126 in.^{3}/2070 cc
compression ratio	22:1
maximum power @ rpm	68 bhp (50.7 Kw) @ 4300 RPM
fuel metering	high pressure (Distributor Pump)
fuel requirement	DF 2

Drive Train

transmission type	3 speed automatic
final drive ratio	3.89:1

Chassis

type	4 door sedan, front engine, rear drive
tire size	645-14
curb weight	2735 lb/(1243 Kg)
inertia weight	3000 lb
passenger capacity	5 passenger

Emission Control System

basic type	None
durability accumulated on system	8094 mi./(13,023 Km)

TEST VEHICLE DESCRIPTION

Chassis model year/make - 1973 Ford F250 Pick-up Truck
Emission control system - Diesel Replacement

Engine

type . . . . CN6-33, I6, 4 cycle, Diesel Swirl Chamber
bore x stroke . . . . 3.27 in x 3.94 in (83 mm x 100 mm)
displacement . . . . 198 CID (3250 cc)
compression ratio 22:1
maximum power @ rpm . . . . 92 bhp @ 4000 RPM (68.5 Kw @ 4000 RPM)
fuel metering . . . . high pressure, in-line pump
fuel requirement DF2

Drive Train

transmission type . . . . 4 speed manual
final drive ratio . . . . N/A

Chassis

type . . . . F250 Pick-up Truck
tire size . . . . N/A
curb weight . . . . N/A
inertia weight . . . . 4500 lbs.
passenger capacity . . . . 3 passenger cab

Emission Control System

basic type . . . . none
durability accumulated on system . about 10,000 mi., (16,090 Km)

TEST VEHICLE DESCRIPTION

Chassis model year/make - Std 1973 Capri - Ford
Emission control system - Engine Modification

Engine

type	I4-4 cycle - otto cycle
bore x stroke	3.6 in x 3.0 in/(91mm x 76mm)
displacement	122 CID/(2000cc)
compression ratio	8.2:1
maximum power @ rpm	85 bhp/64.2 Kw) @ 5400 RPM
fuel metering	2 bbl Holley carburetor
fuel requirement	91 RON unleaded

Drive Train

transmission type	4 speed manual
final drive ratio	3.44:1

Chassis

type	2 door sedan, front engine, rear drive
tire size	165 SR 13
curb weight	2500 lb./1130 kg
inertia weight	2750 lb
passenger capacity	4

Emission Control System

basic type	E.M.
durability accumulated on system .	1385 mi/(2234 Km)

TEST VEHICLE DESCRIPTION

Chassis model year/make - Std 1973 Capri - Ford
Emission control system - Programmed S/C Combustion (PROCO)

Engine

type	I4-4 cycle - Stratified Charge
bore x stroke	3 7/8 in x 3.0 in/(98mm x 76mm)
displacement	141 CID/(2300cc)
compression ratio	11:1
maximum power @ rpm	72 bhp/(52.2 Kw) @ 4000 RPM
fuel metering	Direct fuel injection
fuel requirement	91 RON unleaded

Drive Train

transmission type	4 speed manual
final drive ratio	3.44:1

Chassis

type	2 door sedan, front engine, rear drive
tire size	165 SR 13
curb weight	2100 lb/(966 Kg)
inertia weight	2500 lb.
passenger capacity	4

Emission Control System

basic type	charge stratification
oxidation catalyst location . . .	about 6 in. down from exhaust manifold outlet
substrate	monolith-American Lava w/Mathey Bishop coating
volume	118 in^3
thermal reactor type	low thermal inertia exhaust manifold w/exhaust port liners
rate	8% (1 gm NOx standard)
additional features	Altitude compensated A/F ratio control plus Ford transistorized ignition
durability accumulated on system .	650 mi/(1047 Km)