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A Study of Emissions from Light-Duty Vehicles in Denver

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ABSTRACT

A sample of 300 light-duty vehicles normally operated in the Denver metropolitan area was tested for emissions and fuel economy. The vehicles were from the 1978 through 1982 model years and included both passenger cars and light-duty trucks. One purpose of the program was to gather information for calculations and projections of ambient air quality. Another purpose was to assemble data on current model year vehicles for use in support of Inspection/Maintenance and other regulatory programs.

The test sequence on all of the vehicles included the Federal Test Procedure, the Highway Fuel Economy test, and a series of short tests consisting of the Bagged Idle Test, the 50 mph Cruise Test, the Four Speed Idle Test, and the Loaded Two Mode Test. Some vehicles which exceeded Federal Emission standards were subjected to restorative maintenance and retested. Evaporative emission tests using the Sealed Housing for Evaporative Determination (SHED) procedure were performed on 125 of the 1980-1982 model year vehicles.

Other actions were taken in relation to each vehicle tested. These included an engine and emission control system maladjustment/disablement and status inspection, driveability evaluations, and owner interviews to obtain vehicle maintenance and usage data.

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1. INTRODUCTION

The U. S. Environmental Protection Agency (EPA), under authority of the Clean Air Act, develops, implements and administers a program to assess, quantify and reduce pollution of the nation's resources. Authority for parts of this program is delegated to the agency's Emission Control Technology Division (ECTD). The ECTD's responsibility is to assess, quantify and reduce air pollution from in-use motor vehicles. Such responsibility includes designing, implementing and administering the Emission Factors Program.

The Emission Factors (EF) program consists of a series of annual studies designed to obtain data from in-use vehicles operated under a variety of topographical and climatological conditions. Data obtained from these studies are used in calculating current and projecting future light-duty vehicle emission factors.

EF studies began in the EPA's Fiscal Year (FY) 1971. Subsequent studies were conducted in Fiscal Years 1972, 1973, 1974, 1975, 1977 and 1979. Extensions to the FY 75 and FY 77 programs precluded separate EF studies in each fiscal year following those in which these studies were initiated and by which they are identified. Vehicles have been tested annually with exceptions as indicated in either six or seven of the following U. S. cities: Chicago, Houston, Denver, Los Angeles, Detroit, Phoenix, St. Louis and Washington, D.C.

In the EF program's initial stages, vehicles of interest covered a relatively large number of the most current model years. As more and more information was obtained from these studies, however, the model year span was reduced with each successive program year.

Program test procedures have also been changed as testing technology changed and new emission control technologies were introduced. The Sealed Housing for Evaporative Determination (SHED) came into use for determining fuel evaporative emission factors as concern over this pollution source emerged. For determining modal emission factors,

procedures of the EPA's Surveillance Driving Sequence and Steady State tests also came into use.

The scope of EF study programs has also been expanded over the years. A recent inclusion is the collection of mass and direct tailpipe emission data by abbreviated test procedures. Abbreviated emission tests have come under consideration in recent years for use in state and local vehicle emission inspection and maintenance programs. Also included are investigations of the individual and combined effects of emission control system malfunction, disablement and maladjustment on vehicle emissions and fuel economy.

The FY 80 Emission Factors study, is the subject of this report. To execute a portion of this study, the EPA contracted with Automotive Testing Laboratories, Inc. (ATL) to provide data from vehicles operating in the metropolitan area of Denver, Colorado.

2. TECHNICAL DISCUSSION

2.1 PROGRAM OBJECTIVE

The program's objective was that of obtaining emission test, fuel economy test, vehicle emission control system maintenance and other data from light-duty vehicles operating in the Denver metropolitan area. These data are used in calculating and projecting light-duty vehicle emission factors and in satisfying other of the EPA's data needs.

2.2 PROGRAM DESIGN

Three hundred (300) vehicles from the 1978-1982 model years were tested in the program.

Lists which prescribed the composition of each sample were provided by the EPA. Substitutions were allowed within certain limits. Procedures by which the test vehicles were obtained were in keeping with an EPA-approved procurement strategy. Although some of the vehicles were from car fleets, most were privately owned. Incentives were offered to promote owner participation.

All vehicles were subjected to the 1975 Federal Test Procedure (FTP) which deals with cold and hot start exhaust emissions testing. All vehicles were also subjected to the Highway Fuel Economy (HFET) and to a series of short tests comprised of the Bagged Idle, 50 Cruise, Four Speed Idle and the Loaded Two-Mode tests. One hundred twenty-five vehicles received an evaporative emissions (SHED) test. Some vehicles which exceeded Federal Exhaust Emissions standards applicable to their model year, were given restorative maintenance followed by another test sequence.

Other actions were taken in relation to each vehicle tested. These included: an engine parameters and emission control system maladjustment/disablement inspection, a tire inspection, a vehicle driveability evaluation and an interview of the vehicle owner to obtain historical information on the vehicle's maintenance and use.

Other study-related activities pertained to test equipment calibration and data review, reduction and reporting. Details concerning these and the activities described above are presented in the remainder of this section.

2.3 TEST VEHICLE PROCUREMENT

2.3.1 Sample Criteria

Criteria for the procurement and selection of test vehicles were provided by the EPA. Criteria for the basic emission factors sample were given on a list describing 300 vehicles from the 1978-1982 model years. Vehicles required were specified by model year, vehicle make, vehicle type (passenger car or light-duty truck), model, and in some cases engine size (number of cylinders). The test vehicles were selected by the EPA based on national sales volumes within each model year. Quantities required by model year were weighted for the most part toward the later model years. Vehicles from the later model years are equipped with the latest in emission control technology and are also those on which the least amount of in-use data are available.

The EPA also stipulated that each model year sample be comprised of 20% high mileage vehicles; high mileage was defined as greater than 4,000, 15,000, 30,000 and 30,000 miles for the 1981, 1980, 1979, and 1978 model years respectively.

Other criteria for the emission factors sample consisted of limitations on procurement sources. The use of fleet and rental vehicles was limited to no more than twenty percent for the 1981-1982 model years. Test vehicles from the 1978-1980 model years were to be acquired exclusively through the use of registration lists.

2.3.2 Procurement Plan

The plan for acquiring test vehicles consisted primarily of the use of vehicle registration lists and direct mail solicilations.

Registration lists for counties containing Denver and the surrounding area were obtained from the State of Colorado. A computerized search of the entire registration list was then conducted which resulted in an individual candidate list for each vehicle. The individual list contains all candidate vehicles in the specified area. To insure that a random test fleet was procured each of the individual lists was randomized using standard computer techniques. The resulting list consisted of candidate vehicles assigned numbers one through n where n was the total number of candidates on the individual list. The first ten of these were then used in the mailings to vehicle owners, with number one being the most desired, number two next most desired, etc. The selected owners were mailed a letter, a program explanation, and a post-paid reply card. The reply was provided to enable the owner to supply information otherwise not available and to indicate willingness to participate. The letter and explanation served to solicit participation and described the program's purpose and nature.

Selection was based on the random number generated for the vehicle in question. The lowest number on the returned reply cards was contacted first. If for some reason the vehicle was no longer available the next lowest numbered vehicle owner was then contacted. If a vehicle could not be acquired from returned reply cards, non-respondents were then contacted and asked to participate.

The mail solicatations produced all of the test vehicles except those that had been available for only a short time and were therefore not yet included in the registration files. These test vehicles were obtained from car lots, rental car agencies, and referrals from other participants.

2.3.3 Incentives

An incentive package prescribed by the EPA was offered and provided for each vehicle tested. The package consisted of:

A $100 U. S. Savings Bond

A late-model loan vehicle to serve as a substitute for the test vehicle

Fuel for the loan vehicle

A full tank of fuel for the test vehicle upon return to its owner

2.3.4 Test Vehicle General Handling

Vehicle owners were contacted from telephone numbers given on the reply cards. Vehicle information was confirmed and any missing information was obtained during this contact. Test schedules were also established at this time. Privately owned vehicles were delivered to the laboratory. Laboratory personnel picked up and returned vehicles which were procured from rental car agencies and car lots.

The prospective test vehicle was examined upon arrival at the laboratory to confirm compliance with the sample specification and to assure suitability for testing. Relatively few vehicles were rejected at this or some subsequent point due to exhaust system leakage, transmission problems, brake problems or related factors. Acceptance activities included an incoming vehicle status inspection which was used to limit laboratory liability. Test and loan vehicle exchange agreements were completed upon acceptance of the test vehicle and an EPA-furnished questionnaire was administered to the owner. The questionnaire is designed to gain useage, maintenance and other information concerning the vehicle. The vehicle was subsequently moved to a staging area where remaining pre-test operations were completed.

The vehicle was returned to the staging area for depreparation procedures and refueling after testing was completed. It was then moved to a parking area where it remained until picked up by the owner.

2.4 FACILITIES AND EQUIPMENT

2.4.1 Test Location and Facility

One permanent laboratory facility was used in the study. The location and elevation above sea level is as follows:

Denver	19900 East Colfax Avenue Aurora, Colorado 5,480 ft

The laboratory in Denver is a permanent facility containing about 30,000 square feet of office and laboratory area. The facility is situated east of Denver, two miles (3.2 km) from the city limits. Testing under the contract was performed in an area containing about 15,000 square feet. Ambient air temperature was maintained through the use of gas operated heaters and evaporative coolers.

2.4.2 Chassis Dynamometers

The chassis dynamometer used in the study was Clayton Model ECE-50. The ECE-50 has two continuous rolls, 78 inches in length and 8 5/8 inches in diameter. Axial spacing of the rolls is 17 1/4 inches. The tach-generator was installed on the rear roll. A counter which measured distance traveled by the test vehicle was also installed on the rear roll. Actual distance measurements were taken which were used by the data contractor in calculating test results. Accuracy of the counter was such that it recorded distance traveled in increments under 0.001 of a mile.

The dynamometer was equipped with a digital speed meter which is linear with speed and accurate to within $\pm$ 2.0 km/hr ($\pm$ 1.2 mph) over the 0 to 95 km/hr (0-59 mph) range. It was also equipped with a digital power meter which is accurate to $\pm$ 0.25 hp ($\pm$ 0.187 kw).

The dynamometer was also equipped with direct drive inertia assemblies which provide 125 pound inertia increments from 1000 to 5500 pounds.

The dynamometer was lubricated and maintained in accordance with Clayton's requirements.

2.4.3 Constant Volume Sampler

The constant volume sampler (CVS) used was the AESI Model 1000. The Model 1000 is a positive displacement pump (PDP) type equipped with a gas to water heat exchanger and six sample bags. All plumbing in the sampling and calibration systems was of stainless steel or teflon construction. Leak tight convoluted stainless steel tubing was used to connect the CVS and the vehicle tailpipe. Several lengths were provided to keep the exhaust run as short as practical. Accuflex brand silicone rubber adapters were used to connect the tubing to the tailpipe.

Samplers were modified from the conventional design to facilitate automated sampling system evacuation/leak check.

2.4.4 Analytical Instruments

Listed below are instrument models, and ranges, which were part of the analytical system used for FTP, HFET and Bagged Idle dilute sample analyses:

2 each Beckman Model 400 FID's providing full scale C ranges of:
0-50 ppm, 0-100 ppm, 0-300 ppm, 0-1,000 ppm, 0-3,000 ppm and 0-10,000 ppm

1 each TECO Model 10 CL NO_x analyzer with full scale ranges of:
0-100 ppm, 0-250 ppm, 0-1,000 ppm and 0-2,500 ppm

2 each Horiba Model OPE-115 NDIR CO analyzer providing full scale ranges of:
0-100 ppm, 0-500 ppm, 0-1,000 ppm, 0-.3%, 0-1%, 0-3% and 0-5%

1 each Beckman Model 864B NDIR CO_2 analyzer with full scale ranges of:
0-2.5%, 0-4% and 0-8%

Undiluted emission analysis (50 mph Cruise, Four Speed Idle, Loaded Two Mode tests) was performed using the following analyzers and ranges:

Chrysler Model III C NDIR CO analyzer with full scale ranges of:
0-300 ppm C_6 and 0-2,000 ppm C_6
0-0.5% CO and 0-10% CO

TECO Model 10A CL NO_x analyzer with full scale ranges of:
0-100 ppm, 0-250 ppm, 0-1,000 ppm and 0-2,500 ppm

Beckman Model 864 NDIR CO_2 analyzer with full scale ranges of:
0-8% and 0-16%

The diluted and undiluted exhaust analyzers and the evaporative emission analyzers were respectively situated within rack-type console cabinets. Sampling, analytical and

calibration system plumbing was of stainless steel or teflon construction.

2.4.5 Data Acquisition

The following equipment was used for the acquisition of test data:

Wet and dry bulb temperatures of air supplied to the vehicle under test and temperature of the CVS exhaust gas/dilution air mixing point were recorded on a Soltec Model DB, three channel, ink stylus, strip chart recorder, with a chart width of approximately eleven inches.

Barometric pressure was recorded on a Taylor Model 6450 recording barometer.

Soak area temperature was recorded on a Rustrak Model 2133, single channel, pressure stylus, strip chart recorder, with a chart width of approximately two inches and a range from 10°C to 37.5°C (50°F to 100°F).

The driver's aid was an Esterline Angus two channel, off-set heat stylus, strip chart recorder, with a chart width of approximately eleven inches. The leading pen records the dynamometer speed command signal; the lagging pen records the feedback signal.

Exhaust emission analyzers were connected to Texas Instruments (TI) Model Servoriter II, two channel, ink stylus, strip chart recorders, with a chart width of approximately eleven inches and 100 division full scale chart paper. Diluted CO and CO_2 were connected to one of these recorders. Diluted HC and NO_x were connected to a second. Undiluted CO and CO_2 were connected to a third.

Undiluted HC and NO_x were recorded on a Soltec Model DB4 ink stylus, strip chart recorder, with a chart of approximately 11 inches.

CVS pump revolutions were displayed on an electronic digital meter.

A Data General Model Nova II computer was used to generate driving schedule traces and as a cross-check to ensure accuracy of the analyzer ranges. The computer also provides print-outs of distance traveled by the test vehicle and integrates analyzer and test cell temperature traces.

2.4.6 Sealed Housing for Evaporative Determination

The evaporative emission test conducted in Denver was performed using the Sealed Housing for Evaporative Determination (SHED) technique. The SHED is primarily of aluminum construction. Five expansion panels or windows, each of two feet by three feet dimensions, are situated in the back and in one of the side walls of the enclosure. The door of the enclosure is also designed to act as an expansion panel. The panels are of Tedlar construction. The SHED has nominal dimensions of twenty-one feet deep by twelve feet wide by ten feet high.

Two air-to-water heat exchangers regulated the ambient air temperature inside the enclosure between 20°C and 30°C (68°F and 86°F) during testing. Each of the heaters was equipped with a radiator and a propeller-type fan. The radiator and fan were contained by a small aluminum enclosure with the fan located behind the radiator. In this configuration each unit supplied about 450 cubic feet of air per minute. The units were located in opposite corners of the SHED with the air flow directed along the enclosure's side. SHED radiator pairs were cooled with a closed system water supply. The temperature of the water was maintained at 21.1°C $\pm$ 1.1°C (70° $\pm$ 2° F).

Two type J (iron-constantan) thermocouples were installed on opposite walls of the SHED to measure enclosure temperature. Each was located along the front-to-rear midline of the wall, three feet from the floor. The thermocouples were electrically joined to average temperatures of the enclosure at the two points.

A two kw (maximum) heating blanket was used to heat vehicle tank fuel during the diurnal (or heat build) segment of the test. A manually adjustable rheostat controlled power to the blanket which, in turn, controlled the heat-build rate of the fuel. To monitor the heat-build rate, a type J thermocouple was used. The thermocouple joint was soldered to a cleaned area of the vehicle tank at the approximate mid-point between tank bottom and the forty percent fuel fill line.

A Beckman Model 400 FID HC analyzer monitored hydrocarbon concentrations within the enclosure during the test. Operational ranges of this analyzer were 0-50 ppm, 0-100 ppm, 0-300 ppm and 0-1,000 ppm C.

2.4.7 Laboratory Standard Calibration Gases

A set of secondary calibration gas standards was used to calibrate the analytical instruments. All secondary calibration standards were identified from a set of primary standards which, in turn, were identified by the EPA's laboratory in Ann Arbor.

Primary and secondary calibration gases were bi-blends (CO, CO_2 and NO_x plus zero-grade N_2 as the diluent, HC as propane plus zero-grade air as the diluent).

FID fuel gases were a mixture of 40% H_2 and 60% N_2. Fuel for the SHED FID was a mixture of 40% H_2 and 60% He. Zero gas impurities were maintained below 1 ppm C, 1 ppm CO, 400 ppm CO_2 and 0.1 ppm NO. NO_x calibration gases contained less than 2% NO_2.

2.4.8 Miscellaneous Equipment

As-received vehicle tank fuel was analyzed for lead content. The analysis was performed using a Science Essentials fuel lead test kit (Mobil Method 1125-74).

A Hartzell Model N24DW propeller-type fan, nominally air flow rated at 5300 cubic feet per minute, was used in connection with dynamometer testing to supply vehicle frontal and underhood cooling air.

Wheel chocks and a ratcheting-type winch were used to secure vehicles on the dynamometer and prevent them from rocking on the rolls. A rubber belt dressing was applied to drive tires immediately before cold start testing began to reduce slippage between the drive tires and dynamometer rolls; however, belt dressing was not applied to the tires of vehicles subject to the SHED procedure.

The usual complement of ignition scopes, timing lights, tachometers, hand tools and other engine diagnostic and tune-up equipment was used to perform the emission-related inspections, adjustments and repairs. Special diagnostic and repair equipment was provided and used as needed.

2.5 EQUIPMENT CALIBRATION AND VERIFICATION

Program test equipment calibration and verification requirements were met through application of the following procedures.

2.5.1 Chassis Dynamometer

Dynamometer calibration was performed initially and confirmed each two weeks thereafter.

Initial calibration included setting the speed meter to true zero with the dynamometer at rest followed by establishment of the upscale span point (46.3 mph). A fixed

rate strobe-light was used to establish the upscale span point. The power meter was zeroed with no weight applied to the torque area. A known weight was subsequently applied and the power meter was adjusted accordingly. Dead weight calibration was followed by dynamic calibration using the coast down technique to establish the relationship between indicated and actual horsepower.

Bi-weekly calibration confirmations included the speed point checks and the coast-downs. Coastdown calibrations were maintained within $\pm$ 0.746 kw ($\pm$ 1 hp) for all inertia weights.

Calibration of the driver's aid was checked in relation to the speed meter indication before and after each test. Pre-test driver's aid speed checks were maintained within $\pm$ 1 mph of the indication on the dynamometer speed meter.

2.5.2 Constant Volume Sampler

The constant volume sampler was subjected to an initial checkout and flow calibration. A Meriam Model 50-MC2-6F laminar flow element (LFE), which has an air flow rating of 1,000 cfm, was used as the flow standard. LFE calibration is traceable to the National Bureau of Standards. A minimum of ten points, five on each side of the normal set point, were measured on the CVS pump's single range. Auxiliary devices employed for the calibration included: a mercury barometer for measuring absolute ambient pressure, a close tolerance mercury thermometer for measuring blower inlet temperature, a U-tube water manometer for measuring pressure drop across the blower and blower inlet pressure and a close tolerance inclined water manometer for measuring pressure drop across the LFE. Calibration was such that no data point deviated more than 0.5% from the least squares best-fit line through the points measured and that no data point deviated more than 0.25% from the least squares best-fit line through all points.

CVS calibration was confirmed daily thereafter by propane injection and recovery. The injected amount was such as to produce a concentration falling in the upper one-

third of the 0-300 ppm FID range. Recovery within ± 2% of the injected amount was acceptable. A recovery outside the acceptable range required corrective action and two successive recoveries within range before testing was resumed.

2.5.3 Analytical Instruments

Emission analyzers were set-up in accordance with procedures specified by the manufacturers and subjected to initial calibration. FID, NO_x, CO and CO_2 analyzers were calibrated at seven points spread somewhat evenly across each range. Initial calibration curves were maintained that the actual calibration point was within ± 5% of the curve value and the difference between the actual point and the curve was within ± 1 % of the full scale value. Complete calibrations were conducted on a monthly basis.

Calibration curves for the analyzers were subjected to a complete check on a weekly basis. Each curve point was maintained within ± 1 division (100 divisions, full scale) of the point established in the original calibration.

Analyzers were zeroed with zero gas and spanned on the range in-use at 80 percent to 100 percent of full scale.

Efficiency of the NO_x analyzer converter was checked daily and maintained between ninety and 100 percent.

CVS sample bags were purged with nitrogen, evacuated and leak-checked prior to each test. Other procedural precautions included zero and span point sets immediately before exhaust sample analysis and zero and span point verification immediately following sample analysis. Verified zero and span points were maintained within ± 1 division of the set points. Noise levels of recorded analyzer outputs were maintained within ± 0.5 divisions.

Analyzers used for undiluted tailpipe emission measurements were zeroed with zero gas and spanned with known span gases immediately before each test. These analyzers were otherwise operated in accordance with the manufacturer's specifications.

2.5.4 Sealed Housing for Evaporative Determination

SHED calibrations were performed initially and each thirty days thereafter.

After purging with fresh air the enclosure was sealed, a background hydrocarbon reading was obtained and approximately four grams of instrument-grade propane were injected into the enclosure. Heat exchanger fans were in operation during the injection and subsequent period. After five minutes of mixing, the enclosure's hydrocarbon level was measured and the amount of propane recovered was calculated. Recovery within $\pm$ 2 percent of the injected amount indicated an acceptable calibration.

A retention test was performed following each calibration. The enclosure remained sealed over an additional period of four hours with the heat exchanger fans in continuous operation. The amount of hydrocarbon remaining in the enclosure at the end of this period was again measured and converted to propane by calculation. A four hour retention within $\pm$ 4 percent of original recovery indicated the retention quality of the enclosure to be acceptable.

The enclosure was initially checked for hydrocarbon background emissions. After purging with fresh air the enclosure was sealed, an initial hydrocarbon measurement was taken and a final hydrocarbon measurement was taken four hours later. A four hour increase of 0.4 grams of hydrocarbon or less indicated the enclosure's emission characteristic to be acceptable.

2.6 TEST PROCEDURES

Tests were performed in the following sequence:

Diurnal segment of the SHED tests (if applicable)

Federal Test Procedure

Hot loss segment of the SHED test (if applicable)

Bagged Idle Test

50 Cruise test

Highway Fuel Economy Test

Four Speed Idle Test

Two Mode Loaded Test

A flow chart of the testing flow is shown on page 2-14.

2.6.1 Vehicle Preparation

Subsequent to acceptance the vehicles were drained of as-received fuel and refilled to forty percent of tank capacity. A sample of fuel drained from each vehicle was retained for lead analysis. Those vehicles requiring unleaded fuel were supplied with Indolene Clear. All others were supplied with Indolene 30.

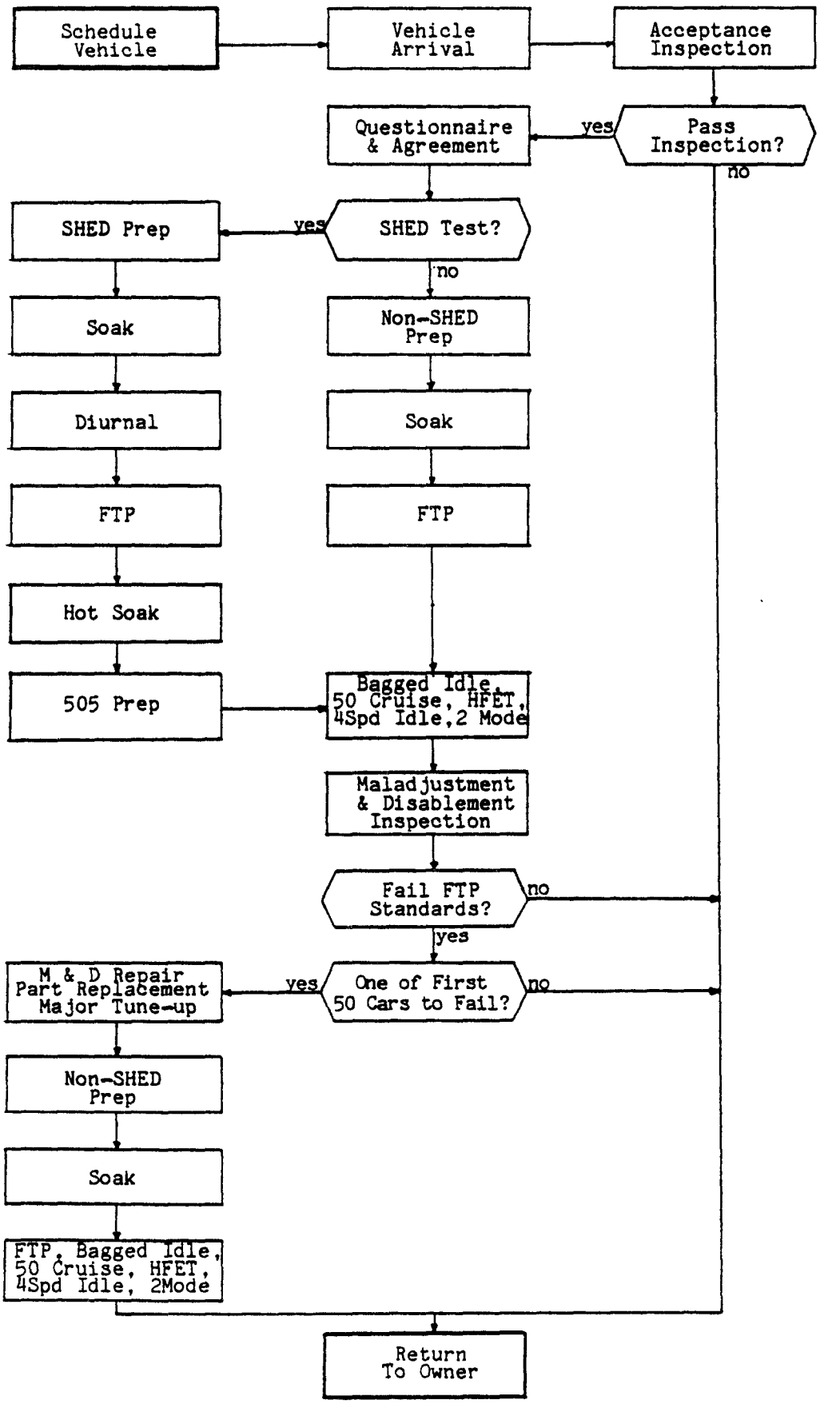
Subsequent to draining but prior to refueling, those vehicles which were scheduled to receive SHED tests were subjected to a pressure check. The fuel system was first sealed and a stabilized pressure of fourteen inches H_2O was applied to the system. Fuel system pressure was observed and recorded five minutes after stabilization was achieved. A loss of 2" H_2O or more would indicate a leaky evaporative system. The thermocouple used in the heat build segment of the test was attached to the tank following the pressure check.

All vehicles were operated for a period of ten minutes on a predetermined road route subsequent to refueling. The purpose of this operation was to purge non-test fuel from the fuel system, to bring the vehicle to normal operating temperature and to assess vehicle operating characteristics. Any moderate to severe operating difficulties were noted for later reference in the cold start tests.

After the test preparation procedures were completed, the vehicle was driven to an indoor, temperature controlled area and shut down to begin the temperature stabilization (soak) period prescribed by the Federal Test Procedure.

2.6.2 Equipment Preparation

Equipment which had been idle or in a stand-by condition was fully activated to begin warm-up. Such equipment included the water heater and mass pump of the CVS


Schedule Vehicle
Vehicle Arrival
Acceptance Inspection
Pass Inspection?
yes
no
Questionnaire & Agreement
SHED Test?
yes
no
SHED Prep
Soak
Diurnal
FTP
Hot Soak
505 Prep
Non-SHED Prep
Soak
FTP
Bagged Idle, 50 Cruise, HFET, 4Spd Idle, 2 Mode
Maladjustment & Disablement Inspection
Fail FTP Standards?
no
yes
One of First 50 Cars to Fail?
yes
no
M & D Repair Part Replacement Major Tune-up
Non-SHED Prep
Soak
FTP, Bagged Idle, 50 Cruise, HFET, 4Spd Idle, 2Mode
Return To Owner

and each of the analytical instruments. If not subjected to extended operation in the two hour period preceding a test the dynamometer was warmed-up for fifteen minutes at thirty mph with a non test vehicle.

With all equipment at normal operating temperature, sensitivity of the constant volume sampler's automatic leak detection system was checked and adjusted as necessary. A leak-check of the undiluted tailpipe analytical system was also performed. Efficiency of the NO_x analyzer thermal converter was checked, strip-chart recorders and other elements of the data acquisition system were aligned with analyzer outputs and the propane recovery test was performed. Calibration of the dynamometer speed meter and driver's aid recorder was also checked for accuracy and adjusted as needed.

Other minor laboratory maintenance and pre-test requirements were attended to during the daily three hour non-test period as needed.

2.6.3 Federal Exhaust Emission Test Procedure

The Federal Exhaust Emission Test was performed in accordance with those parts of 42 Federal Register 124 and as amended in Volume 43, No. 220 which deal with cold and hot start tests.

This test, commonly referred to as the Federal Test Procedure (FTP) is a test which utilizes a constant volume sampler (CVS) and which produces mass emission test results. It is preceded by a minimum vehicle soak period of twelve hours and a maximum of thirty six hours during which the vehicle remaines unstarted and with all accessories off in ambient temperatures between 20° C and 30° C (68° F and 86° F).

At the end of the soak period the vehicle was placed on the dynamometer in preparation for the cold start portion of the test. A cooling fan which directs air to the vehicle only during exhaust sampling periods was situated with its center at the middle of the vehicle grille and twelve inches away. The engine compartment hood was fully opened and the CVS exhaust collector tube was attached to the vehicle tailpipe.

The FTP consists of three sampled portions. Background air and CVS diluted exhaust samples are collected for each portion. The cold transient portion is nominally 505 seconds long and covers a distance of 5.78 km (3.59 miles) with an average speed of 41.19 km/hr (25.6 mph). The cold stabilized portion is nominally 869 seconds in duration covering 6.21 km (3.86 miles) with an average speed of 25.74 km/hr (16.0 mph). The hot transient portion is a hot start repetition of the cold transient portion.

Cold transient CVS sampling commenced with the engagement of the engine starter. The cold transient portion of the FTP driving schedule begins after the engine starts. The time between starter engagement and the point at which the engine begins to run of its own accord is added to the sampling interval. Also, any stall(s) encountered during this or the two subsequent FTP portions is added to the sampling interval of the portion in which it occurs. The driving schedule is stopped when a stall occurrs at other than an idle mode and is restarted from that same place after the engine is restarted. Cold transient sampling is terminated at the 505 second point of the driving schedule.

Cold stabilized sampling begins at the 506 second point of the driving schedule and terminated 5 seconds after the engine stopped running after the ignition was turned off at the 1369 second point, the end of the driving schedule. Any after-run of the engine added to the sampling period of this test portion.

A soak period of ten minutes followed the end of the cold stabilized portion. During this period the engine and cooling fan were off, the engine compartment was closed and the CVS exhaust collection tube was disconnected from the tailpipe. At 10 $\pm$ 1 minutes into the soak period, the engine compartment was re-opened, the collector tube was reconnected and the engine starter was engaged once more to begin the hot transient portion. The fan was turned on upon engagement of the starter and sampling also commenced. Hot transient sampling continued to the 505 second point of the schedule at which time the test was concluded.

2.6.4 Evaporative Emission Test Procedure

Evaporative emission tests were performed in accordance with those parts of 41 Federal Register 164 which deal with evaporative emission testing, the Sealed Housing for Evaporative Determination (SHED) test.

The SHED test consists of two segments: the diurnal (or heat build) segment and the hot loss segment.

The diurnal segment was preceded by a soak period of eleven to thirty-five hours in duration. At the end of this period, test fuel (which was put in the vehicle prior to the 10 minute preconditioning drive) was drained and chilled fuel at a temperature between 10° C and 13.2° C (50°F and 55°F) was added to forty percent of the tank's capacity. The vehicle was subsequently placed in the enclosure with the fuel filler cap off, the luggage compartment and all windows open and with the enclosure ventilation system in operation. The vehicle tank heater (blanket) was attached to the tank and the tank thermocouple was connected to a recorder. Power was applied to the heater and the rising temperature of tank fuel was observed. When tank temperature reached the 15.6° C (60°F) point, the vehicle tank cap was installed, the enclosure ventilation systems were turned off, the enclosure was sealed and the initial hydrocarbon background measurement was taken. Tank fuel was heated so that its temperature rose linearly within ± 1.1° C (± 2° F) from 15.6°C to 29.1°C (60°F to 84°F) within one hour. The enclosure interior hydrocarbon measurements were taken at fifteen minute intervals. At the end of the one hour diurnal soak period a final hydrocarbon reading was taken. The enclosure was opened and purged, and the heater and thermocouple were disconnected. The vehicle was then moved to the dynamometer for the FTP. Maximum permissable time lapse between the end of the diurnal test and the start of the FTP is one hour.

Upon conclusion of the FTP the vehicle was moved into the enclosure for the SHED test's hot loss segment. Just before entering the enclosure, if driven, the engine was shut-down. The enclosure ventilation systems were in operation during the period

immediately preceding vehicle entry. The vehicle's windows and luggage compartments were opened, SHED ventilation systems were turned off, the enclosure was sealed and the initial hot loss hydrocarbon background reading was obtained. The vehicle remained in the enclosure for one hour. (Hydrocarbon measurements were taken each fifteen minutes). At the end of this period the final hydrocarbon reading was taken, the enclosure was opened and ventilated and the vehicle was removed.

Ambient air temperatures in the enclosures were monitored continuously during each of the diurnal and hot loss segments of the test. Two electrically connected thermocouples placed on the front to rear centerlines of the two enclosure sidewalls monitored the ambient air temperature which was maintained between 20°C and 30°C (68°F and 86°F) during both segments of the test.

2.6.5 Bagged Idle Test Procedure

This test followed the FTP and consisted of mass emission measurements of HC, CO, CO_2 and NO_x with the vehicle operated for three minutes at idle with the transmission is drive. Manual transmission vehicles were tested in neutral with the clutch engaged.

If a SHED test had been performed on the vehicle a "505" preconditioning cycle was performed prior to the Bagged Idle Test. In any event the test was preceded by a six minute $\pm$ one minute engine-off soak period. A three minute sample period followed the soak period. Sample collection was initiated at the time of starter engagement such that engine cranking was included as part of the sample.

2.6.6 50 (mph) Cruise Test Procedure

The 50 Cruise Test was conducted during the three minute fifty mph preconditioning period which preceded the Highway Fuel Economy Test. It was preceded by a 6 $\pm$ 1 minute idle period with the cooling fan on and the engine compartment open.

Undiluted HC, CO, CO_2 and NO_x emission measurements were recorded

continuously throughout this test. Equilibrium of vehicle speed, engine speed and analyzer traces were obtained before the reported test readings were bracketed and integrated.

2.6.7 Highway Fuel Economy Test Procedure

The Highway Fuel Economy Test (HFET) was started within the fifteen minute period following conclusion of the Bagged Idle Test.

This test is preceded by a three minute period of operation at 50 mph. Within one minute following the end of this period the vehicle was brought to idle and the HFET driving schedule was begun. CVS sampling began upon commencement of the driving schedule and continued to the end of the 765 second, 16.4 km (10.2 miles) HFET driving schedule. Fuel economy was calculated by means of the Federal Register-contained carbon balance method. Power settings, inertia weights, emission sampling procedures, cooling air temperatures and cooling fan placement and operation were identical to those of the Federal Test Procedure.

2.6.8 Four Speed Idle Test

Employing volumetric sampling, the Four Speed Idle test has four modes with automatic transmissions and three with manual transmissions. It is preceded by the 6 ± 1 minute idle period with the cooling fan on and the engine compartment open. The test sequence is: idle in neutral, idle at 2,500 engine rpm, idle in neutral and in the case of an automatic transmission-equipped vehicle, idle in drive with the brakes applied. The maximum period for each mode was thirty seconds. Speed and HC, CO, CO_2 and NO_x readings were bracketed and integrated.

2.6.9 Loaded Two Mode Test

The Loaded Two Mode Test employs volumetric exhaust emission sampling with the vehicle operating at 30 mph and 9 hp and with the engine idling and the transmission in neutral. Maximum duration of each mode is thirty seconds. Speed and HC, CO, CO_2 and NO_x were bracketed and integrated.

This test is also preceded by the 6 ± 1 minute idle period with the underhood cooling fan on and the engine compartment open. Dynamometer inertia setting for the cruise mode was 1,000 pounds.

2.6.10 Vehicle Inspection Procedure

The procedure used to determine the incoming condition of test vehicles consisted of the measurement of basic engine parameters and visual and functional inspections of emission control systems, subsystems and parts. Parameters measured were idle speed, ignition timing, dwell and idle HC and CO emissions. Whether the idle mixture was rich or lean for the given vehicle was also determined by enriching the mixture with propane. Visual inspections were performed to determine: the presence or absence of an air pump, catalytic converter, idle adjustment limiters, modulators, delay valves, the routing of wires, vacuum lines and any modifications which would affect emission control system operation. The fuel filler neck was inspected for tampering which would enable the use of leaded fuel. Functional checks were performed to determine operational status of the ignition, distributor, induction, fuel, EGR, air injection, PCV, exhaust and evaporative systems. The engine assembly, catalyst and cooling systems were also inspected.

2.6.11 Restorative Maintenance Evaluation

The first fifty vehicles which failed one or more of the Federal HC, CO and NO_x exhaust standards were subjected to a restorative maintenance procedure and then tested again.

The restorative maintenance procedure consisted of repairing all maladjusted or disabled emission control components, replacement of defective emission control parts, and a major tune-up as specified by the appropriate manufacturers maintenance schedule for such tune-up. This procedure was then followed by another complete test sequence, excluding SHED testing.

2.6.12 Daily Test Schedule Procedure

Overall program scheduling was dictated by personnel, equipment and facility availability and the time constraint of the contract. These factors, as well as site workload requirements, dictated the daily testing rates.

Tests were conducted on a two shift per day, five day per week basis. Shifts began at 8:00 AM and 5:00 PM. Daily equipment quality assurance and maintenance activities took place outside of the testing schedule.

Vehicle acceptance activities generally took place between the morning hours of 7:00 - 9:00 and the evening hours of 5:00 - 7:00 as a convenience to participants.

2.7 DATA HANDLING

2.7.1 Data Collection

Many parameters directly associated with the emission tests were recorded on strip charts. Included were: temperature of the soak area, wet and dry bulb temperatures of air supplied to the vehicle under test, temperature of the CVS dilution air/exhaust gas mixing point and the output of each emission analyzer. Barometric pressure was recorded on a seven-day circular chart. Recorders monitoring emission analyzer outputs were allowed to run continuously during calibration and emission analysis. An on-line mini-computer was used to integrate analyzer readings during diluted and undiluted emission analysis and as a cross check to verify analyzer deflections and ranges in use. Other test data were manually collected and recorded.

2.7.2 Data Handling

After an on-site review, raw data in the form of individual test packets were delivered to the data processing department for final review and disposition. Processing of the raw data was performed manually. Manual processing consisted of combining data from the raw data sheets to card format data forms. Once combined, these data forms were assembled into the specified collation and assembled into a packet containing all

forms, instrument charts and other back up information. The assembled packets were then forwarded to the data contractor.

2.7.3 Quality Control

Quality of the test data was assured through reviews and edits which were conducted at several stages in the collection and subsequent handling processes.

The first of two reviews was conducted immediately after test completion. After the completion of each test sequence all data were collected and assembled into a single test packet. Materials in the test packet included: data sheets used to identify the vehicle, vehicle exchange agreements, the completed vehicle-owner questionnaire, raw data sheets associated with each test in the sequence, analyzer strip-chart recordings and on-line computer print-outs, cooling air temperature and humidity recordings for each test in the sequence, tank heat-build and SHED enclosure internal temperature strip-chart recordings and data sheets used to document vehicle preparation procedures and inspection results. Upon assembly, each of these materials was reviewed for completeness and accuracy. This review was started as soon after test sequence completion as practicable in an effort to have it completed before the vehicle started into another testing sequence or was returned to its owner. The practice of early review was employed for two reasons: to keep the necessity for vehicle recall and retest to a minimum and to facilitate immediate feedback to test personnel of errors and omissions as they emerged. Following this part of the quality assurance program the test packets were sent to the data department.

Soak area temperature traces, raw data sheets and strip-chart recordings used to document periodic calibrations and checks of the test equipment and other materials common to tests on a group of vehicles were subjected to a similar review, packaged and also sent to the data department.

Upon arrival in the data department, each packet was reviewed a second time for completeness and accuracy.

Federal Test Procedure and Highway Fuel Economy test results were processed and the results inspected on a reasonability basis. Data was then transferred to the EPA supplied card format forms and coding checked for consistency to the EPA supplied coding formats.

Errors found in the course of on-site reviews were usually associated with inconsistencies between materials in the test packet (eg, information on the vehicle-owner questionnaire conflicted with that of the after-test vehicle inspection) and errors in transposing data from strip charts to raw data sheets (eg, analyzer ranges and deflections). Problems dealt with in subsequent stages of review were most frequently associated with insufficient verbal information backing up numerical emission component failure and vehicle maintenance action codes and inconsistencies in responses within the vehicle-owner questionnaire.

2.7.4 Calculation of Results

Results for the mass emission tests (i.e., those employing the CVS) were calculated by means of the formulae of 42 Federal Register 124. Actual distances traveled by the test vehicle were measured in connection with the tests. These distances were used by the data contractor in the final calculations of the test results. Distance constants of the 42 Federal Register 124 exhaust emission test (FTP) driving schedule and distance constants of other of the mass emission tests were respectively used by ATL in the preliminary data supplied to the data contractor. The equations of 42 Federal Register 124 applied to the following tests:

Federal Exhaust Emission Test (FTP)

Highway Fuel Economy Test

The carbon balance equations of 42 Federal Register 176 which take mass HC, CO and CO_2 emissions into account were used to calculate fuel economy data for the above

tests. The distance constants associated with each test were respectively used for fuel economy calculations, as well.

Results of the Evaporative Emission Tests were calculated using the equations of 41 Federal Register 164.

Volumetric test results were reported as measured. Volumetric results applied to the following tests:

50 Cruise test

Four Speed Idle Test

Loaded Two Mode Test

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