EPA-460/3-76-015
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# MEASUREMENT OF SULFATE AND SULFUR DIOXIDE IN AUTOMOTIVE EXHAUST

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Mobile Source Air Pollution Control
Emission Control Technology Division
Ann Arbor, Michigan 48105

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# MEASUREMENT OF SULFATE AND SULFUR DIOXIDE IN AUTOMOTIVE EXHAUST

by

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Contract No. 68-03-2118

EPA Project Officer: Richard Lawrence

Prepared for

ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Mobile Source Air Pollution Control
Emission Control Technology Division
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ABSTRACT

This report describes the testing of four different groups of cars for sulfates and sulfur dioxide. The collection and analytical techniques used to obtain the sulfate and sulfur dioxide emission rates are described. Sulfate and sulfur dioxide emissions rates in grams per kilometre are presented for a variety of test cycles including the light duty Federal Test Procedure (FTP), the Highway Fuel Economy Test (HFET), and the Sulfate Emissions Test number 7 (SET-7). In addition to sulfates and sulfur dioxide, the usual gaseous emissions of hydrocarbons (HC), carbon monoxide (CO) and oxides of nitrogen ($NO_x$) were measured and reported in grams per kilometre. Total particulate weight on the sulfate filter was determined for tests on two of the groups of cars. In addition, for these same two groups of cars, the sampling tunnel residue from each test car was examined by X-ray fluorescent techniques for content of various elements.

The first of the four groups of cars was tested to characterize sulfate emissions from eight automobiles. Four of these were gasoline powered catalyst cars, three were gasoline powered noncatalyst cars, and one was diesel powered. The second group, consisting of four catalyst cars, were operated for 80,500 km (50,000 miles) to determine the effect of distance accumulation on sulfate emissions. The third group, two 1975 production catalyst cars, was tested in support of the EPA effort to develop a sulfate test procedure. The last group, consisting of eight cars, was part of the EPA sulfate baseline. Of these eight cars, six were production 1975 models (including one diesel), and two were experimental cars with three-way catalysts.

FORWARD

This project was conducted for the U.S. Environmental Protection Agency by the Department of Emissions Research of Southwest Research Institute. The laboratory testing phase of the project began in July 1974 and was completed in May 1976. This project was conducted under EPA Contract No. 68-03-2118 and was identified within Southwest Research Institute as Project 11-4015. The baseline testing reported in Section VII of this report was conducted under Task Order Contract No. 68-03-2196, Task 2, and reported here as specified in that contract.

The EPA Project Officer for this project was Mr. Richard D. Lawrence of the Characterization and Control Branch, Emission Control Technology Division, Office of Mobile Source Pollution Control, EPA, Ann Arbor, Michigan. Mr. Karl J. Springer, Director, Department of Emissions Research at SwRI served as Project Manager. The project was under the supervision of Mr. Melvin N. Ingalls, Senior Research Engineer, as Project Leader. Mr. Harry E. Dietzmann, Senior Research Chemist, supervised the development and application of the chemical analysis. Although a number of SwRI personnel assisted in the laboratory testing, key individuals included J. T. Jack, lead technician, A. J. Winfield, technician, and D. J. Bynum, laboratory assistant. Among others, key personnel involved with the chemical analysis were J. H. Herrington, lead technician, D. L. Milligan, technician and W. M. Saegert, laboratory assistant.

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SUMMARY

Four groups of cars were tested for exhaust sulfate emissions in separate phases of this study. Each group was tested for a different purpose. However, the results from one group supplemented the results from another group to give a more complete understanding of exhaust sulfate emissions. Therefore, the developments, findings and conclusions from this study will be presented by topic rather than by test phase.

1. Sulfate and Sulfur Dioxide Emission Measurement

This project proved the capabilities of a sulfate sampling tunnel 21 cm (8.4 inches) in diameter and approximately 3 meters (10 feet) in total length. This tunnel, while smaller than the 46 cm (18 inch) diameter EPA dilution tunnel, has the advantages of being compact and more compatible with existing 8.5 $m^3$/min (300 CFM) constant volume sampling (CVS) systems and automotive emissions test facilities. Because of the successful use of the tunnel on this project, it has become the primary candidate for use by EPA and by industry.

A TECO pulsed fluorescence (PF) $SO_2$ analyzer was originally scheduled for use on the project to monitor dilute $SO_2$ continuously. However, when the PF unit was placed in service measuring $SO_2$ on dilute automobile exhaust, it greatly overstated the amount of $SO_2$ in the exhaust due to some unknown interference. The effects of the interference were found to be a function both of exhaust $SO_2$ level and fuel composition and sulfur level.

To replace the PF analyzer, a wet chemistry method for $SO_2$ was developed utilizing a sample collection procedure similar to EPA stationary source Method 6. The amount of $SO_2$ collected was determined using the same Barium Chloranilate (BCA) procedure that was used to determine the amount of $H_2SO_4$ collected on the sulfate filters.

At the start of the project, some researchers felt that the stationary source Method 8 procedure might be acceptable for use in measuring automotive exhaust sulfates and $SO_2$. In actual tests, the Method 8 procedure yielded lower $SO_2$ values, higher sulfuric acid values and recovered less of the total sulfur than the BCA procedure. It is felt that Method 8 is inferior to the BCA procedure for measuring automotive exhaust sulfates because it gives erroneously high sulfate values.

2. Test Cycle Development

The work done on cycle development during this project was part of the overall EPA effort to develop a standardized sulfate test procedure. As such, SwRI was one of four laboratories performing test cycle development studies. The results contained in this report were based on tests on two 1975 Federal AMC Hornet Sportabouts.

By the time the laboratory work had begun, the SET-7 driving cycle had been chosen by EPA as the candidate driving cycle. Twenty

repetitive SET-7 tests were run on each of the two Hornets to ascertain the test-to-test variability. The coefficient of variation of the sulfate emissions was 26.6 percent on one car and 30.7 on the other car.

In an effort to reduce test-to-test variability, the SET-9 driving cycle was developed by EPA and tested at SwRI, using 12 repetitive tests These results were then compared with 12 repetitive SET-7 tests by the same driver. The average sulfate emissions from the SET-9 tests were approximately 16 percent higher than the sulfates from the SET-7 tests. The coefficient of variation for the two types of tests were not sifnificantly different, being 3.99 for the SET-7 tests and 5.40 for the SET-9 tests. From these test series it appeared that the SET-9 did not offer any real improvement in test-to-test repeatability over the SET-7. Tests were also run to determine the effects of preconditioning and driver-to-driver differences. The SET-7 has since been slightly modified (SET-7D). This is the cycle which is known as the Congested Freeway Driving Schedule (CFDS).

3. Sulfate Emissions

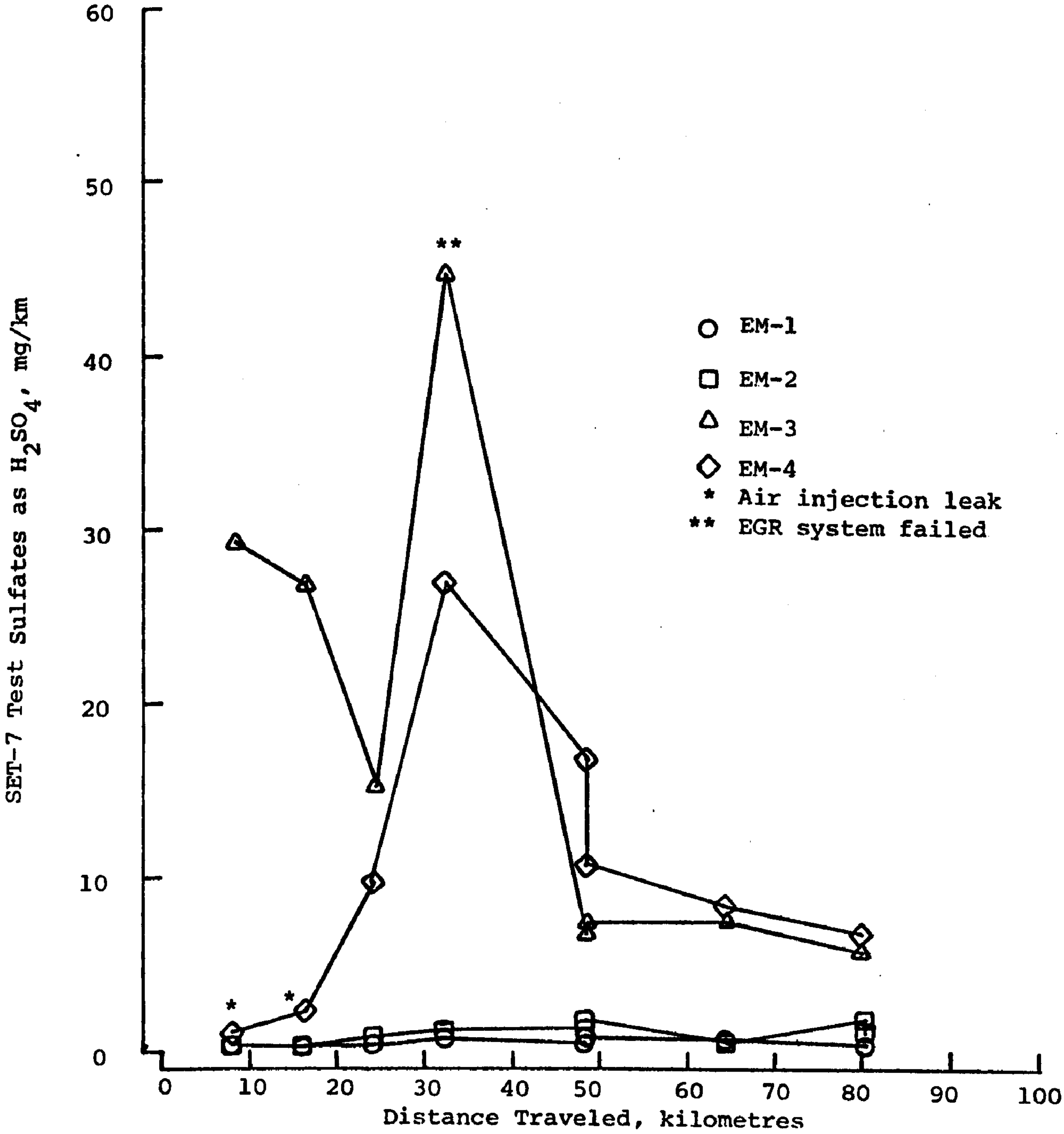
During the course of this project, exhaust sulfate emissions were measured on a variety of test cycles including the FTP, SET-7, HFET, accelerations from 0 to 48 and 96 kilometres per hour (kph) (30 and 60 mph), and from 48 and 96 kph cruise conditions. Sulfate emissions varied from less than 0.01 mg/km for a non air-injected catalyst car (probably operating in a storage mode) during an acceleration to 48 kph to 77.11 mg/km for an air-injected catalyst car during an acceleration to 96 kph. A higher value of 97.30 mg/km was observed for one car after a prolonged (5 hours) preconditioning at 56 kph.

The sulfate emissions also varied widely depending on the type of car tested. In general, noncatalyst cars produce the least sulfates and oxidation catalyst cars without air injection, slightly more sulfates. Odidation catalyst cars with air injection in general produce the most sulfates. One car equipped with a three-way (oxidation-reduction) catalyst without air injection demonstrated sulfate levels on the same order of magnitude as noncatalyst cars. Diesel cars are a special case. The diesel car tested converted approximately the same percentage of fuel sulfur to sulfates as did the noncatalyst cars and nonair-injected catalyst cars. However, because of the high level of sulfur in the diesel fuel (average of 0.23 versus 0.04 weight percent for gasoline used in this project) the sulfate emissions in mg/km were similar to air-injected catalyst cars.

One of the significant findings of the study was that some malfunctions of the emission control system can affect sulfate emissions. It was found, for instance, that disconnecting the fuel evaporative cannister from the carburetor had no effect on the SET-7 sulfate emissions. However, a leak in the air injection system on one of the catalyst cars tended to lower the sulfate emissions on most test cycles. One of the most interesting findings is that an inoperative EGR system will significantly increase sulfate emissions on some cars, particularly air-injected catalyst cars.

4. Sulfate Emission Variation with Distance Traveled

The sulfate emissions also varied with distance accumulated on the car. The change in sulfate emissions with distance traveled was measured on four catalyst cars. The variation in sulfate emissions was found to be dependent upon both the driving cycle and the type of car. For example, as shown on the graph below, on the SET-7 tests, there was almost no change in sulfate emissions over 80,500 km (50,000 miles) for the nonair-injected cars. For the air-injected cars, the sulfate emissions decreased significantly in an exponential fashion from 8,050 km (5,000 miles) to 80,500 km (50,000 miles).



5. Sulfate Storage by Catalysts

From the testing of catalyst cars during this project, it appears that whether a given vehicle operating condition is a sulfur storage or release mode, is dependent not only on what the condition is, but also the distance accumulated on the vehicle. Whether a given operating condition is a storage or release mode also varies from vehicle to vehicle. Three of the four cars tested to 80,000 km, stored sulfur during some of the test cycles and released sulfur during other test cycles. However, one car, EM-4, (pellet w/air) apparently stored sulfur during all test cycles except for the acceleration to 96 kph at the 24,100, 32,200 and 48,300 km test points.

Except for car EM-4, the acceleration from 0 to 96 kph (0-60 mph) always exhibited the largest release of sulfur, while the 48 kph (30 mph) cruise condition showed the largest storage of sulfur compounds. The total sulfur recoveries from the tests performed varied from 10.7 percent at 48 kph (30 mph) cruise on a nonair-injected catalyst car with 32,000 km accumulated use, to 335 percent during an acceleration from 0 to 96 kph (0-60 mph) on a nonair-injected catalyst car at essentially zero kilometres traveled.

6. Relationship of Net Filter Weight to Sulfate Weight

For two of the test phases, the filters used to collect the exhaust sulfates were weighed before and after the test on which they were used. On one phase of the project, the filters were weighed with the sulfate in the form in which it was collected, sulfuric acid. No consistent relationship between net filter weight and sulfate weight were shown by these tests even though the filters were weighed in a controlled-humidity chamber after a stabilization period. During a later phase of the project, the filters were subjected to an ammonia atmosphere after the test but prior to the "after-test" weighing. This converted the sulfuric acid to ammonium sulfate releasing the water vapor. When treated in this manner, there was a good linear relationship between weight of particulate collected on the filter and weight of sulfate from the BCA analysis for all cars on all tests except the 1975 FTP. The FTP tests exhibited a different slope and considerably more scatter.

7. Analysis of Sulfate Tunnel Residue

For two phases of this project, the sulfate tunnel was swept out at the end of each test series on each car. The particulate residue was collected and quantitatively analyzed for various elements using X-ray fluroescence. The analysis was for platinum (Pt), palladium (Pd), aluminum (Al), nickel (Ni), iron (Fe), sulfur (S), lead (Pb), zinc (Zn), copper (Cu) and tin (Sn). Of these 10 elements, no platinum, palladium, nickel, copper or tin was found in any of the samples. Chromium, silicon, and manganese were found in some of the samples. The largest part of each sample was iron. From a visual inspection of the samples, it appears that rust, probably from the exhaust system, is the major constituent of the residue. The other elements were found in much smaller quantities and their origin is not certain.

# I. INTRODUCTION

In 1971 and 1972 EPA sponsored studies at Dow Chemical Company [1,2]* showed that catalyst equipped cars emitted a larger mass of particulate emissions than noncatalyst cars. The additional particulate mass was shown to be sulfuric acid.[3]

EPA studies have been conducted since that time to determine the level of sulfuric acid emissions from automobile exhaust.[4,5,6] The work covered in this report is one of these studies.

## A. Objectives

The original objective of this project was to provide data on the emissions of sulfate (measured as sulfuric acid) and sulfur dioxide ($SO_2$) from passenger cars powered by gasoline and diesel engines. These data could then be used to compare different type engines and catalysts. Two additional objectives were to determine the change in sulfate emissions with mileage accumulation, and to investigate the phenomenon of sulfate storage where possible.

As the project progressed the need by the EPA for further information on sulfate emissions led to the inclusion of two additional studies in the project. One of these studies was in support of the EPA effort to produce a "Notice of Proposed Rule Making" (NPRM) for sulfates. The other study was the SwRI contribution to the EPA sulfate baseline project.

## B. Report Organization

This report has a separate section for each of the study areas; characterization, NPRM, baseline and mileage. Each section covers the objective, test schedule and test results for the study area. Test procedures and equipment common to all areas of investigation are covered in one section.

## C. On-Site Project Reviews

Five project reviews at SwRI by the EPA Project Officer occurred during the testing phase of the project. On September 17, 1974, Mr. Joseph H. Somers and Mr. Richard D. Lawrence of the EPA visited the Department of Emissions Research at SwRI for an inspection and discussion of the project. Several items of procedure were discussed. It was decided that the test gasoline would have a sulfur level of 0.04 percent and the test diesel fuel a sulfur level of 0.25 percent. On January 24, 1975, Mr. Richard Lawrence, EPA Project Officer, again visited SwRI to review the project. It was decided at that time to proceed with the test schedule using the SwRI-BCA procedure for $SO_2$. On October 27 and 28, 1975, Mr. Lawrence visited the Department of Emissions Research at SwRI to review the status of both Contract 68-03-2118 and Task 2 of Contract 68-03-2196. Specific items discussed included reviewing the data obtained from the four mileage accumulation cars, a discussion of the lower than expected emissions on Car EM-4 a review of the future test schedule, a discussion of the final report out-

*Superscript numbers in parentheses refer to the List of References at the end of this report line, and a discussion of the proposed extension of the distance accumulation to 80,500 km on each of the four cars. During the visit all of the baseline cars were at the laboratory. A brief inspection of the cars was made and the test schedule and results discussed.

On April 15 and 16, 1976, Mr. Richard Lawrence visited the Department of Emissions Research to review the status of the project and discuss the outline and contents of the final report. As a result of these discussions, it was decided to run the back-to-back 50 mph tests to determine the effect of an inoperative EGR system on sulfate emissions at the conclusion of the 80,500 km tests.

D. Project Reviews - Ann Arbor

In addition to these visits to SwRI by the Project Officer, two meetings were held at the EPA facility at Ann Arbor, Michigan to discuss the results of testing done under this contract. Mr. Melvin Ingalls attended these meetings representing the Department of Emissions Research at SwRI.

The first meeting was held on July 15, 1975, in Ann Arbor, Michigan, with all four laboratories working on sulfate testing in support of the sulfate regulation studies present. As a result of this meeting, the test schedule for the Part II testing was changed. The testing requested of SwRI was outlined in an EPA memo from J. H. Somers to J. P. DeKany, dated July 18, 1975.

The second meeting was hald on August 19, 1975, in Ann Arbor, with representatives from all four laboratories again in attendance. The results of each laboratory's testing in support of a sulfuric acid test procedure were discussed. In addition, the EPA presented their analysis of the data from all four labs.

## II. EMISSIONS MEASUREMENT PROCEDURES AND EQUIPMENT

This section covers the measurement procedures and equipment used to obtain and analyze the gaseous exhaust emissions and exhaust sulfates in the form of sulfuric acid.

### A. General Procedures

All exhaust emission tests performed during this study were on cars under 6,000 pounds GVW. The 1975 light duty Federal Test Procedure (FTP) without evaporative emissions, was followed in terms of procedure and equipment as much as possible for all tests. It is assumed that the reader is familar with this test procedure. If not, it can be found in 40 CFR Part 85, Subpart A. The latest recodification was published in the Federal Register, Volume 40, Number 126, dated June 30, 1975.

The gasoues emissions of hydrocarbons (HC), carbon monoxide (CO), and oxides of nitrogen ($NO_x$) were collected and analyzed using the procedures of the light duty FTP. The tests were performed on a Clayton chassis dynamometer with the vehicles manually driven. A Constant Volume Sampler (CVS), with a nominal capacity of 350 CFM was used. To collect the sulfate sample, the usual CVS system was modified by inserting a three meter long tunnel approximately 21 cm in diameter between the CVS room air filter box and the entrance to the CVS heat exchanger. Figure 1 shows various views of the test area, CVS system and the analysis instruments for the bagged gaseous emissions.

There were three main driving cycles used during this project. The first was the driving cycle used in the light duty FTP, known as the LA-4 cycle or the Urban Dynamometer Driving Schedule (UDDS). The second was the Highway Fuel Economy Test (HFET) cycle. The third cycle was developed specifically as a sulfate test cycle and is identified as Sulfate Emission Test 7 or SET-7. The speed time traces of these three cycles are shown in Figure 2. A complete speed versus time listing for the SET-7 is contained in Appendix A. In addition to the driving cycles, tests were run at constant 48 kph (30 mph) and constant 96.5 kph (60 mph) conditions during the characterization studies.

At the conclusion of the characterization tests on each car, the sulfate tunnel was swept out with a fine bristled brush. The resulting particulate matter was analyzed using an X-ray fluorescense analyzer for a variety of elements.

### B. Sulfate Collection and Analysis

The exhaust sulfates were collected as sulfuric acid on 47 mm Fluoropore* membrane filters with 0.5 μm pore size. The samples were obtained isokinetically using a pitot type probe centered in the 21 cm diameter tube. Figure 3 is a schematic of the collection system.

For some parts of the study, the filters were weighed before and after

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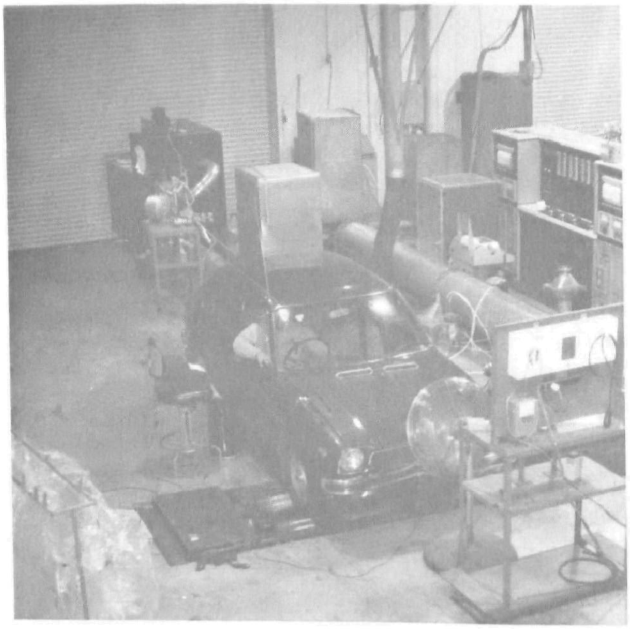
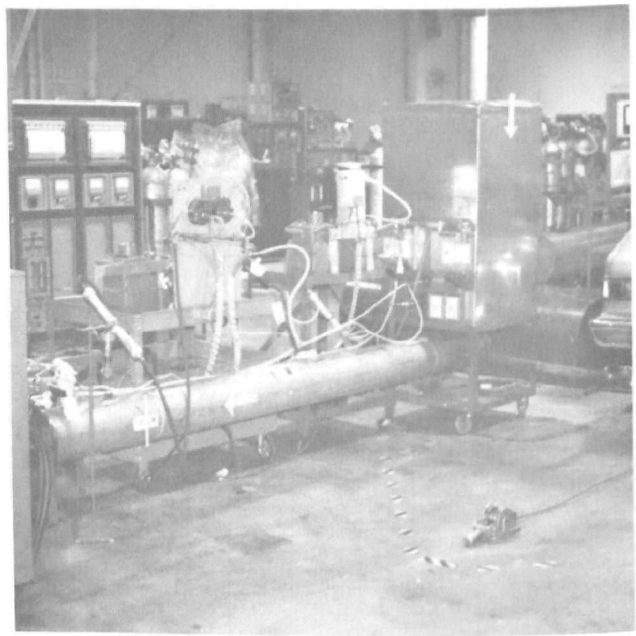
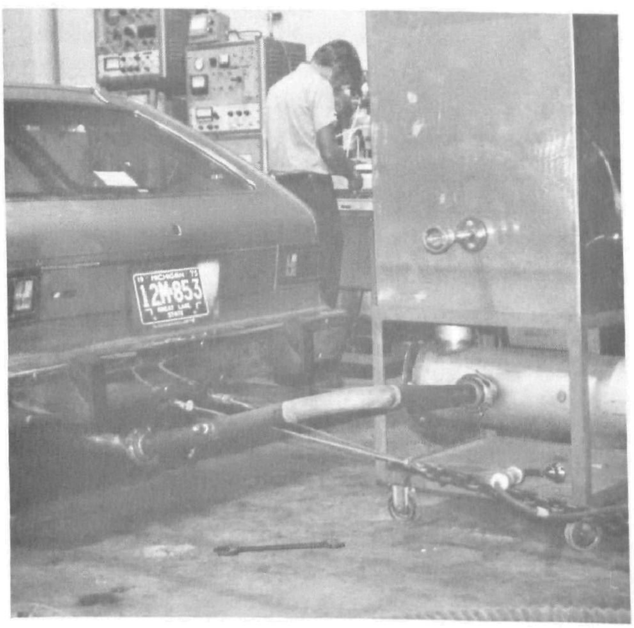
*Fluoropore is a registered trademark of the Millipore Corporation. Fluoropore filters are made of PTFE (Polytetrofluorelthylene) bonded to polyethylene net.



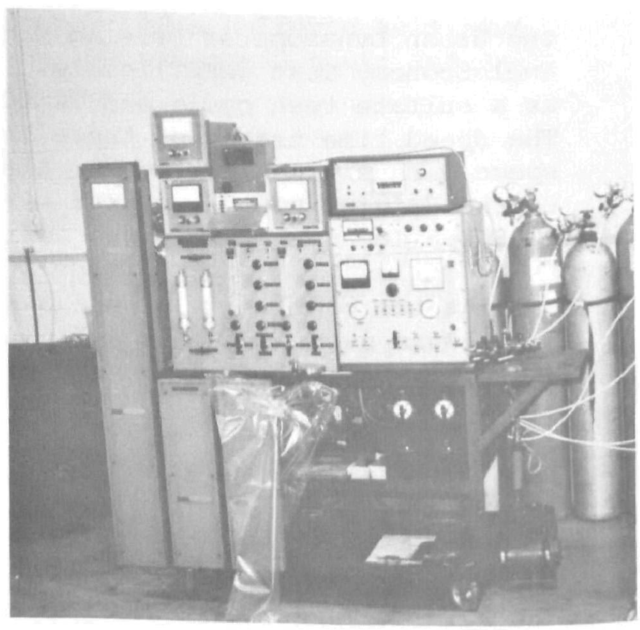
General View of Test Area



Dilution Air Filter Box
and Sulfate Tunnel



Vehicle Exhaust Connection
to CVS System



Emission Analyzers for
Bagged Gaseous Emissions

FIGURE 1. EMISSIONS COLLECTION AND ANALYSIS EQUIPMENT

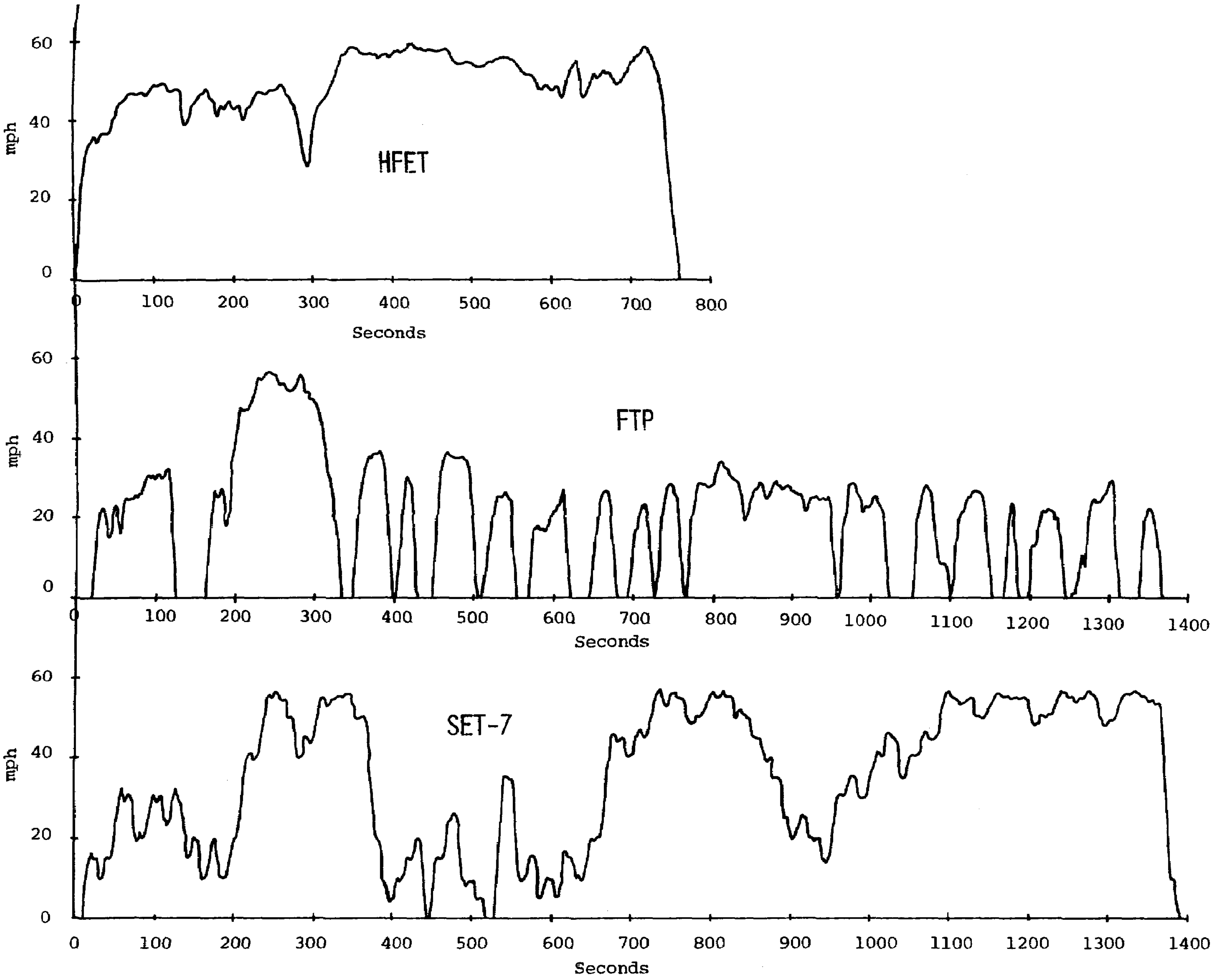



FIGURE 2. SPEED VS. TIME TRACES OF FTP, HFET AND SET-7 DRIVING CYCLES

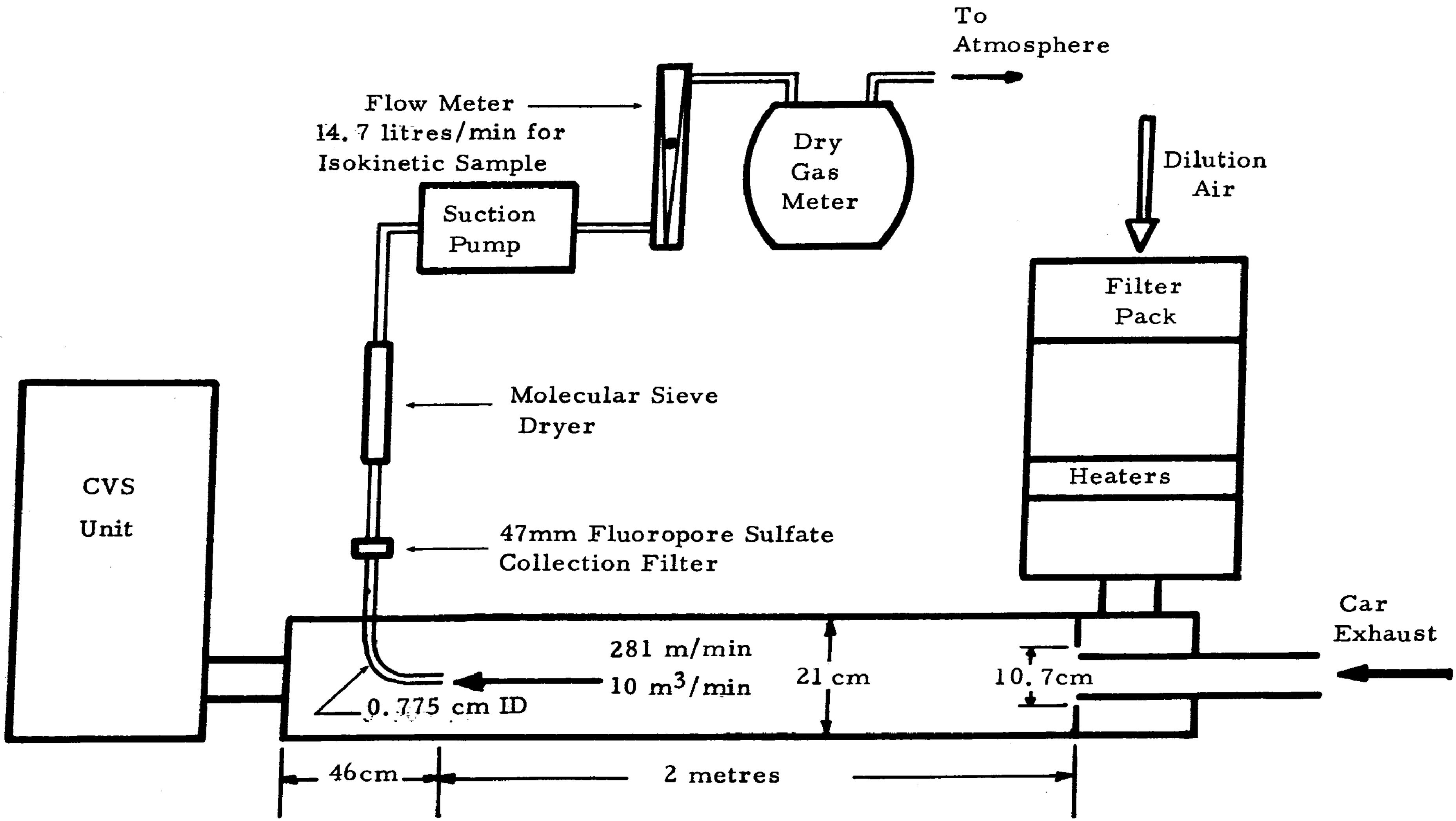



FIGURE 3. SCHEMATIC OF SULFATE SAMPLE COLLECTION SYSTEM

use, using a Mettler microgram balance located in a temperature and humidity controlled chamber. After the test and weighing of the used filter (when required) the filters were leached in a 10 ml solution of 60 percent isopropyl alcohol and 40 percent distilled water (IPA solution). A portion of the mixture was injected into a liquid chromatograph system using a flow through cell in a Model 25 Beckman UV visible spectrophotometer set at 310 nm. A high pressure liquid chromatograph sampling valve and one ml loop was employed. to insure sample injection repeatability.

Once injected, the sample passed through a strong cation exchange resin column to remove possible interfering cations and to convert ammonium sulfate to sulfuric acid. The solution then passed through a column packed with barium chloranilate. The barium combines with the sulfate in the sample to form barium sulfate, releasing chloranilic acid. The concentration of the released chloranilic acid, which is proportional to the amount of sulfate in the sample, is measured by the UV spectrophotometer. This method of sulfate determination is commonly called the barium chloranilate (BCA) procedure for sulfates. It was developed by Dr. Silvestre Tejeda of the EPA at their Research Triangle Park, N.C., facility. Figure 4 contains photographs showing the various components of the sulfate collection and analysis system. A complete description of the analytical procedure is contained in Appendix B.

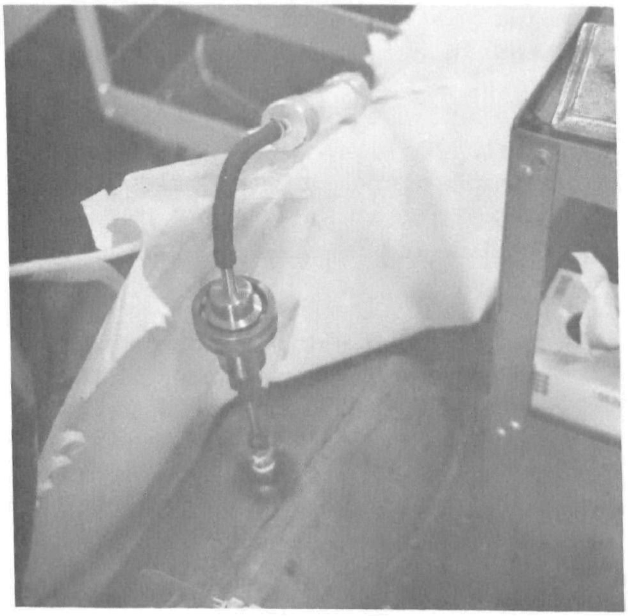
Part way through the project, an improvement in filter handling was recommended by the EPA at Research Triangle Park and subsequently put into practice. This improvement involved exposing the used filters to ammonia gas to convert the sulfuric acid on the filters to ammonium sulfate which is a solid and hence should be more stable. In addition, it is not hydroscopic, so that moisture from the air is not taken up on the filter to add to the filter weight.

The first car tested in the project was run on leaded fuel. During the test preparations the question arose as to whether the cation exchange column could remove all the lead in the sample. More importantly, it was questioned whether the chloride and bromide ions from the ethylene dichloride and ethylene dibromide in the leaded fuel (which would be anions like sulfate) would interfere in the BCA procedure. A series of tests were run to answer these questions. The results indicated that the BCA procedure could not be used with leaded fuel. A detailed presentation of the results of these tests is included in Appendix B. The BCA procedure has recently been modified to eliminate these interferences.

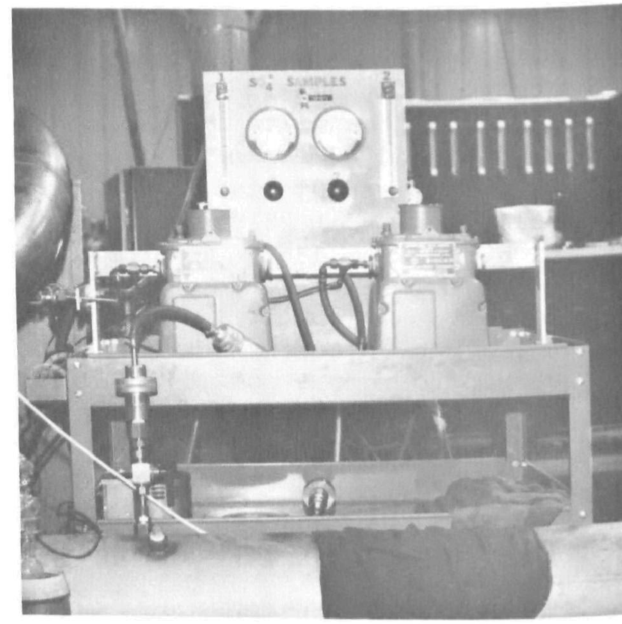
C. Sulfur Dioxide by Pulsed Fluorescence

Originally it was planned that a TECO Model 40 Pulsed Fluorescent (PF) $SO_2$ Analyzer would be used to measure the exhaust $SO_2$ emissions. Considerable work was done investigating interferences and the instrument's ability to measure SO2 in dilute automobile exhaust at fuel sulfur levels on the order of 0.04 percent.

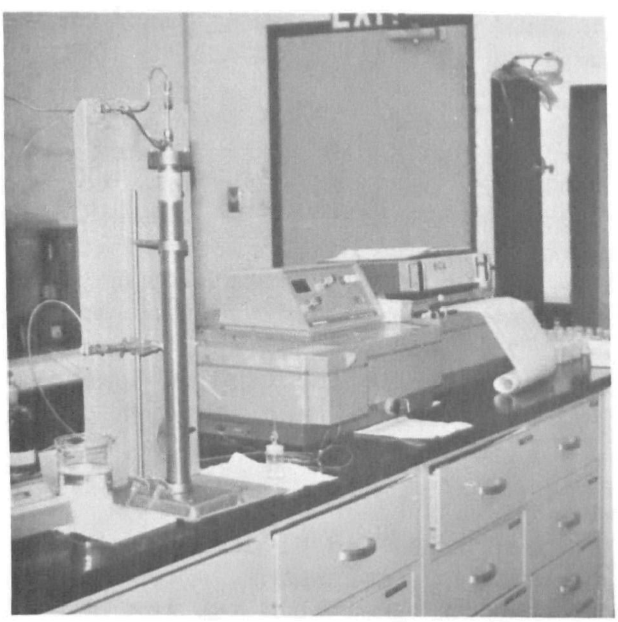
The interference tests essentially showed that in an air-rich sampling system such as the CVS, the interferences from CO, $CO_2$. $NO_x$ and at least two of the aromatic hydrocarbons would be negligible. However, when the PF unit was placed in service measuring $SO_2$ during tests on an actual car running on 0.05 percent sulfur fuel, it greatly overstated the amount of $SO_2$ in the



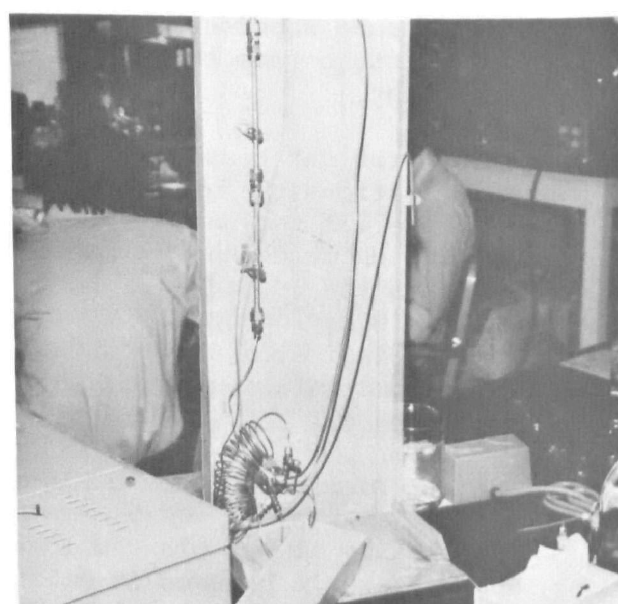
Sulfate Filter Holder on Probe



Sample Collection System
With Total Flow Meters



UV Spectrophotometer



BCA Column, Cation Exchange
Column and Sample Loop

FIGURE 4. COMPONENTS OF SULFATE COLLECTION AND ANALYSIS SYSTEM

exhaust. The exhaust $SO_2$ reading on the instrument was found to be a function of both exhaust $SO_2$ level and composition of the fuel. Complete details of both the interference checks and the actual car tests are contained in Appendix C.

Almost three months of effort were expended in trying to adapt the PF unit for $SO_2$ determination on CVS tests of automobiles without success. It was felt that more than enough effort had been expended and that an alternate method would have to be used for $SO_2$ determination.

D. Sulfur Dioxide Procedure Using Bubblers and BCA Analysis

The procedure developed to replace pulsed fluorescent measurement of $SO_2$ involved bubbling a sample of the exhaust gas through a 3 percent solution of hydrogen peroxide ($H_2O_2$). A schematic of the sample collection equipment is shown in Figure 5. A sample of the exhaust gas was drawn through the glass probe and a 0.5 µm Fluoropore filter to remove any sulfuric acid, then in series through two impingers filled with 25 ml of 3 percent solution of $H_2O_2$ where the SO2 is oxidized to $SO_4^{=}$ and stays in the solution. The second bubbler serves only as a back-up to insure that all the $SO_2$ is collected.

After the test, the 25 ml of hydrogen peroxide solution was evaporated to 10 ml. Several drops of ammonium hydroxide solution (1M) were then added to convert the mixture to ammonium sulfate and the sample evaporated to dryness. The remaining white residue of ammonium sulfate was dissolved in a 60-40 percent IPA solution and analyzed using the barium chloranilate procedure used to analyze the filters. Several photographs showing various parts of the collection and analysis systems are contained in Figure 6. A complete description of the analytical procedure called the SwRI $SO_2$-BCA procedure is contained in Appendix D.

Extensive experiments were conducted to validate the sampling and extraction procedures. The experiments were conducted in both areas of the procedure; the sample acquisition and the sample analysis. The detailed description and results of these tests are also listed in Appendix D. The validation experiments proved that the $SO_2$-BCA method gave satisfactory sulfur recoveries on non-catalyst vehicles. These sulfur recovery levels were orders of magnitude better than the TECO PF analyzer and an improvement over what others had reported using titration or gravimetric analysis of hydrogen peroxide $SO_2$ collection systems.

E. EPA Method 8 Tests

At the start of the project, it was felt by some researchers that the EPA stationary source Method 8 test might be an acceptable procedure for use in determining automotive exhaust sulfates and $SO_2$. Consequently, some of the characterization cars were scheduled to use the Method 8 sampling procedure concurrently with the sulfate filter tests.

Method 8 is a wet chemical procedure utilizing four impingers. The first impinger contains 80 percent isoproponal and is used to entrain the sulfuric acid in the sample. A filter is placed between the first and second impinger to prevent any sulfuric acid carryover to the second impinger. The second and

Note: All tubing in sample train up to the impingers is glass or teflon.

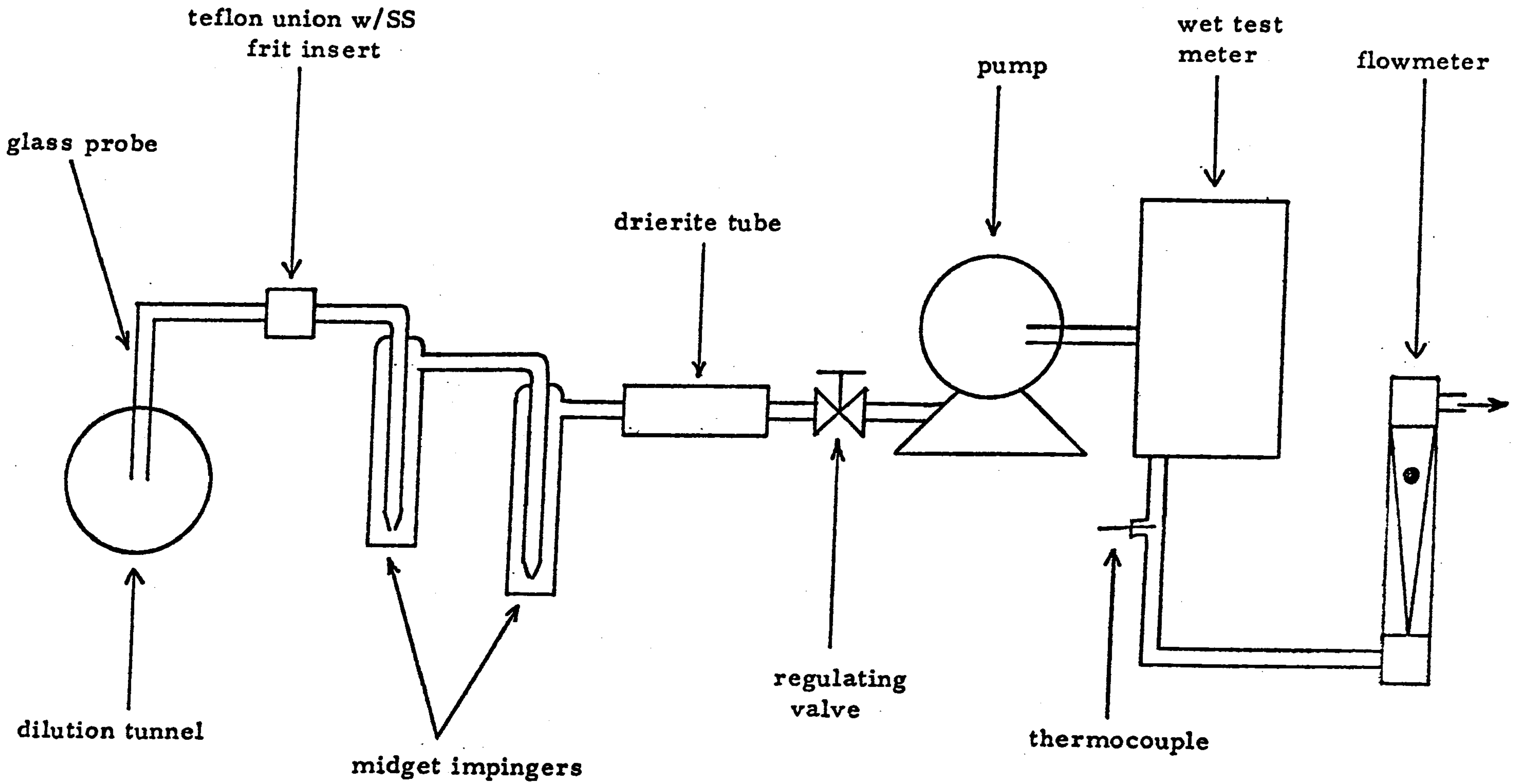



FIGURE 5. $SO_2$-BCA FLOW SCHEMATIC

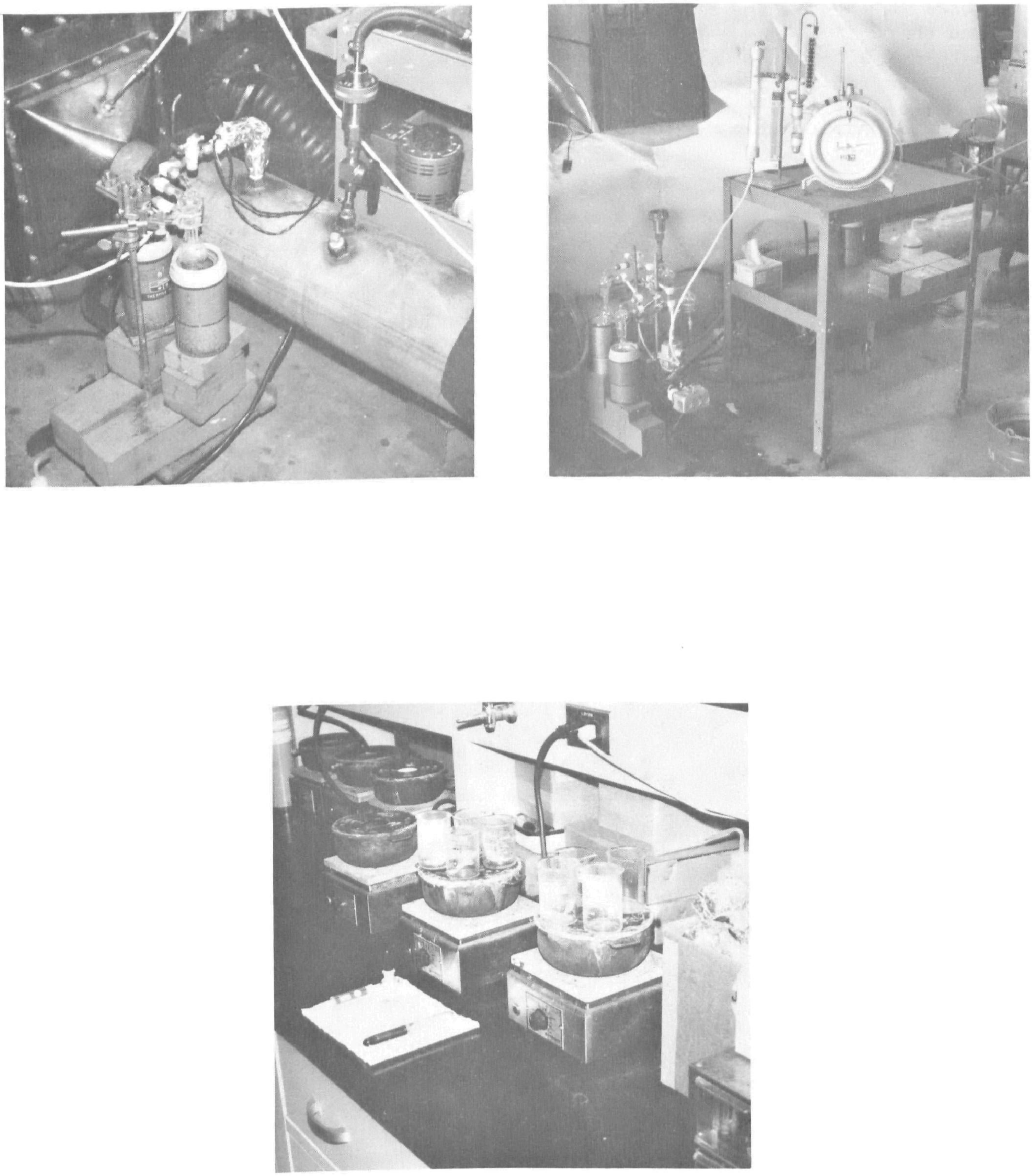


FIGURE 6. PHOTOGRAPHS OF $SO_2$ SAMPLE COLLECTION SYSTEM

third impinger contain a solution of 3 percent hydrogen peroxide to trap the $SO_2$ in the sample. The fourth impinger contains silica gel.

The analysis for sulfuric acid is performed using the solution from the first impinger; the analysis for $SO_2$, using the solution from the second and third impinger. The analytical procedure uses the barium-thorin titration method. A complete description of Method 8, as given in the Federal Register is contained in Appendix E. Figure 7 is a photograph of the Method 8 impingers in place during a test.

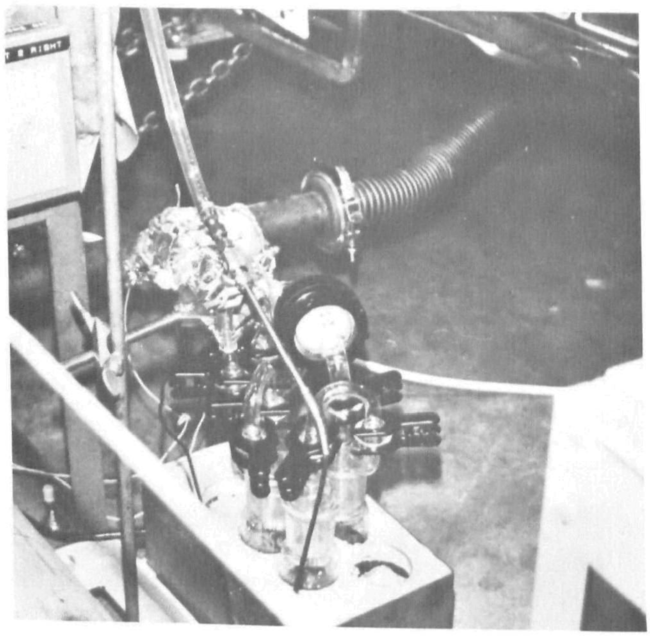


FIGURE 7. METHOD 8 IMPINGERS IN PLACE DURING A TEST

## III. SULFATE EMISSIONS CHARACTERIZATION

This section covers the sulfate emission testing of eight cars selected under the original scope of the project.

### A. Purpose

The purpose of this phase of the project was to provide data on the emissions of sulfate ($SO_4^=$) expressed as sulfuric acid ($H_2SO_4$) and sulfur dioxide ($SO_2$) from various types of passenger cars powered by both gasoline and diesel engines. The primary use of the data is to permit comparisons between different type engines and catalyst systems.

### B. Cars Tested

To meet the objective of this phase of the project, a variety of engines and catalysts were selected for testing. Since sulfate emissions were thought to be a problem when catalysts were used in the exhaust system, a noncatalyst 1972 car was chosen as a baseline. At the time this work was done, the sulfate detection procedure could not be used with leaded fuel. Therefore, it was necessary to choose a baseline car that was manufactured with the capability to run on unleaded gasoline.

To test sulfate emissions from catalyst cars, it was considered desirable to have both pelleted and monolithic catalysts. It was also desired to have each of the catalyst types with and without air injection systems.

Current model non catalyst cars were also included to characterize sulfate emissions from cars which met the then current standards wihout catalysts. Three cars were chosen in this category. One was powered by a conventional spark-ignition engine without a catalyst but calibrated to meet the 1975 standards. Another of these cars was powered by the Honda compound vortex controlled combustion(CVCC) engine. The remaining car was powered by a diesel engine. Table 1 lists the eight cars together with a brief description of engine and exhaust systems. Figures 8 and 9 are pictures of the cars tested.

The cars were obtained from various sources. The 1972 Plymouth is owned by SwRI and used as a general transportation car by the Department of Emissions Research. The Honda Civic CVCC and Mercedes 240D cars were government-provided emission test cars. The Ford Granada was obtained from an automobile dealership where it had been operated on long term lease service. The four catalyst cars were leased new for this project to study the effects of mileage on sulfate emissions from catalyst cars.

### C. Fuels Used

Three different fuels were used for this part of the project, a leaded gasoline for one series of tests on the 1972 Plymouth, an unleaded gasoline for all other tests of both catalyst and non catalyst cars, and 2-D diesel fuel for the diesel car.

TABLE 1. DESCRIPTION OF SULFATE CHARACTERIZATION CARS

| Make | Model | Model Year | Engine CID | Engine Cycle | Catalyst Type | Air Pump |
|---|---|---|---|---|---|---|
| Plymouth | Fury | 1972 | 360 | Conventional gasoline | None | None |
| Honda | Civic CVCC | 1974 | 90 | Strat. Charge gasoline | None | None |
| Ford | Granada | 1975 | 351W | Conventional gasoline | None | Yes |
| Plymouth | Gran Fury (Federal) | 1975 | 360 | Conventional gasoline | Monolith | No |
| Chevrolet | Impala (Federal) | 1975 | 350 | Conventional gasoline | Pelleted | No |
| Plymouth | Gran Fury (Calif) | 1975 | 360 | Conventional gasoline | Monolith | Yes |
| Chevrolet | Impala (Calif) | 1975 | 350 | Conventional gasoline | Pelleted | Yes |
| Mercedes | 240D | 1975 | 147 | Conventional diesel | None | No |


1972 Plymouth

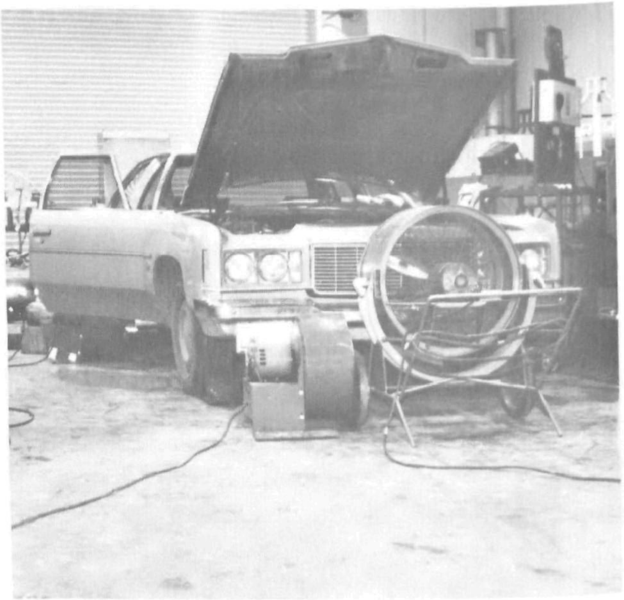
1975 Honda CVCC

1975 Ford Granada

1975 Mercedes 240D

FIGURE 8. NON-CATALYST SULFATE CHARACTERIZATION CARS

1975 Federal Plymouth Gran Fury



1975 Federal Chevrolet Impala

1975 California Plymouth Gran Fury


1975 California Chevrolet Impala

FIGURE 9. CATALYST EQUIPPED SULFATE CHARACTERIZATION CARS

The leaded fuel used was a base stock, a Phillips unleaded gasoline which was obtained by EPA, Research Triangle Park, in a large batch for use in several emissions projects. Sufficient tetraethyl lead in the form of "motor mix" was added to this fuel at SwRI to bring the lead concentration to 3 g/gallon. This gasoline meets the EPA specifications for leaded FTP emissions test fuel except for the 50 percent distillation point of 199°F and the Reid Vapor Pressure (RVP) of 10.2.

The unleaded gasoline was locally obtained Gulf Crest gasoline as sold at local retail stations. This gasoline meets the EPA specifications for unleaded FTP emissions test fuel except for Research Octane Number (RON)of 92.0 and the 10, 90,and 100 percent distillation points of 119°F, 352°F and 420°F respectively.

The diesel fuel used was a commercially-available Gulf 2D diesel fuel. This fuel was chosen rather than a diesel fuel blended to meet the EPA specifications for emissions test fuel. The emission test fuel is higher in sulfur and aromatics than normal diesel fuels.

From the Bureau of Mines Gasoline Survey available at the time for leaded gasoline, the national average sulfur content was estimated to be 0.04 percent. It was decided to use 0.04 percent sulfur level in all gasoline fuels. Later Bureau of Mines surveys available after the project had begun, which contained more information on unleaded gasoline, showed the average fuel sulfur level for unleaded fuel to be approximately 0.03 percent. However, it was decided not to change the fuel sulfur level in the middle of the project. From similar Bureau of Mines surveys of diesel fuel, it was decided to use 0.23 percent sulfur in the diesel fuel.

Thiophene was added to increase the sulfur levels of the gasoline stock to the required percentage. Ditertiary butyl disulfide was added to the diesel fuel to obtain the required sulfur percentage.

The list of fuels used is shown in Table 2, together with the actual weight percent sulfur in the fuel. A complete analysis of each fuel is included in Appendix F.

D. Test Sequence

After receipt of the vehicles, the engines were checked to insure that timing, idle speed and dwell were within manufacturers specification and that the engine was running properly. A visual inspection was made for loose vacuum lines, spark plug wires, etc. The car was tuned as necessary, so that the items checked were within specifications prior to testing. The test sequence for both noncatalyst and catalyst cars is shown in Table 3. Unfortunately, this test series was planned, and for the most part conducted, before the sulfate test cycle (SET-7) had been developed; thus, it is conspicuously absent from the test series.

TABLE 2. FUELS USED IN SULFATE EMISSIONS CHARACTERIZATION STUDIES

| | SwRI Fuel Code | Description | Base Stock Source | Local Additives | Fuel Sulfur Percent | Cars Using Fuel |
|---|---|---|---|---|---|---|
| 1. | EM-208F | leaded gasoline | unleaded Phillips EPA Contract 68-02-1122 | Thiopene & Motor Mix | 0.051 | '72 Plymouth |
| 2. | EM-212F | unleaded gasoline | Gulf Crest | Thiophene | 0.041 | Honda CVCC, '75 Ford Granada 4 catalyst cars |
| 3. | EM-246F | 2D diesel | Gulf 2D | Ditertiary Butyl Disulfide | 0.23 | Mercedes 240D |

TABLE 3. TEST SEQUENCE FOR SULFATE CHARACTERIZATION CARS

A. Test sequence for the Non Catalyst vehicles.

1. Check vehicle specifications and tune as required.
2. Condition vehicle on modified AMA route for 200 miles.
3. Soak vehicle for 10 hours. (Do not run "hot start LA-4" following 200 mile conditioning).
4. Run 1975 FTP, 30 and 60 mph.
5. Repeat " 3 - 4" once.

B. Test sequence for the catalyst equipped vehicles

1. Check vehicle specifications (timing, dwell, idle speed, etc.) Tune as required.
2. Condition vehicle on modified AMA route for 500 miles.
3. Soak vehicle for 10 hours. (Do not run "hot start LA-4" following the 500 mile conditioning).
4. Run 1975 FTP, 30 and 60 mph.
5. Repeat "2 - 4" above once.

Both gaseous emissions (including $SO_2$) and sulfates were measured during the test series. The regulated gaseous emissions were obtained using the standard CVS procedures, except that the 1975 FTP was run as two complete 23 minute cycles, rather than as a 23 minute cycle and a hot 505 second cycle. The emissions from the two complete cycles were then added, weighting the cold cycle 43 percent and the hot cycle 57 percent. If it is assumed that the emissions from the stabilized portion of the cold and hot 23 minute cycle are the same, then it can be shown mathematically that the two 23 minute cycles will give the same results as the regular three bag '75 FTP.

Sulfur dioxide and sulfates were obtained on all cars using the BCA method explained in the Test Procedure section. For the FTP, one filter was obtained for each 23 minute cycle. The sulfates from each filter were then added in the same manner as the gaseous emissions. The EPA stationary Method 8 procedure, also explained in the Test Procedure section, was used to obtain $SO_2$ and sulfates from the 1972 Plymouth using both leaded and unleaded fuels, and the 1975 Honda CVCC.

It should be pointed out that the cars were not all tested on the same base fuel. Six of the seven gasoline powered cars were tested using a nominal 0.04 percent sulfur fuel. The fuel for the 1972 Plymouth contained 0.05 percent sulfur.

After the test series was completed on a car, the sulfate tunnel was carefully swept out with a fine bristled brush. Any particulates deposited in the tunnel during the test were thus collected for analysis using X-ray fluroescence techniques.

The sulfate filters were weighed prior to processing by the BCA method. During the project, a filter ammoniation technique was developed at EPA Research Triangle Park, to provide a more stable form of sulfate on the filters and sharper peaks during analysis. This technique was adopted at SwRI during the project. Thus, some filters were weighed with the sulfate as $H_2SO_4$ and some with the sulfate as ammonium sulfate, $(NH_4)_2SO_4$.

## E. Test Results

The test results from the eight cars tested under this part of the project fell into four different classifications and are covered in the following four subsections.

### Gaseous and BCA Sulfate Test Results

A summary of the gaseous emissions and the sulfate emissions using the BCA procedure is given in Table 4. The emission standards in grams/kilometre for a 1975 FTP type test are also included for reference. Figures 10 to 12 show the emissions results in the form of histograms for the regulated emissions at the three test conditions. The two sulfur emissions ($SO_2$ and sulfate) are shown in Figures 13 to 15 for each test type. For the detailed data on individual tests see Appendix G.

Figure 10 shows that all cars met their respective $NO_x$ standard except

TABLE 4. EXHAUST EMISSIONS SUMMARY OF CARS TESTED FOR SULFATE CHARACTERIZATION PROJECT

| | | | | | | Exhaust Emissions g/km | | | | | Barium Chloranilate | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Vehicle | Make | Test Type | Fuel | Fuel % S | Catalyst | HC | CO | $NO_x$ | $SO_2$-BCA | $H_2SO_4$-BCA | % Fuel S as $SO_2$ | % Fuel S as $H_2SO_4$ | Total S Recovery |
| 1 | 1972 Plymouth | 1975 FTP | leaded | 0.051 | none | 2.89 | 55.04 | 3.19 | 0.14 | ---- | 89.5 | ---- | 89.5 |
| 1 | 1972 Plymouth | 1975 FTP | unleaded | 0.051 | none | 2.63 | 51.30 | 3.45 | 0.16 | 2.1 | 99.8 | 0.9 | 100.8 |
| 2 | Honda CVCC | 1975 FTP | unleaded | 0.041 | none | 0.71 | 2.43 | 0.55 | 0.05 | 0.4 | 81.7 | 0.5 | 82.2 |
| 3 | 1975 Granada | 1975 FTP | unleaded | 0.041 | none | 1.01 | 5.77 | 2.07 | 0.10 | 0.5 | 90.0 | 0.3 | 90.3 |
| 4 | 1975 49S Ply. | 1975 FTP | unleaded | 0.041 | mono w/o air | 0.32 | 7.27 | 1.41 | 0.09 | 0.3 | 58.8 | 0.1 | 58.9 |
| 5 | 1975 49S Chev. | 1975 FTP | unleaded | 0.041 | pel w/o air | 0.40 | 9.59 | 1.25 | 0.06 | 0.1 | 45.8 | 0.1 | 45.9 |
| 6 | 1975 Cal. Ply. | 1975 FTP | unleaded | 0.041 | mono w/air | 0.26 | 3.23 | 0.75 | 0.24 | 6.2 | 120.9 | 2.9 | 123.8 |
| 7 | 1975 Cal. Chev. | 1975 FTP | unleaded | 0.041 | pel w/air | 0.44 | 7.89 | 1.01 | 0.06 | 8.9 | 44.1 | 4.2 | 48.4 |
| 8 | 1975 Mercedes | 1975 FTP | diesel 2 | 0.230 | none | 0.09 | 0.47 | 0.10 | 0.34 | 10.1 | 96.0 | 1.9 | 97.92 |
| 1 | 1972 Plymouth | 48 kph | leaded | 0.051 | none | 1.51 | 28.93 | 0.41 | 0.08 | ---- | 91.9 | ---- | 91.9 |
| 1 | 1972 Plymouth | 48 kph | unleaded | 0.051 | none | 1.21 | 32.00 | 0.38 | 0.08 | 0.1 | 89.0 | 0.1 | 89.1 |
| 2 | Honda CVCC | 48 kph | unleaded | 0.041 | none | 0.07 | 1.08 | 0.37 | 0.04 | 0.2 | 113.0 | 0.5 | 113.5 |
| 3 | 1975 Granada | 48 kph | unleaded | 0.041 | none | 0.22 | 1.15 | 0.49 | 0.06 | 0.1 | 82.6 | 0.1 | 82.7 |
| 4 | 1975 49S Ply. | 48 kph | unleaded | 0.041 | mono w/o air | 0.03 | 0.04 | 0.83 | 0.01 | 2.4 | 17.3 | 2.6 | 19.8 |
| 5 | 1975 49S Chev. | 48 kph | unleaded | 0.041 | pel w/o air | 0.03 | 0.06 | 0.25 | 0.01 | 8.3 | 13.8 | 7.3 | 21.1 |
| 6 | 1975 Cal. Ply. | 48 kph | unleaded | 0.041 | mono w/air | 0.03 | 0.06 | 0.62 | 0.02 | 4.8 | 30.7 | 4.8 | 35.5 |
| 7 | 1975 Cal. Chev. | 48 kph | unleaded | 0.041 | pel w/air | 0.07 | 0.04 | 0.19 | 0.01 | 32.2 | 13.5 | 25.6 | 39.1 |
| 8 | 1975 Mercedes | 48 kph | diesel 2 | 0.230 | none | 0.02 | 0.15 | 0.53 | 0.15 | 3.4 | 79.0 | 1.2 | 80.2 |
| 1 | 1972 Plymouth | 96 kph | leaded | 0.051 | none | 1.08 | 6.75 | 3.63 | 0.08 | ---- | 103.7 | ---- | 103.7 |
| 1 | 1972 Plymouth | 96 kph | unleaded | 0.051 | none | 0.98 | 7.40 | 3.66 | 0.08 | 1.8 | 88.0 | 1.4 | 89.4 |
| 2 | Honda CVCC | 96 kph | unleaded | 0.041 | none | 0.02 | 0.56 | 1.40 | 0.04 | 0.9 | 105.4 | 1.3 | 106.7 |
| 3 | 1975 Granada | 96 kph | unleaded | 0.041 | none | 0.17 | 1.79 | 1.62 | 0.06 | 0.2 | 98.8 | 0.2 | 99.0 |
| 4 | 1975 49S Ply. | 96 kph | unleaded | 0.041 | mono w/o air | 0.02 | 1.62 | 0.57 | 0.12 | 0.3 | 174.2 | 0.3 | 174.5 |
| 5 | 1975 49S Chev. | 96 kph | unleaded | 0.041 | pel w/o air | 0.01 | 0.85 | 0.75 | 0.15 | 0.2 | 157.4 | 2.3 | 158.8 |
| 6 | 1975 Cal. Ply. | 96 kph | unleaded | 0.041 | mono w/air | 0.03 | 0.05 | 0.38 | 0.03 | 43.7 | 41.1 | 42.0 | 83.1 |
| 7 | 1975 Cal. Chev. | 96 kph | unleaded | 0.041 | mono w/air | 0.02 | 0.02 | 0.62 | 0.02 | 17.9 | 28.7 | 16.0 | 39.5 |
| 8 | 1975 Mercedes | 96 kph | diesel 2 | 0.230 | none | 0.01 | 0.36 | 1.08 | 0.37 | 13.3 | 124.9 | 2.9 | 127.8 |

Note: Results from Vehicles 4 to 7 are for 2000 mile tests.

FTP Standards in terms of g/km and 1975 - cold/hot procedure

| Year | HC | CO | $NO_x$ |
|---|---|---|---|
| 1972 | 1.85 | 17.25 | --- |
| 1975 Fed. | 0.9 | 9.3 | 1.9 |
| 1975 Cal. | 0.6 | 5.6 | 1.2 |

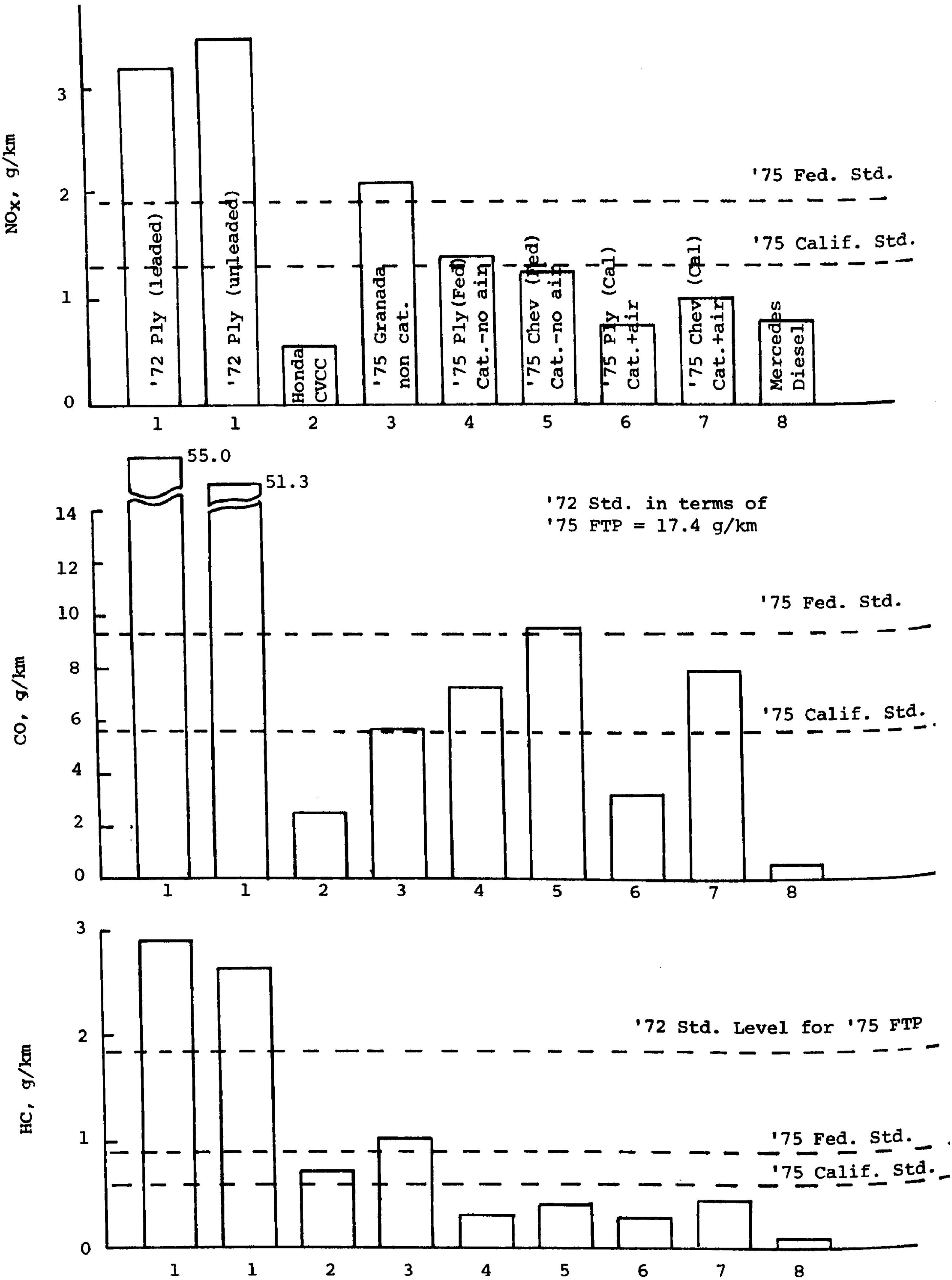



FIGURE 10. REGULATED GASEOUS EMISSIONS FROM 1975 FTP TESTS OF EIGHT CARS

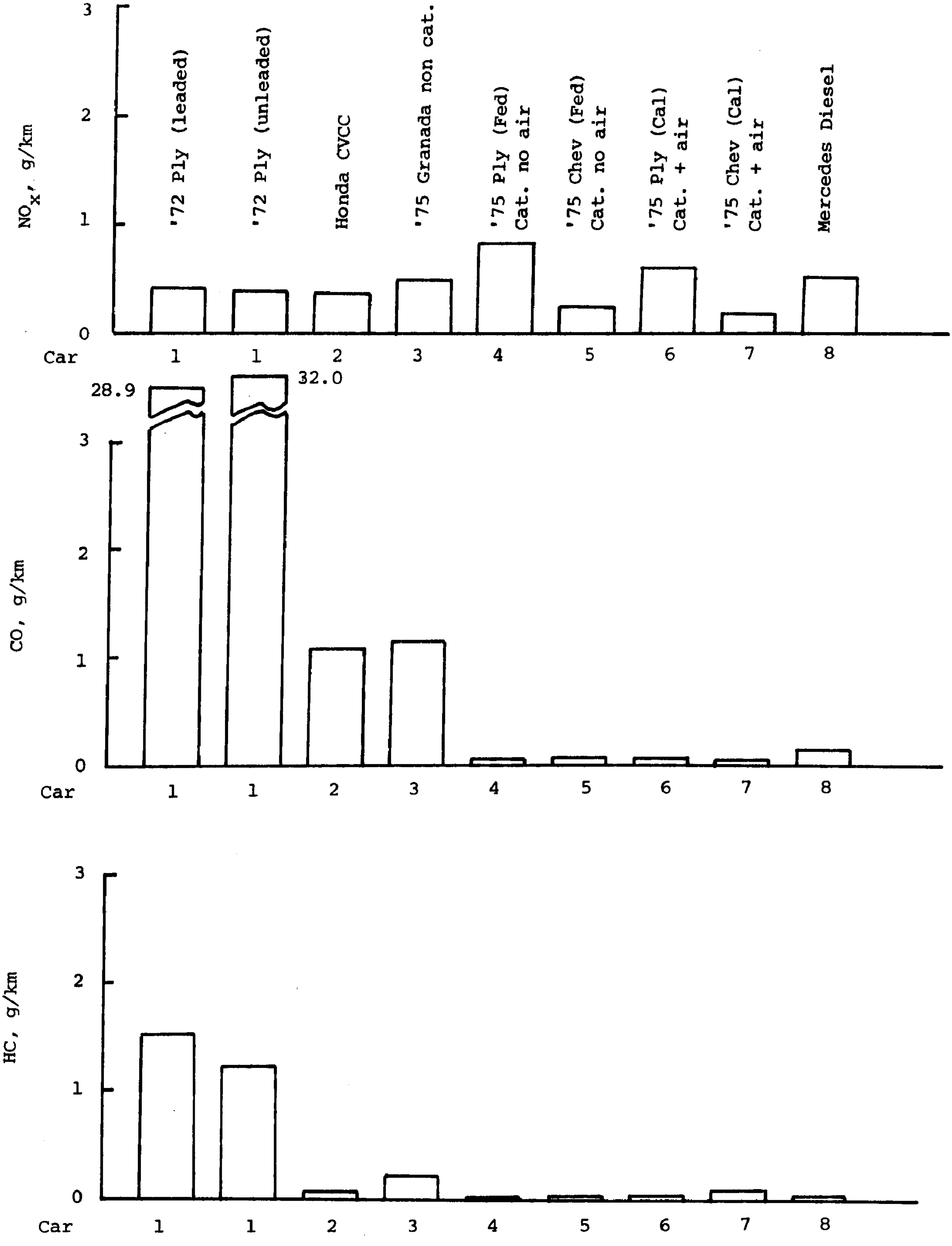



FIGURE 11. GASEOUS EMISSION IN g/km FROM TESTS AT 48 km/hr ON EIGHT CARS

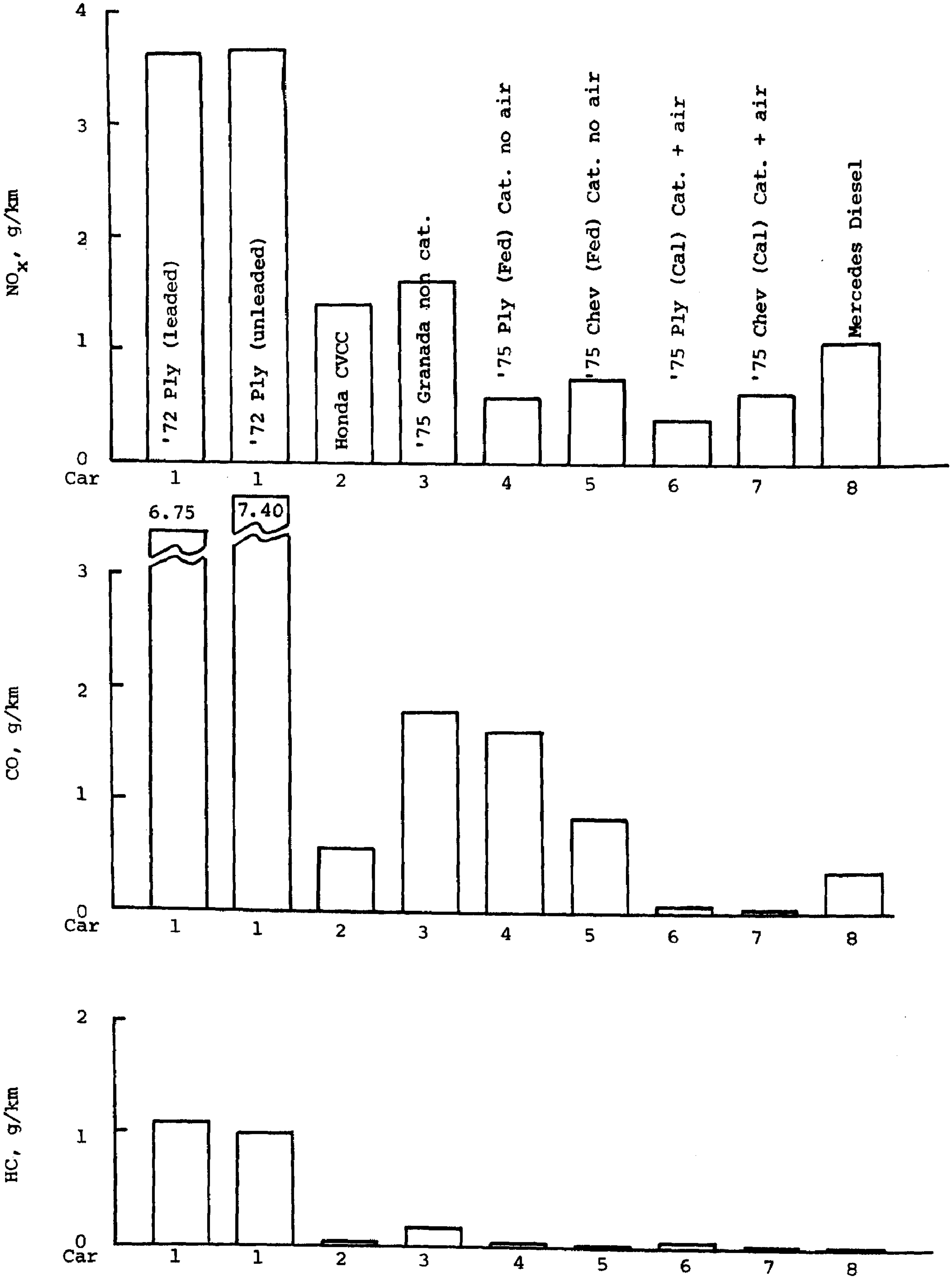



FIGURE 12. GASEOUS EMISSIONS IN g/km FROM TESTS AT 96 km/hr ON EIGHT CARS

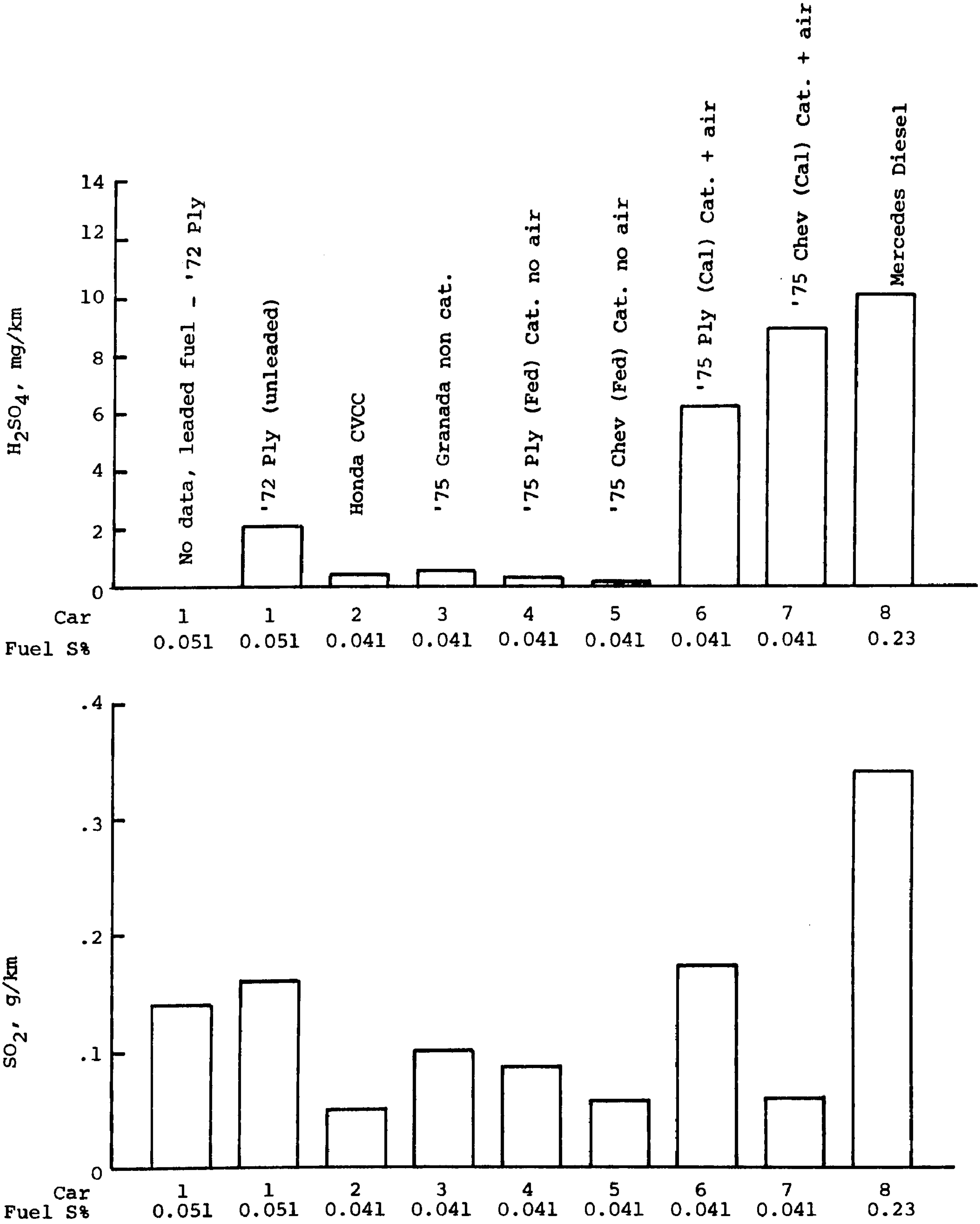



FIGURE 13. SULFURIC ACID AND SULFUR DIOXIDE EMISSIONS FROM 1975 FTP TESTS ON EIGHT CARS

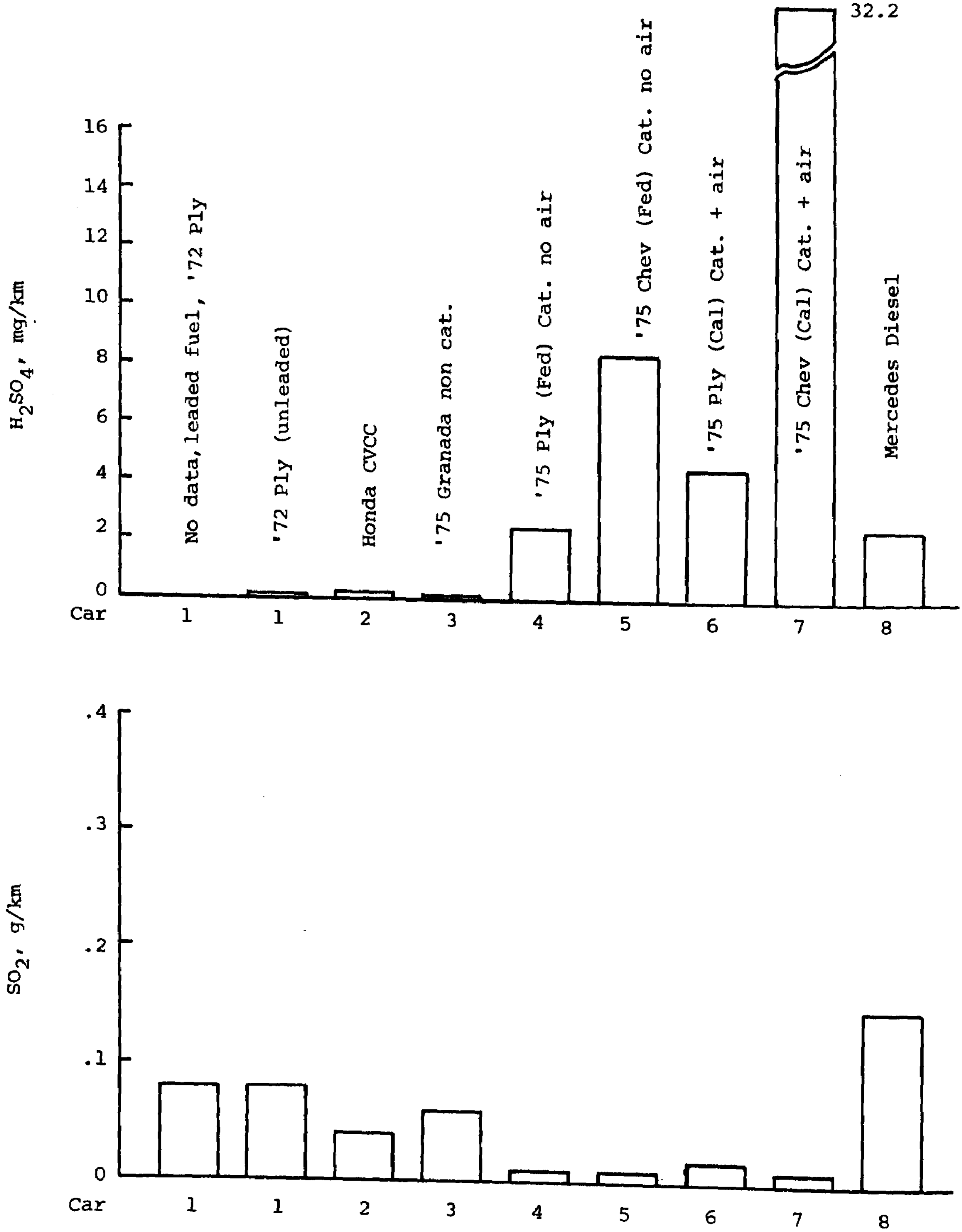



FIGURE 14. SULFURIC ACID AND SULFUR DIOXIDE EMISSIONS FROM TESTS AT 48 km/hr ON EIGHT CARS

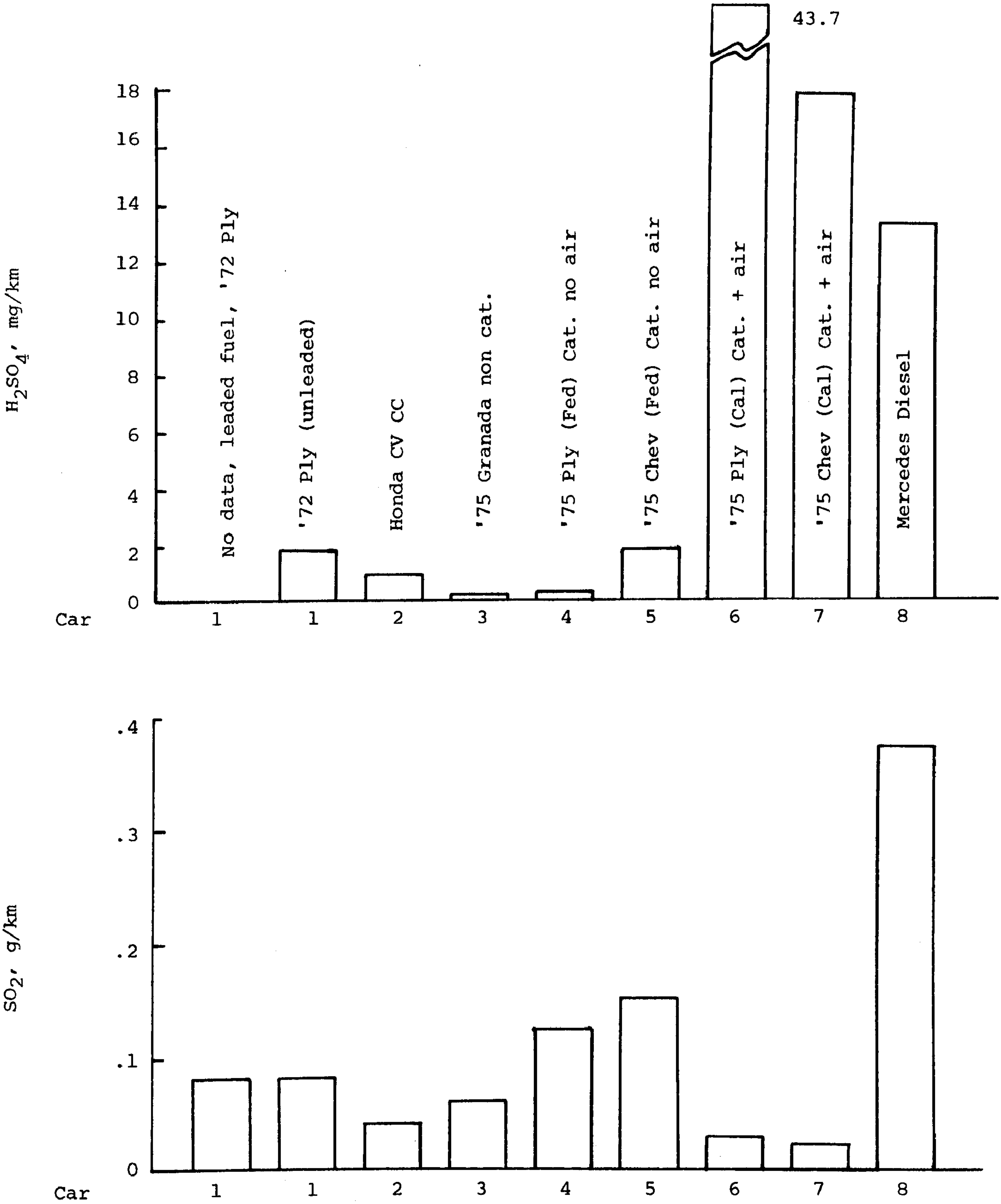



FIGURE 15. SULFURIC ACID AND SULFUR DIOXIDE EMISSIONS FROM TESTS AT 96 km/hr ON EIGHT CARS

for the 1975 Federal Ford Granada. The 1972 Plymouth, the 1975 Federal Chevrolet and the 1975 California Chevrolet did not meet their respective CO standards. The 1972 Plymouth and the 1975 Federal Ford Granada did not meet their respective HC standards. In general, however, the cars were considered close enough to their standards that they could be considered typical of their respective model.

The HC and CO emissions at 48 and 96 kph (30 and 60 mph) constant speed conditions are significantly lower than the FTP emissions for all cars. It is particularly interesting to compare the CO emissions for the 1972 Plymouth and the four catalyst cars (cars 4 through 7) at the 48 kph constant speed condition. The catalyst car CO emissions are approximately 2 percent of the 1972 car CO emissions at this condition. The $NO_x$ emissions at 48 kph are less than the FTP $NO_x$ emissions. The 96 kph $NO_x$ emissions are approximately the same as the FTP emissions for all cars, except for the Honda CVCC and the 1975 Federal Plymouth.

The sulfate emissions, shown in Figures 13 to 15, are somewhat more difficult to compare since the percent sulfur in the fuel is not the same for all cars. Since it is not certain that the sulfate emissions are directly proportional to the amount of sulfur in the fuel for a given car, no attempt will be made to adjust the emissions in mg/km to a single fuel sulfur level.

The sulfate emissions from the gasoline fueled, non-catalyst cars are in general agreement with those seen by other researchers. The 30 and 60 mph sulfate levels are in good agreement with the Ford and Exxon data summarized in Reference 7. The 1975 FTP sulfate levels of the 1972 Plymouth are approximately one and a half times the levls obtained by EPA-RTP on similar non-catalyst cars.[7] It should also be mentioned that the sulfate levels from the 1972 Plymouth are approximately 10 times the sulfate emissions seen from 1975 FTP tests of a 1972 Chevrolet engine tested on a special engine dynamometer by the Department of Emissions Research at SwRI.[8]

A careful comparison of the test data from these two different "vehicles" indicates that this difference is real. The 1972 Plymouth had been operated for approximately 30,000 miles on leaded fuel prior to being tested with unleaded fuel in this program. It is possible that despite efforts to ensure that the lead "motor mix" components were purged from the exhaust system prior to testing for sulfate, some artifacts of leaded fuel operation remained in the exhaust system contaminating the sulfate samples. See Appendix B for a discussion of the interferences to the BCA system caused by lead, bromine and chlorine compounds.

It is likely, considering that the car was operated for 500 miles to purge the motor mix compounds, that the FTP sulfate emission level from this car is real. The large percentage variation in noncatalyst FTP sulfate emis sions that would result from comparing this car with others is largely due to the small absolute magnitude of the noncatalyst FTP sulfate emissions.

The 48 kph steady state sulfate emissions in g/km are the lowest of the three test conditions. This is not surprising since sulfate emissions for a given noncatalyst vehicle tend to be a function of the amount of fuel used and the 48 kph condition uses the least fuel. It is interesting to note that the Honda has higher sulfate emissions at the 48 kph and 96 kph conditions than the Granada, despite the fact the Honda has considerably lower fuel consumption.

The sulfate emissions from the catalyst cars were also in general agreement with those found by other researchers.[7] As can be seen in Figures 13 to 15, catalyst cars equipped with air injection and calibrated to meet the 1975 California standard of 0.6 g/km HC, 5.6 g/km CO and 1.3 g/km $NO_x$, in general, have higher sulfate emissions than catalyst cars without air injection and calibrated to meet the 1975 Federal Standard of 0.9 g/km HC, 9.3 g/km CO and 1.9 g/km $NO_x$.

For the catalyst cars without air injection (cars 4 and 5), the 48 kph cruise condition produced the largest amount of sulfates in terms of mg/km. The catalyst cars equipped with air injection systems (cars 6 and 7) do not show the same results. Car 6 produces the most mg/km of sulfates at 96 kph and the least mg/km of sulfates at 48 kph. Car 7 produces the most sulfate at 48 kph and the least during the FTP test. The diesel car sulfate emissions in mg/km are in good agreement with those seen on single car tests at GM[9] and EPA[10] considering the size of the car tested in each case. The GM and EPA tests were on smaller cars. The GM test on a "small diesel-powered car" gave 9.94 g/km by a 1972 FTP using No. 2 diesel fuel with 0.39 percent sulfur. The EPA baseline test on a prototype diesel-powered VW Rabbit gave 5.3 g/km on a 1975 FTP using No. 2 diesel fuel with 0.27 percent sulfur. The sulfate emissions from the diesel car are probably a function of the fuel consumed since the lowest sulfate emissions are at 48 kph and the highest at 96 kph. While the diesel car has the highest sulfate emissions of any of the noncatalyst cars, it should be kept in mind that the test diesel fuel contained approximately six times the sulfur contained in the test gasoline.

Since the cars were run on fuels with three different sulfur levels, it is instructive to compare the cars in terms of percentage of fuel sulfur converted to sulfuric acid. This is done in Figures 16 to 18. The noncatalyst gasoline powered cars had total sulfur recoveries between 82 percent and 114 percent for the three different test types. This range should probably be considered the range of values obtainable for complete sulfur recovery using the $SO_2$-BCA method. There is apparently no temporary storage and release of sulfur compounds associated with the noncatalyst cars. Less than 1.5 percent of the fuel sulfur was converted to exhaust sulfuric acid for any of the three test conditions run on the three non catalyst cars (cars 1 to 3).

The catalyst cars without air injection had total recoveries of approximately 45 to 59 percent for the FTP and approximately 19 to 21 percent for the 48 kph test. These total sulfur recoveries indicate that there is a net sulfur storage in the catalyst during these tests. The total sulfur recoveries for these two cars from the 96 kph tests were approximately 175 and 159 percent, indicating a net sulfur release from the catalyst for this test. The highest percentage of fuel sulfur converted to exhaust sulfuric acid for the test series run on the catalyst cars without air injection was 7.3 percent. This occurred on the 48 kph test of car number 5. It is interesting that on both these cars the highest fuel sulfur conversion to sulfuric acid occurred at 48 kph; the test condition with the smallest total sulfur recovery.

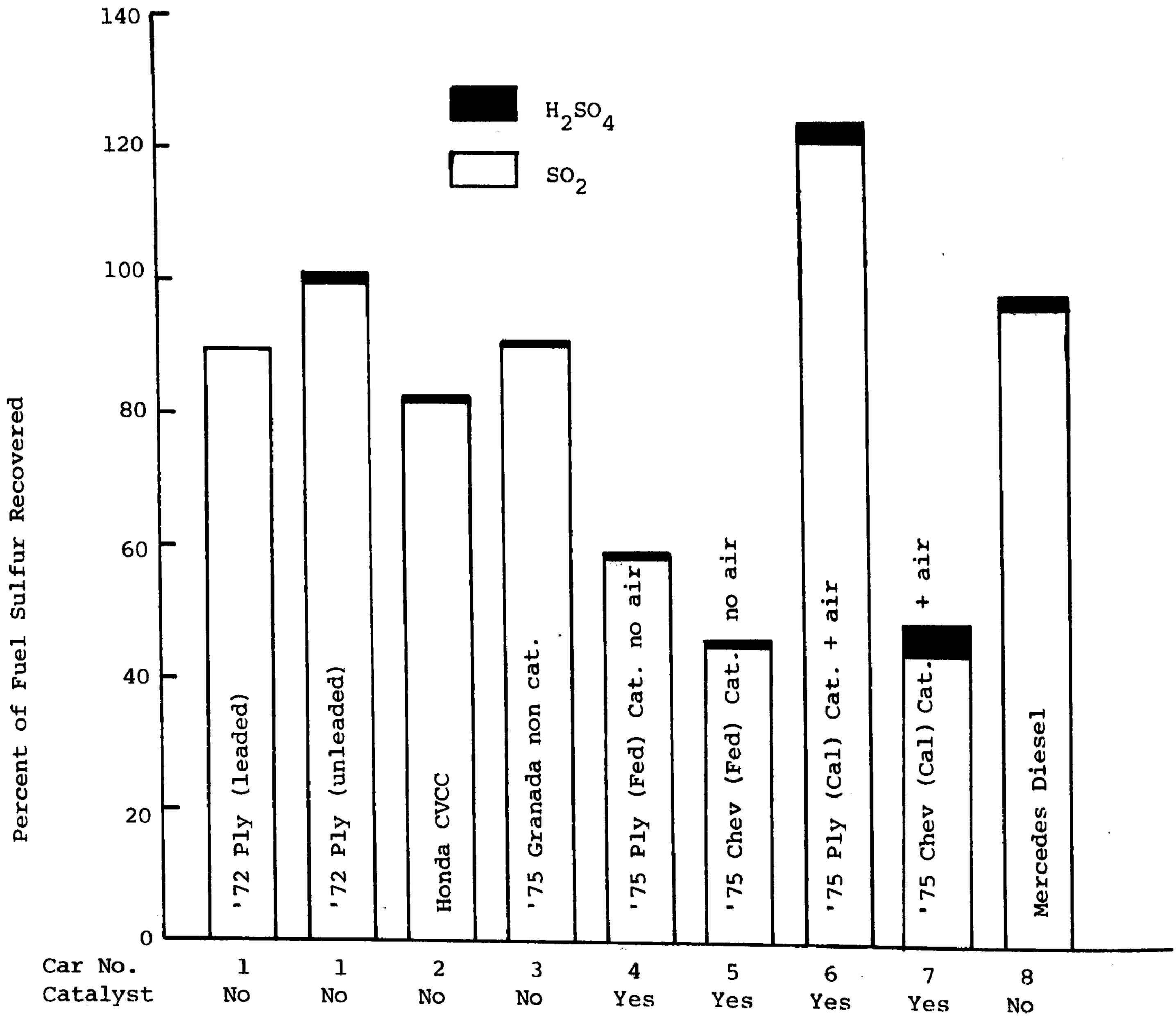



FIGURE 16. PERCENT OF FUEL SULFUR RECOVERED IN VEHICLE EXHAUST AS SULFURIC ACID AND SULFUR DIOXIDE FOR FTP TESTS ON EIGHT CARS

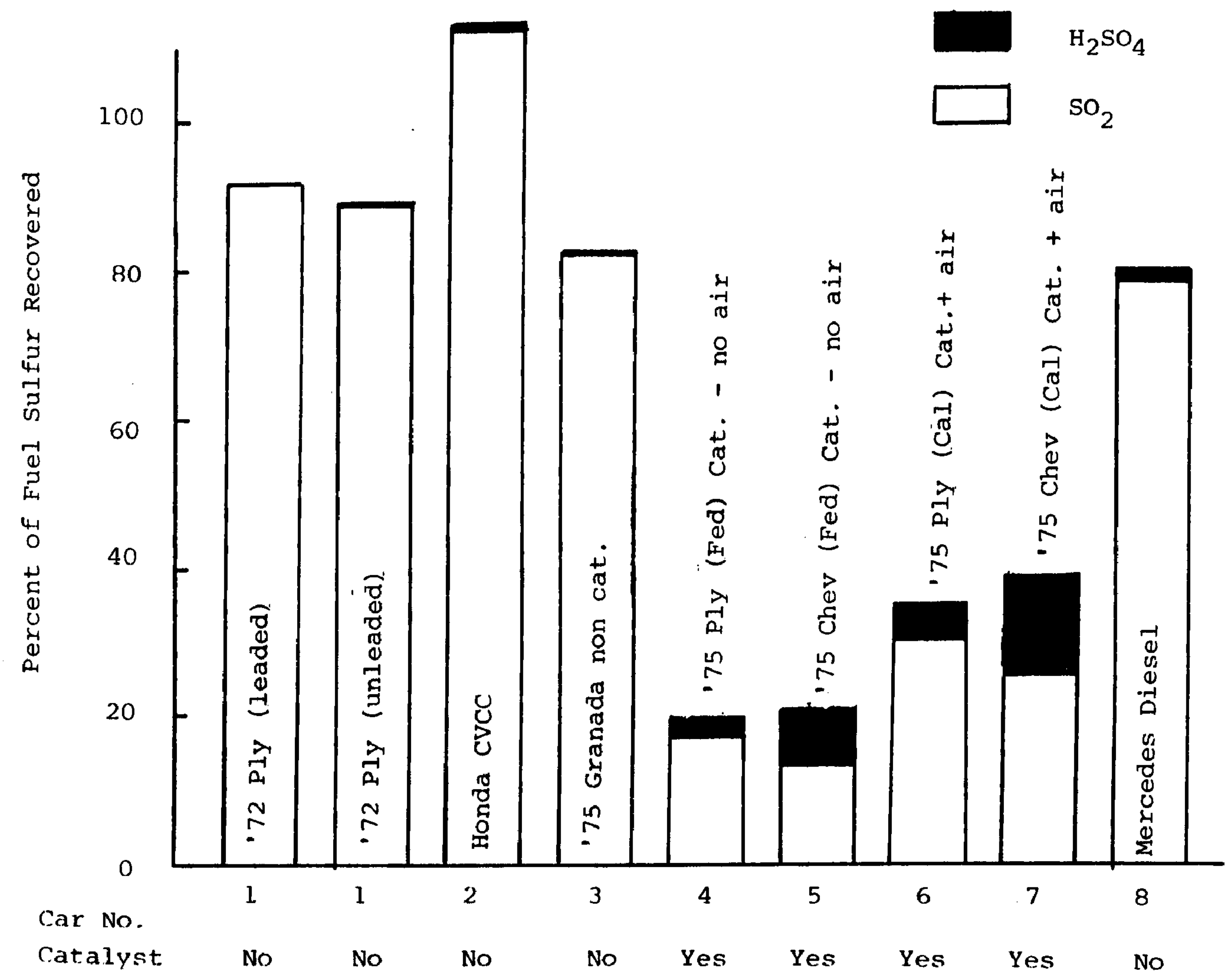



FIGURE 17. PERCENT OF FUEL SULFUR RECOVERED IN VEHICLE EXHAUST AS SULFURIC ACID AND SULFUR DIOXIDE FOR 48 kph STEADY STATE TESTS OF EIGHT CARS

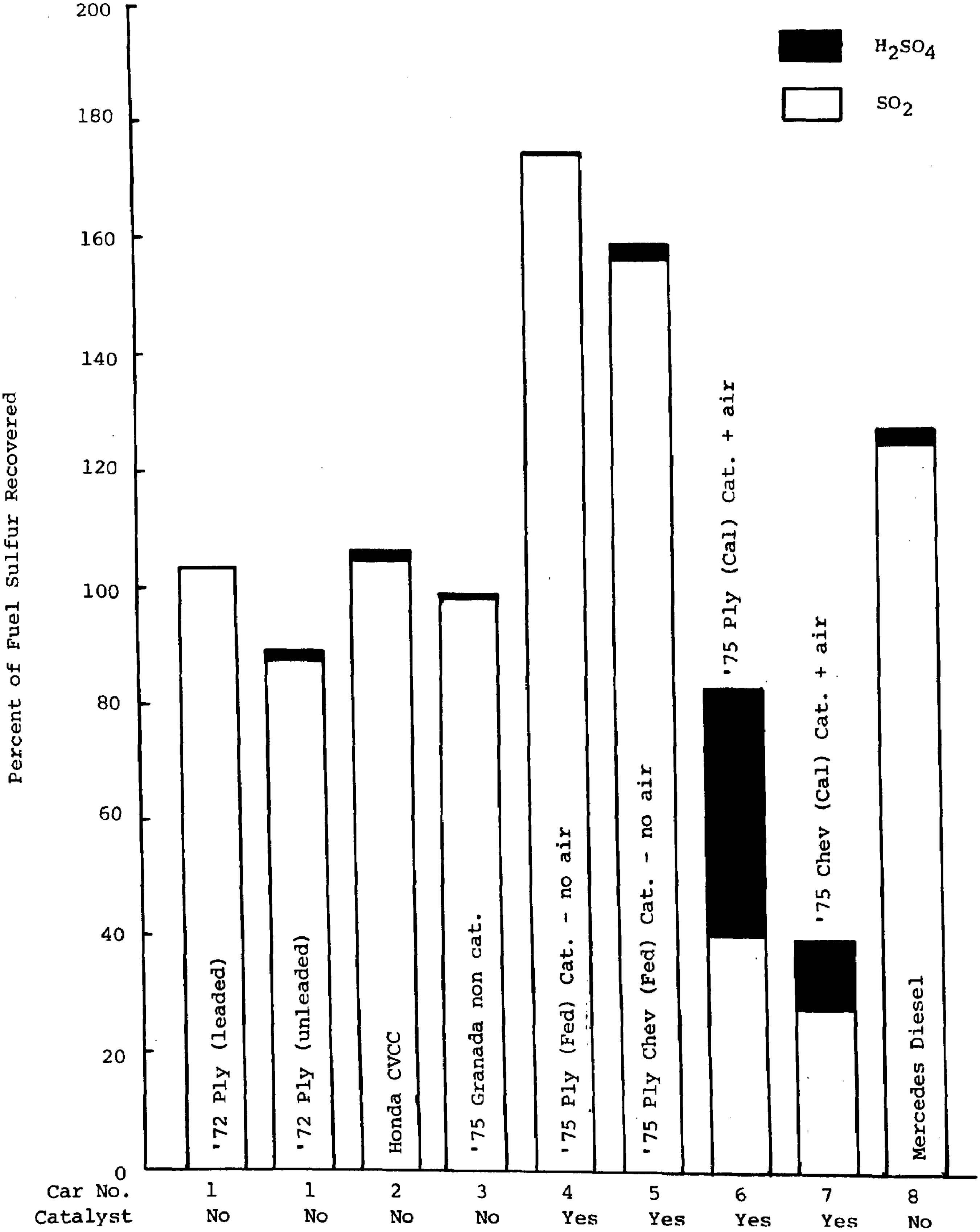



FIGURE 18. PERCENT OF FUEL SULFUR RECOVERED IN VEHICLE EXHAUST AS SULFURIC ACID AND SULFUR DIOXIDE FOR 96 kph STEADY STATE TESTS OF EIGHT CARS

The results from catalyst cars with air injection (cars 6 and 7) are again, harder to interpret. Examining the total sulfur recoveries from the FTP it appears that car 6 had a net release of sulfur and car 7 a net storage of sulfur during this test. Both cars definitely stored sulfur during the 48 kph run as evidenced by their total recoveries of approximately 36 percent for car 5 and 39 percent for car 7. Unlike the catalyst cars without air injection, cars with air injection (6 and 7), did not release sulfur during the 96 kph test. Car 6 may have had some storage, but the sulfur recovery data indicates essentially complete recovery of the fuel sulfur. Car 7 definitely stored sulfur during the 96 kph test.

For car 6, more of the fuel sulfur was converted to sulfuric acid (42 percent) at 96 kph than at any other test condition. Car 7, like the two non-air injected cars converted the largest amount of fuel sulfur to sulfuric acid (20 percent) during the 48 kph test.

The diesel car had total recoveries ranging from approximately 80 to 128 percent for the three tests. It is felt that this range of recoveries represents complete fuel sulfur recovery for each test, with no storage or release of sulfur. The maximum percent of fuel sulfur converted to sulfuric acid for any of the diesel car tests was 2.9 percent at the 96 kph condition. The conversion percentage is similar to the non-catalyst gasoline cars. This indicates that the relatively higher diesel mg/km sulfate emissions are caused by the diesel fuel sulfur levels being higher than the gasoline levels (0.23 versus 0.04).

Results of Method 8 Tests

As explained in Section II of this report, at the beginning of the project, it was felt by some researchers that EPA stationary source Method 8 test might be an acceptable procedure for determining automobile exhaust sulfates and $SO_2$. To determine the Method's applicability, steady state tests at 48 and 96 kph were run on the 1972 Plymouth, with leaded and unleaded fuel, and on the 1975 Honda CVCC. The results of these tests are presented in Table 5. The top part of the table contains the results of the tests with leaded and unleaded fuel on the 1972 Plymouth. The lower part of the table contains the test results from the 1975 Honda CVCC.

The $SO_2$ levels from the leaded fuel 48 and 96 kph tests on the 1972 Plymouth using Method 8 were 0.07 and 0.08 g/km, respectively. No sulfate was detected from leaded fuel tests of this car using Method 8, even after sampling for 90 minutes at 48 kph and 60 minutes at 96 pkh. This does not necessarily mean that no sulfuric acid was formed inthe exhaust. it merely indicates that it was not detected by the sampling method. The problem was one of obtaining a definite end-point for the sulfate analysis procedure of Method 8. In the analysis of the leaded fuel tests, the solution from the first (sulfate) bubbler did not turn a bright yellow when the thorin indicator was added as it did in the unleaded fuel tests and in the $SO_2$ bubblers from both unleaded and leaded fuel tests. The color produced was a dirty orange-yellow that did not change regardless of the amount of barium perchlorate added during the titration. Thus, it is uncertain what the leaded fuel test results demonstrate. It may be that there is no sulfate present,

TABLE 5. SUMMARY OF EPA METHOD 8 TEST RESULTS

| Test Date | Test Type | Test Duration min | $SO_2$, g/km | $H_2SO_4$, Mg/km | Percent Fuel S as $SO_2$ | Percent Fuel S as $H_2SO_4$ | Percent Fuel S Recovered |
|---|---|---|---|---|---|---|---|
| **1972 Plymouth With 360 CID Engine Leaded Fuel, (0.051% Sulfur)** | | | | | | | |
| 10/22/74 | 48 kph | 90 | 0.074 | None detected | 80.2 | - | 80.2 |
| 11/7/74 | 48 kph | 90 | 0.062 | | 78.5 | - | 78.5 |
| 11/18/74 | 48 kph | 90 | 0.080 | | 88.1 | - | 88.1 |
| 2/17/75 | 48 kph | 90 | 0.050 | | 52.9 | - | 52.9 |
| 2/18/75 | 48 kph | 90 | 0.067 | | 73.5 | - | 73.5 |
| Average | 48 kph | 90 | 0.067 | | 74.5 | - | 74.5 |
| 11/8/74 | 96 kph | 70 | 0.070 | | 69.6 | - | 69.6 |
| 11/8/74 | 96 kph | 60 | 0.080 | | 84.1 | - | 84.1 |
| 11/18/74 | 96 kph | 60 | 0.082 | | 78.0 | - | 78.0 |
| 11/21/74 | 96 kph | 60 | 0.076 | | 71.3 | - | 71.0 |
| Average | 96 kph | | 0.077 | | 75.8 | - | 75.8 |
| **Unleaded Fuel (0.051% Sulfur)** | | | | | | | |
| 1/27/75 | 48 kph | 90 | 0.065 | 5.52 | 69.9 | 3.9 | 73.8 |
| 1/28/75 | 48 kph | 90 | 0.065 | 4.28 | 74.8 | 3.2 | 78.0 |
| Average | 48 kph | 90 | 0.065 | 4.97 | 72.2 | 3.6 | 75.8 |
| 1/29/75 | 96 kph | 60 | 0.074 | 3.73 | 85.1 | 2.8 | 87.9 |
| 1/29/75 | 96 kph | 60 | 0.071 | 3.31 | 75.1 | 2.3 | 77.4 |
| Average | 96 kph | 60 | 0.073 | 3.52 | 80.0 | 2.6 | 82.6 |
| **1975 Honda Civic With a 1500cc CVCC Engine Unleaded Fuel, (0.041% Sulfur)** | | | | | | | |
| 2/10/75 | 48 kph | 90 | 0.027 | 1.67 | 81.5 | 3.3 | 84.8 |
| 2/19/75 | 48 kph | 90 | 0.027 | 1.55 | 84.3 | 3.2 | 87.5 |
| Average | 48 kph | 90 | 0.027 | 1.61 | 83.0 | 3.2 | 86.2 |
| 2/6/75 | 96 kph | 60 | 0.036 | 4.99 | 83.7 | 8.5 | 92.2 |
| 2/10/75 | 96 kph | 60 | 0.036 | 3.15 | 90.4 | 5.2 | 95.6 |
| Average | 96 kph | 60 | 0.036 | 4.07 | 87.0 | 6.8 | 93.9 |

or it may be that the lead in the exhaust reacts with the thorin indicator giving the color observed.

Thus for the leaded fuel tests, only the fuel sulfur converted to $SO_2$ was measured in the exhaust. The percentage of fuel sulfur recovered in this manner was approximately 75 percent for both the 48 and 96 kph tests.

For the tests of the 1972 Plymouth using unleaded fuel, the Method 8 $SO_2$ levels for 48 and 96 kph averaged 0.06 g/km and 0.07 g/km, respectively. Note that the $SO_2$ emissions from the unleaded fuel show good agreement with the $SO_2$ emissions from the leaded fuel tests.

The unleaded fuel sulfate emissions using the Method 8 procedure averaged 5.0 mg/km of $H_2SO_4$ at 30 mph and 3.5 mg/km of $H_2SO_4$ at 60 mph. The Method 8 sulfate results are questionable since no definite pink end-point occurred for the sulfate sample in the titration procedure. During the titration procedure, the sulfate sample color turns from a bright yellow to a dirty-orange-yellow very gradually with no sharp end-point. The Method 8 $SO_2$ samples do, however, have a reasonably good pink end-point.

The total sulfur recovery for the unleaded fuel tests on the 1972 Plymouth was approximately 76 percent for the 48 kph tests and 83 percent for the 96 kph tests. Note that these recoveries are in close agreement with the leaded fuel tests. The sulfate emissions expressed as percent of fuel sulfur averaged 3.6 for the 48 kph tests and 2.6 for the 96 kph tests.

The $SO_2$ emissions from tests on the Honda CVCC were 0.03 g/km for the 48 kph tests and 0.04 for the 96 kph tests, as shown in the lower part of Table 5. These $SO_2$ emissions are lower than the Plymouth $SO_2$ emissions as would be expected since fuel used on the Honda tests has a lower sulfur level and the Honda used less fuel.

The total sulfur recovery for the Honda was somewhat better than the total recovery for the Plymouth. The Honda had a total sulfur recovery of 86 percent at 48 kph and 94 percent at 96 kph. The percent of fuel sulfur recovered as sulfuric acid was 3.2 percent at 48 kph and 6.8 percent at 96 kph. As was the case with the sulfate samples from the Plymouth, there was no distinct end-point in the titration of the sulfate samples from the Honda CVCC.

The Method 8 test results and the BCA test results in mass units per kilometre are compared in Figure 19. As can be seen in the figure, the $SO_2$ emissions by Method 8 are always lower than the $SO_2$ emissions by BCA. However, they are generally within 0.015 g/km of the BCA $SO_2$ emissions. The Method 8 $SO_2$ emissions at 48 kph averaged about 22 percent less than the BCA-$SO_2$ emissions. At 96 kph, the Method 8 $SO_2$ emissions averaged about 8 less than the BCA-$SO_2$ emissions.

Recall that for leaded fuel tests of the Plymouth, sulfate was measured using Method 8 only. The barium chloranilate procedure for analyzing sulfate on filters was not useable with leaded fuel because of the interferences from the scavengers used with the lead. Therefore, there is no comparison data available for the leaded fuel tests on the Plymouth. For the remainder of the tests, Method 8 sulfate results in mg/km were from 2 to 50

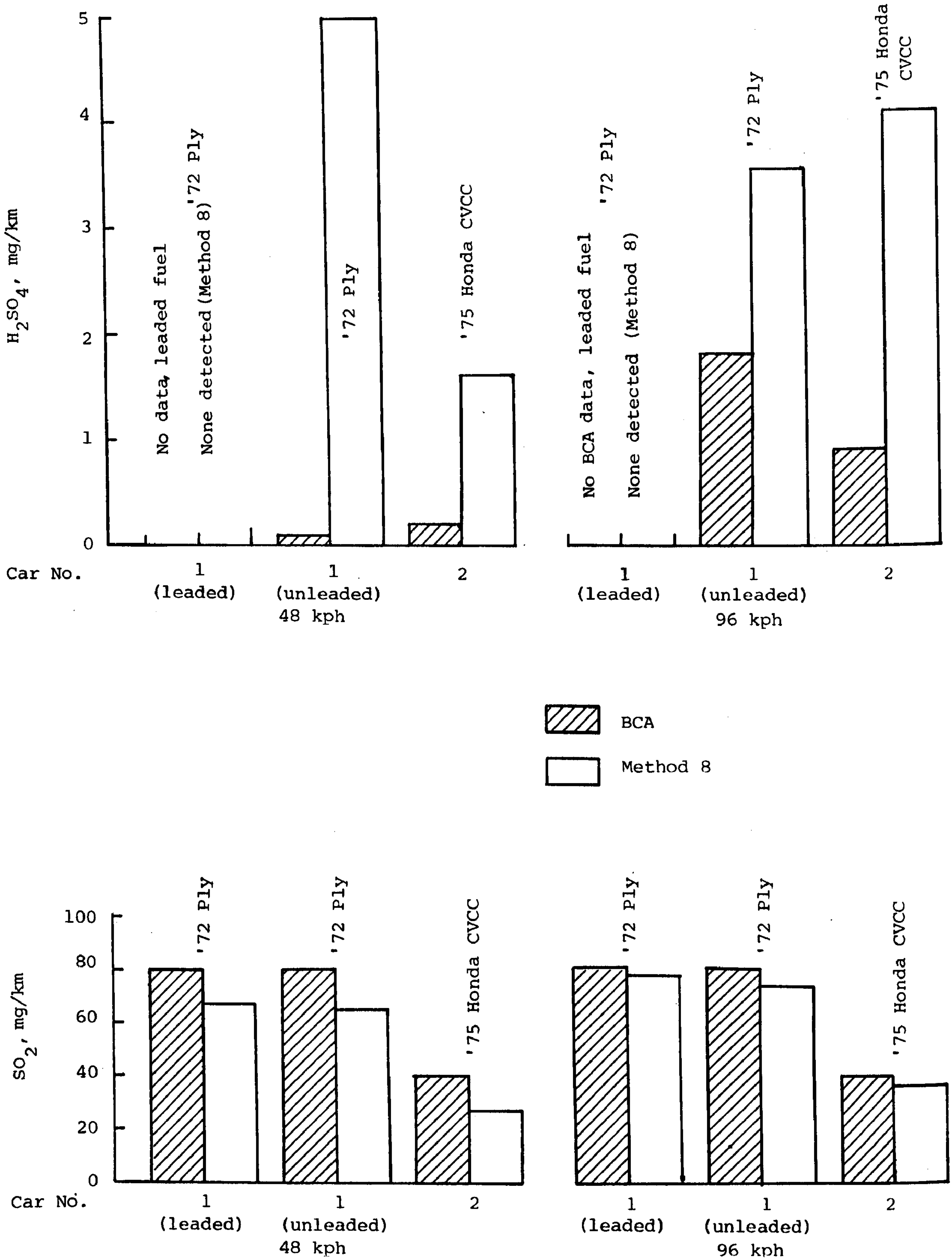



FIGURE 19. COMPARISON OF METHOD 8 AND BCA $SO_2$ AND SULFATE RESULTS IN mg/km FOR 48 AND 96 kph STEADY STATE TESTS FOR TWO NON CATALYST CARS

times higher than the BCA sulfate results.

Figure 20 shows the comparison of Method 8 and BCA results in terms of percent of fuel sulfur recovered as $SO_2$ and sulfuric acid. At 48 kph, the total recovery by the BCA procedure averaged 98 percent, while the total recovery by Method 8 averaged 79 percent. At 96 kph, the total recovery by the BCA procedure averaged 100 percent, while the total recovery by Method 8 averaged 84 percent. In all cases the total recovery by BCA was greater than the total recovery by Method 8. The BCA values were closer to the desired 100 percent recovery. The percentage of fuel sulfur recovered as sulfuric acid was less for the BCA procedure for all tests.

In summary, the Method 8 procedure yielded lower $SO_2$ values, higher sulfuric acid values, and recovered less of the total fuel sulfur than the BCA procedure. It is felt that the Method 8 procedure as outlined in the Federal Register for stationary sources is inferior to the BCA procedure because of the problem of obtaining a definite titration end-point for the sulfate sample. Apparently, Method 8 can yield accurate results at higher sulfate levels that are more free from interferences such as may be the case for stack samples, but is not as satisfactory for sulfate in automobile exhaust.

Of course, there are improvements that could be made to Method 8, such as passing the sample through a cation exchange column prior to titration and the use of automatic titration equipment. However, at the conclusion of these three sets of tests, it was felt that there was no need to develop the Method 8 procedure further. The BCA procedure for analyzing sulfate filters was entirely satisfactory and there was no pressing need for an alternate method. Therefore, the use of Method 8 was discontinued.

Filter Particulate Weights

As mentioned in the introduction, sulfuric acid emissions from catalyst cars were originally confirmed during studies of particulate emissions from gasoline-powered automobiles. There was some interest as to how much of the total particulate mass collected on a filter was sulfuric acid. It should be mentioned that although the 21 cm tunnel is adequate for sulfate, no claim was made that the 21 cm diameter sulfate sampling tunnel is an adequate tunnel for total particulate sampling. No checks were run to determine its ability to collect particulate matter over the range that might be seen in automobile exhaust. Thus, no claim is made that a representative sample of all exhaust particulates were collected on the sulfate filter. Nevertheless, each sulfate filter was weighed on a microgram balance before and after use.

The three noncatalyst gasoline-powered cars were tested prior to the initiation of the filter ammoniation procedure, thus the sulfate on the filter is in the form of sulfuric acid when weighed. Since sulfuric acid is hydroscopic, there is also some amount of water associated with the sulfuric acid on the filter. The amount of water is dependent in part, on the amount of sulfuric acid and the humidity of the environment to which it has been exposed. Thus, it is not unreasonable to expect a varying amount of water from filter to filter. This makes interpretation of the net filter

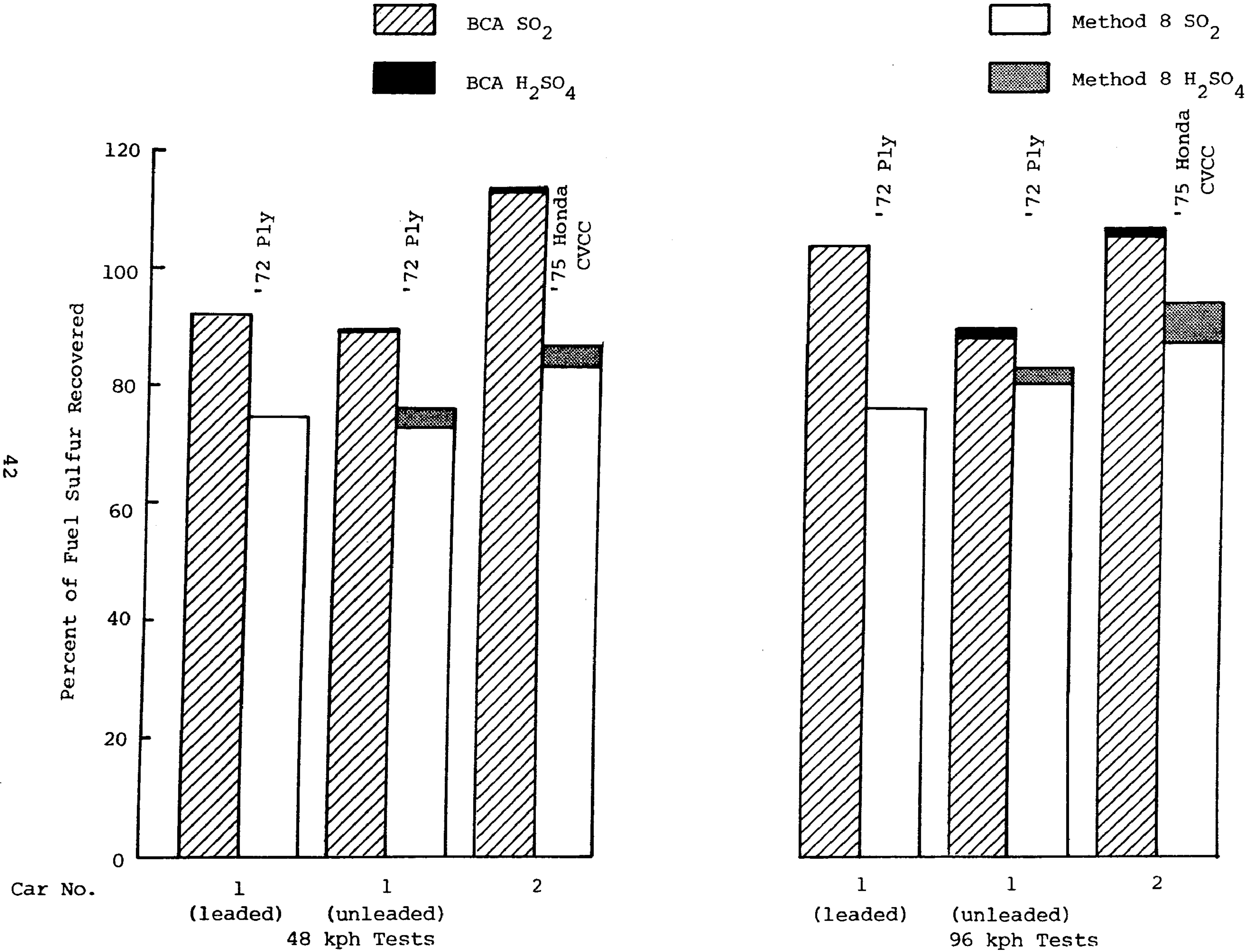



FIGURE 20. COMPARISON OF METHOD 8 AND BCA RESULTS AS PERCENT OF FUEL SULFUR RECOVERED FOR TWO NON CATALYST CARS

weight difficult. This variability is not due to conditions under which the filter was weighed since the temperature and humidity were rigidly maintained.

Table 6 contains the net filter weights obtained from the microgram balance together with the sulfate, as sulfuric acid, per filter from the BCA analysis. Figure 21 is a plot of these data. As can be seen from the figure there is no simple relationship between the net balance weight and the BCA sulfuric acid weight.

Starting with the four catalyst cars, the sulfate laden filters were exposed to ammonia gas prior to the after test weighing. This exposure converted the sulfuric acid to ammonium sulfate. This compound has the advantage of not being hydroscopic, thus eliminating the problem of absorbed water on the filter.

The sulfate characterization tests were only a small part of the sulfate testing done on the four catalyst cars. Since the report section of distance accumulation includes a discussion of the relationships between filter weight and BCA sulfate weight for all tests on these cars, those results will not be covered here.

Elemental Analysis of Tunnel Sweepings

There has been some concern that catalysts may emit, as particulate matter from the exhaust, amounts of the noble metals used in the catalyst. To investigate this problem as well as to try and identify, on an elemental basis, any difference in exhaust particulate emissions from several car types the sulfate tunnel particulate residue was analyzed by X-ray fluorescence techniques.

After the test series was completed on each gasoline-powered car, the sulfate sampling tunnel was swept out with a fine bristle brush. The tunnel residue from the diesel car tests was not collected. The special problem of diesel engine particulate is currently being researched at SwRI[11] in a far more rigorous and complete manner than could be done with the amount of effort allotted to the examination of tunnel residue.

Elemental analysis of the tunnel residue for each car, as percent of sample by weight, is shown in Table 7. The analysis was requested for platinum (Pt), palladium (Pd), aluminum (Al), nickel (Ni), iron (Fe), sulfur (S), lead (Pb), zinc (Zn), copper (Cu), and tin (Sn). Of these 10 elements, no platinum, palladium, nickel, copper or tin was found in any of the samples. Chromium, silicon, and manganese were found in some of the samples and are included in Table 7. The detection limits for the 10 elements requested are also shown in Table 7.

Examination of Table 7 indicates that the largest part of each sample was iron. From a visual inspection of the samples, the iron is apparently in the form of rust, probably from the exhaust system. The other elements were found in much smaller quantities. It is thought that the silicon may be from traces of the glass $SO_2$ probe which was broken rather frequently during test preparations. The genesis of the other elements is open to speculation.

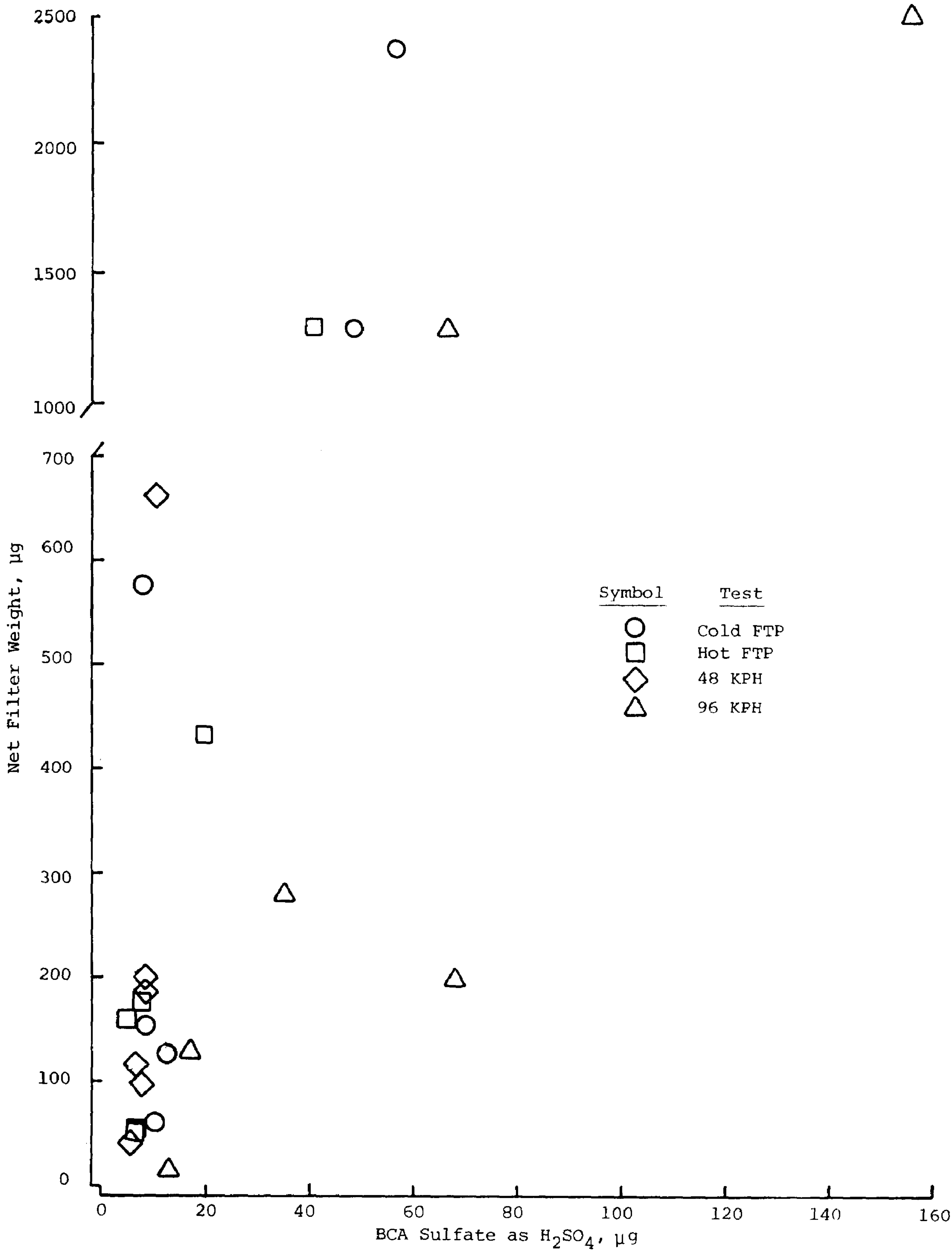



FIGURE 21. COMPARISON OF FILTER WEIGHT AND SULFATE WEIGHT PER FILTER BY BCA ANALYSIS FOR THREE CARS

TABLE 6. COMPARISON OF FILTER WEIGHTS AND SULFATE WEIGHTS PER FILTER BY BCA ANALYSIS FOR THREE CARS

| Date | Test | Filter No. | Balance net μg/filter | BCA $SO_4^=$ μg/filter | BCA as $H_2SO_4$ |
|---|---|---|---|---|---|
| | | | 1973 PLYMOUTH, UNLEADED FUEL | | |
| 1/28/75 | FTP Cold | 47-FH-122 | 2363 | 55.63 | 56.80 |
| 1/28/75 | FTP Hot | 47-FH-123 | 1297 | 39.58 | 40.41 |
| 1/27/75 | 48 kph | 47-FH-121 | 663 | 10.19 | 10.40 |
| 1/29/75 | 96 kph | 47-FH-128 | 2763 | 151.78 | 154.97 |
| 1/29/75 | FTP Cold | 47-FH-126 | 1370 | 47.26 | 48.25 |
| 1/29/75 | FTP Hot | 47-FH-127 | 432 | 19.21 | 19.61 |
| 1/28/75 | 48 kph | 47-FH-125 | 118 | 6.66 | 6.80 |
| 1/29/75 | 96 kph | 47-FH-129 | 1285 | 65.10 | 66.47 |
| | | | 1975 HONDA CIVIC CVCC | | |
| 2/11/75 | FTP Cold | 47-FH-146 | 62 | 9.95 | 10.16 |
| 2/11/75 | FTP Hot | 47-FH-147 | 178 | 7.65 | 7.81 |
| 2/10/75 | 48 kph | 47-FH-142 | 189 | 8.58 | 8.76 |
| 2/10/75 | 96 kph | 47-FH-143 | 281 | 34.57 | 35.30 |
| 2/12/75 | FTP Cold | 47-FH-148 | 155 | 8.40 | 8.58 |
| 2/12/75 | FTP Hot | 47-FH-149 | 161 | 4.44 | 4.53 |
| 2/19/75 | 48 kph | 47-FH-152 | 205 | 8.38 | 8.55 |
| 3/12/75 | 96 kph | 47-FH-210 | 197 | 67.02 | 68.43 |
| | | | 1975 FORD GRANADA | | |
| 3/10/75 | FTP Cold | 47-FH-189 | 578 | 7.81 | 7.97 |
| 3/10/75 | FTP Hot | 47-FH-190 | 53 | 6.37 | 6.50 |
| 3/06/75 | 48 kph | 47-FH-177 | 100 | 7.38 | 7.53 |
| 3/06/75 | 96 kph | 47-FH-178 | 128 | 16.90 | 17.25 |
| 3/07/75 | FTP Cold | 47-FH-179 | 127 | 11.92 | 12.17 |
| 3/07/75 | FTP Hot | 47-FH-180 | 55 | 6.37 | 6.50 |
| 3/07/75 | 48 kph | 47-FH-181 | 41 | 5.66 | 5.78 |
| 3/07/75 | 96 kph | 47-FH-182 | 17 | 12.83 | 13.10 |

TABLE 7. RESULTS OF X-RAY FLUORESCENT ANALYSIS OF SULFATE SAMPLING TUNNEL PARTICULATE RESIDUE FOR SULFATE CHARACTERIZATION CARS

| Car | Total Weight Collected grams | Weight X-rayed mg | Elements, Percent by Weight | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Al | Fe | S | PB | An | Cr | Si | Mn |
| 72 Plymouth (Leaded fuel) | 2.316 | 2.46 | 0.3 | 13.7 | 0.7 | 2.5 | --- | --- | 0.2 | --- |
| 72 Plymouth (Unleaded) | 1.629 | 1.75 | 0.2 | 18.3 | 0.6 | --- | --- | 0.3 | 0.3 | --- |
| 75 Honda CVCC | 1.285 | 2.47 | --- | 30.2 | 0.1 | --- | --- | 0.2 | 0.1 | 0.3 |
| 75 Ford Granada | 0.113 | 1.43 | --- | 21.0 | 0.9 | 2.6 | 0.4 | --- | 0.9 | --- |
| EM-1 2000 mi | 0.053 | 1.36 | 0.4 | 29.3 | 0.2 | --- | --- | 0.2 | 0.4 | 0.2 |
| EM-2 2000 mi | 0.163 | 2.16 | 0.2 | 24.2 | 0.3 | --- | --- | 0.1 | 0.1 | 0.4 |
| EM-3 2000 mi | 0.051 | 1.31 | 0.4 | 28.1 | 0.5 | --- | --- | --- | 0.9 | --- |
| EM-4 2000 mi | 0.019 | 1.46 | 0.2 | 21.8 | 0.2 | --- | --- | --- | 0.1 | --- |
| Detection limits, µg | | | 1.0 | 1.0 | 1.0 | 12.5 | 1.0 | | | |
| Detection limit, wt % of 1000 µg sample | | | 0.1 | 0.1 | 0.1 | 1.25 | | | | |

Note: Detection limit for Pt, Ni, Cu, Sn and Pd are all 1.0 µg or 0.1% of 1000 µg sample.

## IV. EFFECTS OF DISTANCE ACCUMULATION

This section covers the sulfate emission testing of four catalyst cars at regular intervals during an accumulation of approximately 80,500 kilometres on each vehicle.

### A. Purpose

The purpose of this portion of the project was to measure HC, CO, $NO_x$, $SO_2$ and sulfates on four catalyst equipped cars to determine the behavior of sulfate emissions with distance accumulation. Where possible, the conditions of storage and release of sulfur compounds from the catalyst were to be identified.

### B. Cars Tested

To meet the objectives of this part of the project, four popular full size, 1975 passenger cars were selected for testing. Two of the cars were Chevrolet Impalas equipped with pelleted catalysts. The other two cars were Plymouth Gran Furys equipped with monolith catalysts. One of each of the models was manufactured to meet 1975 California emission standards and was equipped with an air injection system upstream of the catalyst. Table 8 gives a complete description of the four cars. Pictures of the four cars are shown in Figure 9 of Section III.

### C. Fuel Used

Initially the cars were scheduled to complete the distance accumulation program at 24,100 km. One 15,000 litre batch of fuel was felt to be sufficient for the testing scheduled. As the project progressed, additional tests were added to the test sequence consuming the fuel at a faster rate than planned. Just prior to the 16,000 km test on all cars, a new 15,000 litre batch of fuel was obtained from the same supplier. After the 24,100 km tests, the distance accumulation was extended to 80,500 km. Because available tankage had already been committed to other projects, it was not possible to secure one batch of fuel for the 24,100 to 80,500 km distance accumulation. Thus, two additional batches of fuel were required to complete the 80,000 km accumulation on all four vehicles.

The base fuel used was Gulf Oil company's "Gulf Crest" brand of unleaded gasoline. This fuel was chosen because of its low sulfur content as delivered and its commercial availability, since it was desired to operate the cars on a typical retail gasoline. As mentioned in the characterization section, a sulfur level of 0.040 percent was chosen based on Bureau of Mines gasoline surveys of leaded fuels in the early 1970's. Thiophene, a sulfur compound occurring naturally in gasoline, was used to increase the fuel sulfur level to a nominal 0.040 percent.

Table 9 lists the four fuel batches used and the sulfur content of each batch after addition of thiophene. Also shown are the test sequences for which each fuel batch was used. Complete analyses of the fuels designated EM-212F, EM-250F and EM-254F and the sulfur analysis of all four fuels are contained in Appendix F.

TABLE 8. CARS TESTED IN DISTANCE ACCUMULATION

| SwRI Car Number | EM-1 | EM-2 | EM-3 | EM-4 |
|---|---|---|---|---|
| Manufacturer | Plymouth | Chevrolet | Plymouth | Chevrolet |
| Model | Gran Fury | Impala | Gran Fury | Impala |
| Model Year | 1975 | 1975 | 1975 | 1975 |
| Applicable Emission Std. | '75 Fed. | '75 Fed. | '75 Calif. | '75 Calif. |
| Date Manufactured | 9/74 | 3/75 | 3/75 | 4/75 |
| Veh. Ident. No. | PH41K5D-<br>114692 | 1L69H5S-<br>137797 | PH41J5D-<br>209866 | 1L69L5J-<br>216102 |
| Engine Size, litres | 5.90 | 5.73 | 5.90 | 5.73 |
| Arr. & No. of Cyl. | V-8 | V-8 | V-8 | V-8 |
| Engine Serial No. | 5E114692 | 15S137797-<br>VO312CMJ | 5E209866 | 15J21602-<br>VO411CMM |
| Transmission | Automatic | Automatic | Automatic | Automatic |
| Catalyst Type | Monolith | Pelleted | Monolith | Pelleted |
| Catalyst Serial No. | | 009454 | | 094546 |
| Air Injection | NO | NO | YES | YES |
| Carburetor Mfgr. | Holley | Rochester | Carter | Rochester |
| No. of Carb. Barrels | 2 | 2 | 4 | 4 |
| Car. Serial No. | R7226A-<br>3830563 2494 | 22-5-TH-<br>7045114 | | 7045504-<br>TM0505 |
| Ignition System | Breakerless<br>Electronic | Breakerless<br>Electronic | Breakerless<br>Electronic | Breakerless<br>Electronic |
| Tires | Radial<br>GR78-15 | Radial<br>HR78-15 | Radial<br>GR78-15 | Radial<br>HR78-15 |

TABLE 9. FUEL BATCHES USED IN DISTANCE ACCUMULATION STUDY

| Fuel* | EM-212-F | EM-243-F | EM-250-F | EM-254-F |
|---|---|---|---|---|
| Pct. Sulfur | 0.0415 | 0.0420 | 0.0405 | 0.0410 |
| Used: From | 11/26/74 | 9/15/75 | 12/30/75 | 2/25/76 |
| To | 9/15/75 | 12/30/75 | 2/25/76 | 5/15/76 |
| Used for Distance Accumulation on | | | | |
| EM-1 | to approx. 16,000 km | 16,000 to 32,200 km | 32,200 to 55,000 km | 55,000 to 80,500 km |
| EM-2 | to approx. 16,000 km | 16,000 to 32,200 km | 32,200 to 60,000 km | 60,000 to 80,500 km |
| EM-3 | to approx. 16,000 km | 16,000 to 32,200 km | 32,200 to 48,000 km | 48,300 to 80,500 km |
| EM-4 | to approx. 16,000 km | 16,000 to 32,200 km | 32,200 to 56,000 km | 56,000 to 80,500 km |
| Used for tests on: | | | | |
| EM-1 | to 8,050 km | 16,000, 24,100, 32,200 km | 48,300 km | 64,400, 80,500 km |
| EM-2 | to 8,050 km | 16,000, 24,100, 32,200 km | 48,300 km | 64,400, 80,500 km |
| EM-3 | to 8,050 km | 16,000, 24,100, 32,200 km | 48,300 km | 64,400, 80,500 km |
| EM-4 | to 8,050 km | 16,000, 24,100, 32,200 km | 48,300 km | 64,400, 80,500 km |

*Base fuel for all fuel batches was Gulf Oil Company "Gulf Crest" brand unleaded gasoline.

D. Vehicle Maintenance

The vehicles were maintained according to the maintenance schedule provided by the car manufacturer. Basically, the Plymouths, cars EM-1 and EM-3, received scheduled maintenance at approximately 8,000 kilometre intervals; the Chevrolets, cars EM-2 and EM-4, at approximately 12,000 kilometre intervals. The complete maintenance schedule for each car is included in Appendix H.

Engine oil level was checked daily (usually this was equivalent to 650 kilometres) and added as needed. Brake linings were also replaced as needed. Tires were replaced on all four cars between the 48,300 and 64,400 kilometre tests with tires of the same size and type as those being replaced.

There were several items of unscheduled maintenance. On car EM-3, the EGR system vacuum amplifier was found to have failed sometime after the 24,100 kilometre test and prior to the 32,200 kilometre test. It was replaced after the 32,200 km test. Also, on this car, a valve guide insert was installed on the exhaust valve of the number one cylinder at approximately 50,000 kilometres to correct a low compression problem in that cylinder. The transmission on car EM-4 failed and was rebuilt at approximately 33,500 kilometres. A leak in the catalyst air injection system on car EM-4 was discovered and corrected at 19,000 kilometres. From test data on the car, it is assumed that this leak started sometime between the 3,200 and 8,050 kilometre tests.

E. Test Sequence

The test plan called for emission tests in factory new condition (i.e., less than 150 kilometres) and at 3,200, 8,050, 16,100 and 24,100 kilometres. During the test program the distance was extended to 80,500 kilometres with emissions tests at 32,200, 48,300, 64,400 and 80,500 kilometres. The distance was accumulated by driving the cars over a modified MVMA durability schedule per MSAPC Advisory Circular 37, dated December 20, 1973 for 55 mph top speed. A copy of this procedure is contained in Appendix H, together with a description of the actual route driven. In addition, all wide-open throttle accelerations were eliminated from the schedule to prevent inadvertent purging of stored sulfates.

The "zero" kilometre and 3,200 kilometre test sequence is shown in Table 10. The time period during which the cars were accumulating 24,100 kilometres was one of rapid change in sulfate test cycles and scheduling philosophy. As a result of this, the 8,050 mile tests on all cars incorporated the SET-7 test and the Highway Fuel Economy Test (HFET), as shown in Table 11. This test sequence was also used for the 16,100 kilometre tests of EM-1 and EM-2. The test sequence was changed again to that shown in Table 12 for the 16,100 kilometre tests of EM-3 and EM-4 and the 24,100 kilometre test on all four cars.

The test sequence for tests up to and including the 24,100 kilometre test were run twice with approximately 500 kilometres of durability driving between each test sequence. For tests following the 24,100 kilometre test, the test sequence shown in Table 13 was run only once, except for the 80,500

TABLE 10. TEST SEQUENCE FOR 0 AND 3200 KILOMETRE TESTS

| TEST | DESCRIPTION |
| --- | --- |
| 1 | Cold start LA-4 cycle |
| | 10 minute soak |
| 2 | Hot start LA-4 cycle |
| | Soak 10 min. or as required while preparing $SO_x$ sampling equipment, but not over one hour |
| 3 | Start vehicle, accelerate to 48 kph in about 15 seconds, then 48 kph cruise for 20 minutes, sampling from "key on" |
| 4 | Cruise at 48 kph for 30 minutes |
| | Soak 10 min, or as required while preparing $SO_x$ sampling equipment, but not over one hour |
| 5 | Start vehicle, accelerate to 96 kph in about 30 seconds then 96 kph cruise 20 minutes, sampling from "key on" |
| 6 | Cruise at 96 kph 20 minutes |

TABLE 11. TEST SEQUENCE FOR 8,050 KILOMETRE TEST ON ALL CARS AND 16,100 KILOMETRE TEST ON CARS EM-1 AND EM-2

| TEST | DESCRIPTION |
|---|---|
| 1 | Cold start LA-4 |
| | 10 minute soak |
| 2 | Hot start LA-4 |
| | Soak 10 minutes* |
| 3 | SET-7 test |
| | Soak 10 minutes* |
| 4 | SET-7 test |
| | Soak 10 Minutes* |
| 5 | HFET test |
| | Soak 10 minutes* |
| 6 | HFET test |
| | Soak 10 minutes* |
| 7 | Start vehicle, accelerate to 48 kph in about 15 seconds, then 48 kph cruise for 20 minutes, sampling from "key on" |
| 8 | Cruise at 48 kph for 30 minutes |
| | Soak 10 minutes* |
| 9 | Start vehicle accelerate to 96 kph in about 30 seconds, then 96 kph cruise for 20 minutes, sampling from "key on" |
| 10 | Cruise at 96 kph for 20 minutes |

*or as required while preparing $SO_x$ sampling equipment, but not over one hour

TABLE 12. TEST SEQUENCE FOR 24,100 KILOMETRE TEST ON ALL CARS AND 16,100 KILOMETRE TESTS ON CARS EM-3 AND EM-4

| TEST | DESCRIPTION |
|---|---|
| 1 | 1975 light duty FTP (single sulfate and $SO_2$ sample) |
| | 10 minute soak* |
| 2 | SET-7 test |
| | 10 minute soak* |
| 3 | SET-7 test |
| | 10 minute soak* |
| 4 | HFET test |
| | 10 minute soak |
| 5 | SET-7 test |
| | 10 minute soak |
| 6 | SET-7 test |
| | 10 minute soak |
| 7 | Start vehicle, accelerate to 48 kph in about 15 seconds, then 48 kph cruise for 20 minutes, sampling from "key on" |
| 8 | Cruise at 48 kph for 30 minutes |
| | Soak 10 minutes |
| 9 | Start vehicle, accelerate to 96 kph in about 30 seconds, then 96 kph cruise for 20 minutes, sampling from "key on" |
| 10 | Cruise at 96 kph for 20 minutes |

*or as required while preparing $SO_x$ sampling equipment, but not over one hour

TABLE 13. TEST SEQUENCE FOR TESTS AT 32,200 KILOMETRES, 48,300 KILOMETRES, 64,400 KILOMETRES AND 80,500 KILOMETRES FOR ALL CARS

| TEST | DESCRIPTION |
|---|---|
| 1 | 1975 FTP[1] (single sulfate and $SO_2$ sample |
| | 5 minute idle[2] |
| 2 | SET-7 test |
| | 5 minute idle |
| 3 | SET-7 |
| | 5 minute idle |
| 4 | HFET test |
| | 5 minute idle |
| 5 | SET-7 test |
| | 5 minute idle |
| 6 | SET-7 test |
| | 5 minute idle |
| 7 | Accelerate to 48 kph in about 15 seconds, then 48 kph cruise for 20 minutes |
| 8 | Cruise at 48 kph for 30 minutes |
| | 5 minute idle |
| 9 | Start vehicle, accelerate to 96 kph in about 30 seconds, then 96 kph cruise for 20 minutes |
| 10 | Cruise at 96 kph for 20 minutes |

[1]No preconditioning following mileage accumulation on modified AMA cycle.
[2]All idles are 5.0 ± 0.5 minutes.

Sulfate, $SO_2$, HC, CO, $NO_x$ and $CO_2$ emissions are taken during all test modes except idle.

kilometre test which was run in duplicate. The replicate 80,500 km tests or cars EM-1 and EM-2 were not averaged as was done for cars EM-3 and EM-4, because of the erratic emissions results obtained from cars EM-1 and EM-2. The test data from these two cars was thoroughly checked for possible errors which might have caused the erratic emission results. Since no errors were found, it is concluded that the variation in emissions is due to vehicle operation. Because 48,300 kilometres was a major maintenance point for all cars, the test sequence was run before maintenance and after maintenance plus 500 kilometres durability driving.

It is emphasized that in the discussions to follow, the tests identified as "acceleration to 48 kph" and "acceleration to 96 kph," include not only the actual acceleration from 0 to the indicated speed, but also a portion of time at the stabilized speed.

## F. Test Results

The test results from the four cars tested under this phase of the project fell into four different classifications and are covered in the following four subsections; 1. Gaseous and BCA Sulfate Emissions, 2. Storage of Sulfur Compounds, 3. Particulate Weights, and 4. Analysis of Tunnel Residue.

### 1. Gaseous and BCA Sulfate Emissions

A summary of the average gaseous emissions is given for each test type on all four cars at each distance interval in Tables 14 through 16 for HC, CO, and $NO_x$ emissions, respectively. To aid in determining any trends with distance, this information has been plotted as Figures 22 to 24. Results for each individual test are contained in Appendix H. Figure 22 shows the HC, CO and $NO_x$ emissions from the FTP tests on all four cars at each distance interval test. For comparison purposes, the 1975 Federal and 1975 California emission standards in terms of grams/kilometre are shown on the plots. As can be seen from this figure, the HC emissions were generally within the applicable standard throughout the 80,500 kilometres on all cars. The exceptions being car EM-4 at 8,050 and 16,100 kilometres, EM-3 at 48,300 and 80,500 kilometres, and the second test of EM-2 at 80,500 kilometres. The high HC emissions from car EM-4 at 8,050 and 16,000 kilometres are attributed to a leak in the air injection system. In fact, the high HC emissions helped lead to the discovery of the leak shortly after the 16,000 kilometre test. There was a general tendency for HC emissions from all cars to increase from the 48,300 km test to the 80,500 km test.

The CO emissions from the FTP were generally above the applicable standard. EM -1 had CO emissions below the 1975 Federal CO standard of 9.3 g/km for 4 of the 10 tests and CO emissions from EM-2 were below the standard 2 of 10 times. The CO emissions from EM-3 were below the 1975 California CO standard of 5.6 g/km 6 of 10 times. The CO emissions from car EM-4 were never below the 1975 California CO standard. The general trend of CO emissions was increasing after the 3,200 km test for all cars, with the largest increases after the 48,300 km tests. This increase in both HC and CO emissions after 38,300 km may be an indication of catalyst deterioration.

## TABLE 14. AVERAGE HYDROCARBON EMISSIONS BY TEST TYPE FOR DISTANCE INTERVAL TESTS ON FOUR CARS

| Test Type | Car Number | HC Emissions g/km | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 0 km | 3200 km | 8050 km | 16100 km | 24100 km | 32200 km | 48300 km B/A | 64400 km | 80500 km*** |
| FTP | EM-1 | 0.39 | 0.32 | 0.30 | 0.32 | 0.25 | 0.31 | 0.49/0.44 | 0.63 | 0.66/0.59 |
| | EM-2 | 0.49 | 0.40 | 0.42 | 0.34 | 0.35 | 0.39 | 0.36/0.24 | 0.39 | 0.80/3.47 |
| | EM-3 | 0.56 | 0.26 | 0.48 | 0.49 | 0.44 | 0.46** | 0.64/0.41 | 0.57 | 0.68 |
| | EM-4 | 0.37 | 0.44 | 1.12* | 1.68* | 0.42 | 0.27 | 0.43/0.47 | 0.61 | 0.60 |
| SET-7 | EM-1 | ---- | ---- | 0.12 | 0.11 | 0.09 | 0.13 | 0.28/0.39 | 0.51 | 0.31/0.52 |
| | EM-2 | ---- | ---- | 0.07 | 0.11 | 0.12 | 0.12 | 0.11/0.06 | 0.27 | 0.34/1.51 |
| | EM-3 | ---- | ---- | 0.04 | 0.03 | 0.03 | 0.06** | 0.17/0.06 | 0.15 | 0.13 |
| | EM-4 | ---- | ---- | 0.95* | 1.18* | 0.09 | 0.06 | 0.12/0.14 | 0.18 | 0.17 |
| FET | EM-1 | ---- | ---- | 0.09 | 0.06 | 0.06 | 0.07 | 0.26/0.31 | 0.41 | 0.19/0.38 |
| | EM-2 | ---- | ---- | 0.04 | 0.05 | 0.06 | 0.05 | 0.07/0.03 | 0.20 | 0.13/1.35 |
| | EM-3 | ---- | ---- | 0.03 | 0.03 | 0.03 | 0.04** | 0.19/0.07 | 0.20 | 0.12 |
| | EM-4 | ---- | ---- | 0.35* | 0.39* | 0.06 | 0.04 | 0.07/0.10 | 0.13 | 0.08 |
| Accel to 48 kph | EM-1 | 0.14 | 0.11 | 0.09 | 0.09 | 0.03 | 0.03 | 0.12/0.11 | 0.11 | 0.09/0.17 |
| | EM-2 | 0.06 | 0.07 | 0.11 | 0.04 | 0.02 | 0.03 | 0.03/0.02 | 0.43 | 0.05/0.21 |
| | EM-3 | 0.04 | 0.04 | 0.07 | 0.04 | 0.05 | 0.09** | 0.18/0.10 | 0.42 | 0.53/0.09 |
| | EM-4 | 0.12 | 0.16 | 0.21* | 0.21* | 0.08 | 0.11 | 0.16/0.40 | 0.08 | 0.26 |
| 48 kph | EM-1 | 0.03 | 0.03 | 0.02 | 0.03 | 0.04 | 0.03 | 0.05/0.04 | 0.05 | 0.06/0.06 |
| | EM-2 | 0.08 | 0.03 | 0.03 | 0.04 | 0.03 | 0.03 | 0.03/0.02 | 0.24 | 0.05/0.04 |
| | EM-3 | 0.03 | 0.03 | 0.05 | 0.04 | 0.05 | 0.09 | 0.24/0.10 | 0.22 | 0.34/0.10 |
| | EM-4 | 0.04 | 0.07 | 0.10* | 0.07* | 0.07 | 0.04** | 0.05/0.21 | 0.05 | 0.24 |
| Accel to 96 kph | EM-1 | 0.06 | 0.08 | 0.06 | 0.05 | 0.05 | 0.03 | 0.09/0.12 | 0.19 | 0.08/0.31 |
| | EM-2 | 0.09 | 0.03 | 0.04 | 0.02 | 0.04 | 0.05 | 0.05/0.05 | 0.08 | 0.00/0.45 |
| | EM-3 | 0.03 | 0.05 | 0.04 | 0.04 | 0.04 | 0.04** | 0.20/0.11 | 0.15 | 0.16 |
| | EM-4 | 0.08 | 0.14 | 0.15* | 0.02* | 0.06 | 0.04 | 0.10/0.15 | 0.08 | 0.05 |
| 96 kph | EM-1 | 0.04 | 0.02 | 0.03 | 0.02 | 0.02 | 0.03 | 0.15/0.04 | 0.68 | 0.09/0.81 |
| | EM-2 | 0.01 | 0.01 | 0.03 | 0.02 | 0.02 | 0.02 | 0.15/0.02 | 0.19 | 0.06/0.02 |
| | EM-3 | 0.02 | 0.03 | 0.03 | 0.02 | 0.03 | 0.03** | 0.12/0.09 | 0.12 | 0.08 |
| | EM-4 | 0.03 | 0.02 | 0.01* | 0.00* | 0.07 | 0.03 | 0.06/0.18 | 0.09 | 0.06 |

* air injection system leak

**EGR system inoperative

***Duplicate Tests on Cars EM-1 and 2 not averaged.
See explanation page 55.

B = Before Maintenance
A = After Maintenance

FTP Standards: '75 Federal = 0.9 g/km
'75 California = 0.6 g/km

## TABLE 15. AVERAGE CO EMISSIONS BY TEST TYPE FOR DISTANCE INTERVAL TESTS ON FOUR CARS

| Test Type | Car Number | CO Emissions g/km 0 km | 3200 km | 8050 km | 16100 km | 24100 km | 32200 km | 48300 km B/A | 64400 km | 80500 km*** |
|---|---|---|---|---|---|---|---|---|---|---|
| FTP | EM-1 | 9.73 | 7.27 | 8.16 | 8.75 | 6.90 | 10.89 | 12.57/11.03 | 15.58 | 11.77/15.25 |
| | EM-2 | 13.42 | 9.59 | 10.16 | 9.81 | 11.79 | 10.04 | 9.61/5.22 | 11.91 | 14.74/24.43 |
| | EM-3 | 7.18 | 3.23 | 4.62 | 5.69 | 7.61 | 3.55** | 6.72/5.07 | 5.52 | 8.43 |
| | EM-4 | 9.36 | 7.89 | 8.23* | 11.40* | 11.11 | 7.97 | 9.03/10.37 | 12.92 | 11.43 |
| SET-7 | EM-1 | ---- | ---- | 7.44 | 4.32 | 2.59 | 5.74 | 11.11/14.57 | 18.92 | 10.51/18.41 |
| | EM-2 | ---- | ---- | 3.07 | 4.55 | 5.97 | 5.93 | 4.68/1.69 | 12.25 | 9.14/9.44 |
| | EM-3 | ---- | ---- | 0.48 | 0.45 | 0.85 | 0.22** | 0.67/0.72 | 0.86 | 1.17 |
| | EM-4 | ---- | ---- | 5.35* | 5.74* | 3.22 | 0.87 | 3.01/4.03 | 6.91 | 4.38 |
| FET | EM-1 | ---- | ---- | 4.61 | 1.77 | 1.30 | 4.91 | 11.56/12.26 | 16.17 | 6.47/13.80 |
| | EM-2 | ---- | ---- | 1.02 | 1.76 | 2.07 | 1.42 | 3.08/0.67 | 10.45 | 3.56/3.00 |
| | EM-3 | ---- | ---- | 0.06 | 0.09 | 0.07 | 0.08** | 0.69/0.14 | 0.21 | 0.14 |
| | EM-4 | ---- | ---- | 1.71* | 1.38* | 1.02 | 0.11 | 0.78/1.50 | 0.37 | 1.36 |
| Accel to 48 kph | EM-1 | 0.38 | 0.81 | 1.06 | 0.68 | 0.12 | 0.06 | 0.60/0.91 | 1.08 | 0.79/0.88 |
| | EM-2 | 0.79 | 0.66 | 0.74 | 0.18 | 0.24 | 0.20 | 0.11/0.04 | 11.27 | 0.07/0.57 |
| | EM-3 | 0.20 | 0.08 | 0.20 | 0.16 | 0.04 | 0.17** | 0.27/0.21 | 0.09 | 0.10/.08 |
| | EM-4 | 0.36 | 0.21 | 0.47* | 0.35* | 0.11 | 0.23 | 1.00/0.65 | 0.54 | 0.23 |
| 48 kph | EM-1 | 0.01 | 0.04 | 0.04 | 0.06 | 0.03 | 0.01 | 0.00/0.00 | 0.02 | 0.01/0.00 |
| | EM-2 | 3.54 | 0.06 | 0.20 | 0.34 | 0.00 | 0.04 | 2.17/0.00 | 8.40 | 0.00/0.02 |
| | EM-3 | 0.04 | 0.06 | 0.03 | 0.22 | 0.04 | 0.02** | 0.04/0.03 | 0.04 | 0.03/0.02 |
| | EM-4 | 0.02 | 0.04 | 0.13* | 0.18* | 0.05 | 0.02 | 0.01/0.06 | 0.02 | 0.04 |
| Accel to 96 kph | EM-1 | 0.64 | 1.61 | 0.92 | 0.70 | 0.14 | 0.76 | 3.17/3.45 | 7.87 | 2.70/10.97 |
| | EM-2 | 0.77 | 0.50 | 0.34 | 0.08 | 1.14 | 2.38 | 2.28/1.22 | 5.40 | 0.50/1.88 |
| | EM-3 | 0.81 | 0.60 | 0.11 | 0.24 | 0.72 | 0.08** | 1.76/1.62 | 0.06 | 1.30 |
| | EM-4 | 2.07 | 1.58 | 1.78* | 0.14* | 1.14 | 0.11 | 1.75/2.63 | 0.27 | 0.18 |
| 96 kph | EM-1 | 2.56 | 1.62 | 1.05 | 1.33 | 0.09 | 1.56 | 9.45/1.72 | 22.31 | 20.86/23.70 |
| | EM-2 | 0.69 | 0.85 | 0.82 | 0.35 | 1.46 | 0.54 | 16.07/1.10 | 17.88 | 3.73/0.08 |
| | EM-3 | 0.56 | 0.05 | 0.06 | 0.13 | 0.03 | 0.03** | 0.05/0.04 | 0.04 | 0.03 |
| | EM-4 | 0.01 | 0.02 | 0.06* | 0.04* | 0.07 | 0.01 | 0.08/0.05 | 0.23 | 0.18 |

* air injection system leak

** EGR system inoperative

*** Duplicate Tests on Cars EM-1 & 2 not averaged,
See explanation page 55.

B = Before Maintenance
A = After Maintenance

FTP Standards: '75 Federal = 9.3 g/km
'75 California = 5.6 g/km

## TABLE 16. AVERAGE $NO_x$ EMISSIONS BY TEST TYPE FOR DISTANCE INTERVAL TESTS ON FOUR CARS

| Test Type | Car Number | $NO_x$ Emissions g/km: 0 km | 3200 km | 8050 km | 16100 km | 24100 km | 32200 km | 48300 km B/A | 64400 km | 80500 km*** |
|---|---|---|---|---|---|---|---|---|---|---|
| FTP | EM-1 | 1.08 | 1.41 | 1.40 | 1.65 | 1.80 | 2.69 | 1.79/2.02 | 1.70 | 2.27/1.97 |
| | EM-2 | 0.96 | 1.25 | 1.29 | 1.32 | 1.49 | 2.62 | 1.91/1.60 | 1.99 | 2.04/1.76 |
| | EM-3 | 0.68 | 0.75 | 0.66 | 1.02 | 1.10 | 3.26** | 1.07/0.93 | 1.98 | 2.00 |
| | EM-4 | 0.85 | 1.01 | 1.16* | 1.11* | 1.14 | 1.25 | 1.81/0.99 | 1.30 | 1.03 |
| SET-7 | EM-1 | ---- | ---- | 1.16 | 1.41 | 1.73 | 2.18 | 1.45/2.12 | 1.62 | 1.99/1.84 |
| | EM-2 | ---- | ---- | 1.19 | 1.12 | 1.34 | 2.07 | 1.63/1.60 | 1.50 | 2.27/1.66 |
| | EM-3 | ---- | ---- | 0.55 | 0.77 | 0.86 | 3.00** | 0.81/0.80 | 1.52 | 1.92 |
| | EM-4 | ---- | ---- | 0.96* | 0.78* | 1.00 | 1.28 | 0.96/0.84 | 1.00 | 0.88 |
| FET | EM-1 | ---- | ---- | 1.22 | 1.91 | 1.77 | 2.47 | 1.72/1.73 | 1.79 | 2.44/2.01 |
| | EM-2 | ---- | ---- | 1.10 | 0.98 | 1.32 | 1.99 | 1.53/1.41 | 1.45 | 2.21/1.82 |
| | EM-3 | ---- | ---- | 0.48 | 0.61 | 0.75 | 3.38** | 0.87/0.85 | 1.11 | 2.32 |
| | EM-4 | ---- | ---- | 0.77* | 0.78* | 0.89 | 1.16 | 0.86/0.70 | 1.10 | 0.88 |
| Accel to 48 kph | EM-1 | 0.78 | 1.06 | 0.79 | 0.95 | 0.67 | 1.19 | 0.94/0.82 | 1.09 | 0.99/1.42 |
| | EM-2 | 0.28 | 0.28 | 0.35 | 0.46 | 0.40 | 0.70 | 0.56/0.61 | 0.63 | 0.62/0.53 |
| | EM-3 | 0.71 | 0.67 | 0.69 | 0.55 | 0.88 | 0.92** | 0.79/0.87 | 1.07 | 2.14/1.37 |
| | EM-4 | 0.25 | 0.21 | 0.19* | 0.15* | 0.20 | 0.15 | 0.48/0.26 | 0.65 | 0.25 |
| 48 kph | EM-1 | 0.68 | 0.83 | 0.85 | 0.80 | 0.65 | 1.19 | 0.98/0.75 | 0.87 | 0.86/0.94 |
| | EM-2 | 0.15 | 0.25 | 0.45 | 0.36 | 0.58 | 0.68 | 0.72/0.56 | 0.79 | 0.80/0.60 |
| | EM-3 | 0.98 | 0.62 | 0.67 | 0.53 | 0.80 | 0.98** | 0.64/0.74 | 0.89 | 2.21/1.37 |
| | EM-4 | 0.21 | 0.19 | 0.15* | 0.13* | 0.17 | 0.18 | 0.34/0.32 | 0.28 | 0.19 |
| Accel to 96 kph | EM-1 | 1.34 | 1.33 | 1.96 | 2.17 | 1.94 | 2.58 | 1.75/1.63 | 2.09 | 2.29/2.12 |
| | EM-2 | 1.03 | 1.07 | 1.08 | 0.89 | 1.33 | 2.49 | 1.65/1.57 | 1.93 | 2.26/1.64 |
| | EM-3 | 0.51 | 0.43 | 0.51 | 0.59 | 0.90 | 4.22** | 1.15/1.04 | 1.33 | 2.77 |
| | EM-4 | 0.69 | 0.72 | 0.76* | 0.30* | 1.49 | 1.38 | 0.96/0.91 | 1.43 | 0.93 |
| 96 kph | EM-1 | 0.44 | 0.57 | 1.14 | 1.24 | 2.26 | 1.91 | 1.22/1.55 | 2.08 | 2.20/2.22 |
| | EM-2 | 0.66 | 0.75 | 0.95 | 1.22 | 1.17 | 1.98 | 1.78/1.04 | 1.45 | 1.74/1.49 |
| | EM-3 | 0.46 | 0.38 | 0.50 | 0.54 | 0.95 | 3.72** | 1.17/0.96 | 1.93 | 2.79 |
| | EM-4 | 0.62 | 0.62 | 0.75* | 0.30* | 1.17 | 1.15 | 0.72/0.86 | 1.30 | 0.96 |

* Air Ins Leak
** Inoperative EGR System
*** Duplicate tests on cars EM-1 & 2 not averaged. See explanation page 55.

B = Before Maintenance
A = After Maintenance
FTP Standards: '75 Federal = 1.9 g/km
'75 Calif. = 1.2 g/km

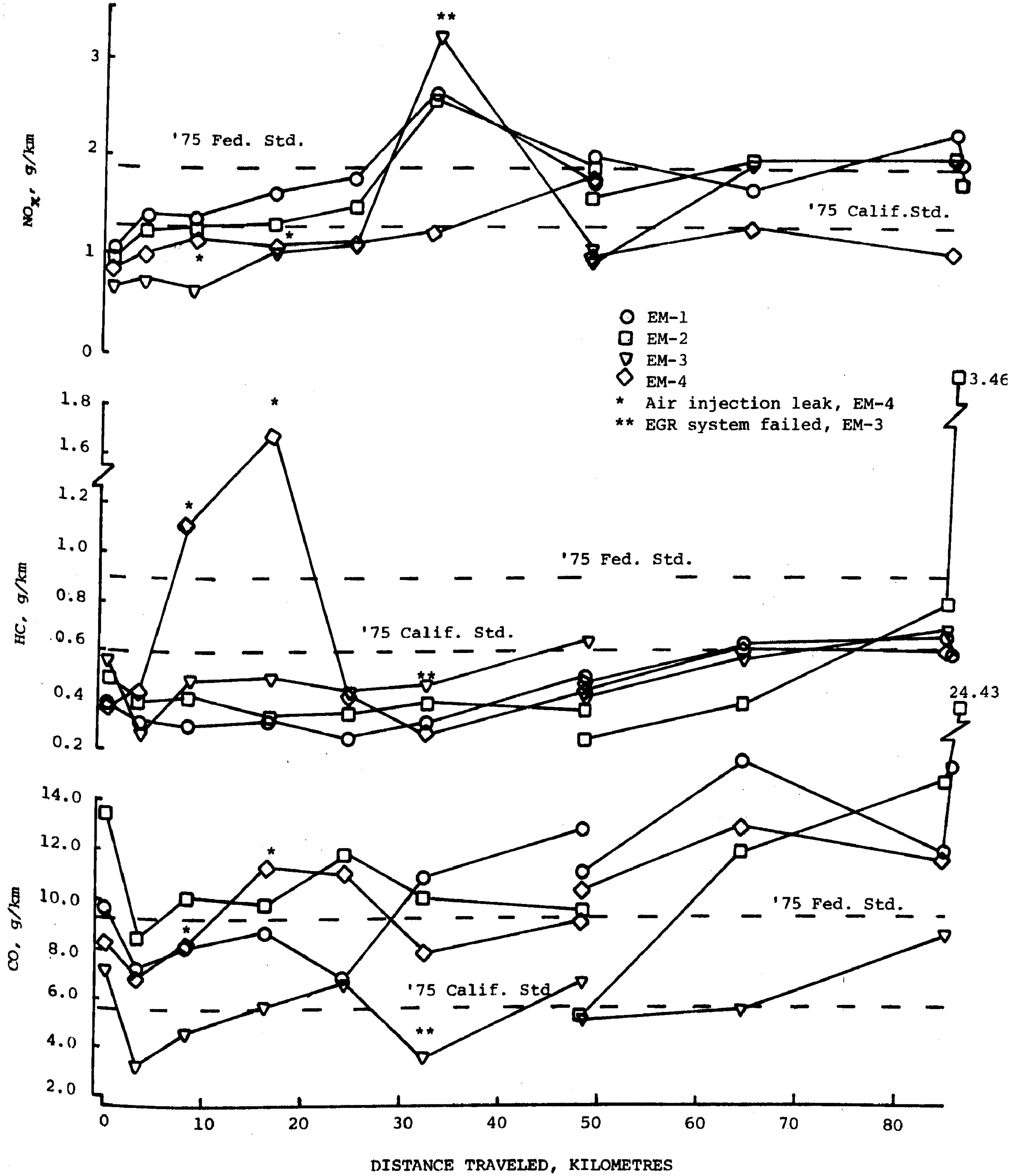



FIGURE 22. EMISSIONS FROM FTP TESTS AT DISTANCE INTERVALS ON FOUR CARS

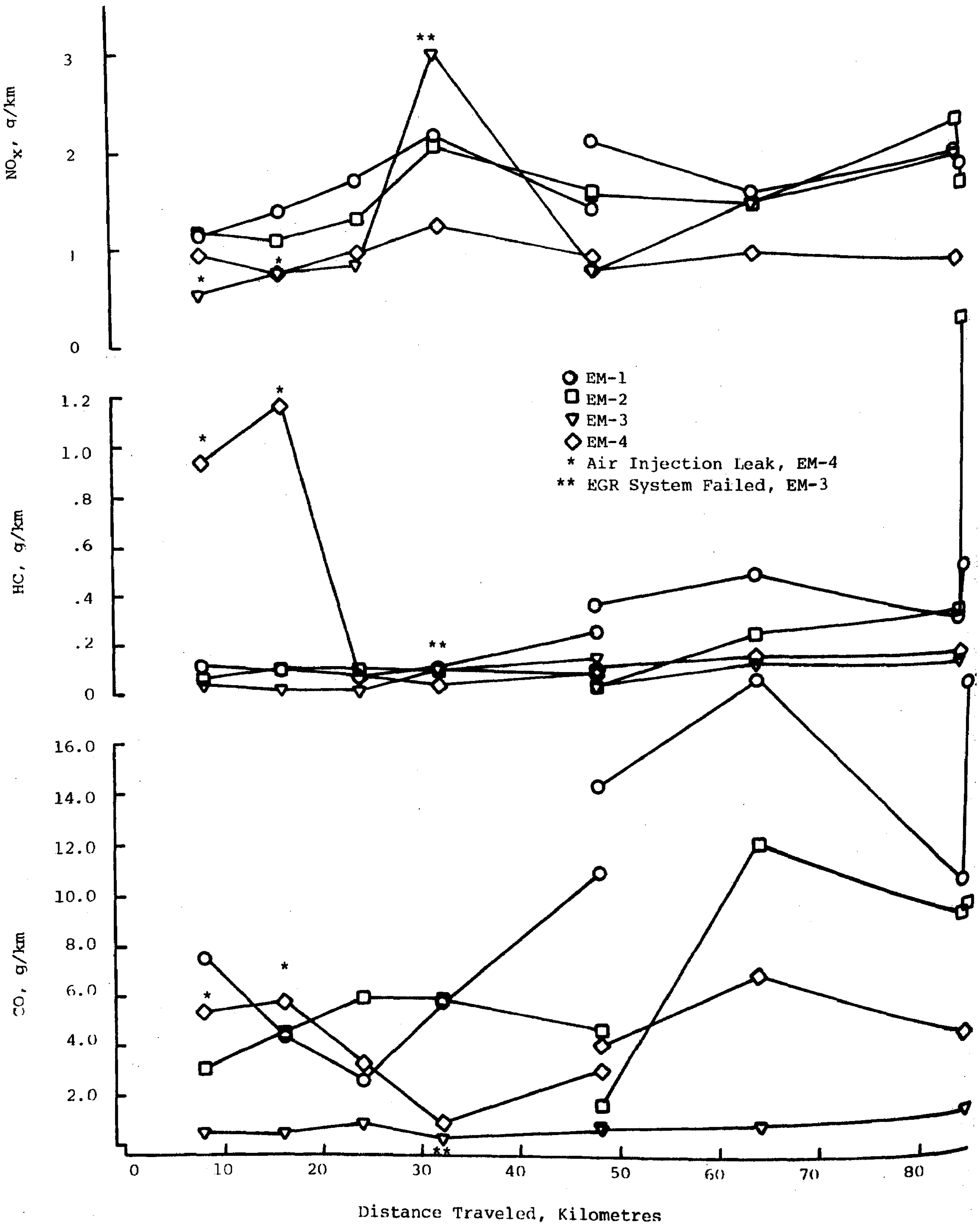



FIGURE 23. EMISSIONS FROM SET-7 TESTS AT DISTANCE INTERVALS FOR FOUR CARS

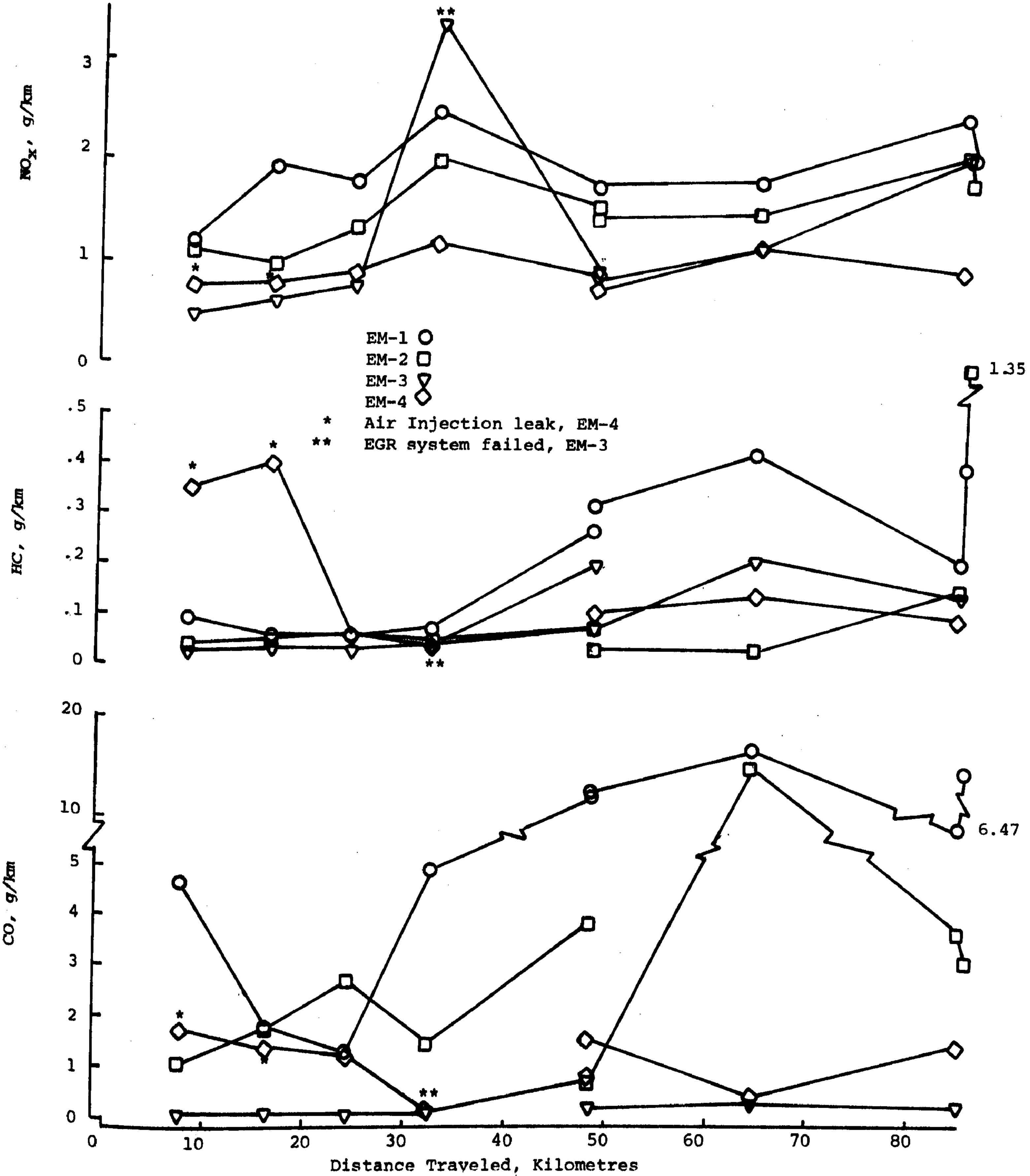



FIGURE 24. EMISSIONS FROM HFET TESTS AT DISTANCE INTERVALS FOR FOUR CARS

The $NO_x$ emissions from all cars were within their respective standards through the 24,100 kilometre test. Except for EM-4, the general trend of $NO_x$ emissions was increasing for the 80,500 km.

The vacuum amplifier in the EGR system of car EM-3 failed between the 24,100 and 32,200 km tests, causing the large increase in $NO_x$ at the 32,200 km test. It was replaced after the 32,200 km test. The subsequent test at 48,300 km showed a reduction in $NO_x$ emissions. After this test, the $NO_x$ emissions from EM-3 again increased for the remaining two tests. At the conclusion of the 80,500 km test, the tailpipe $NO_x$ emissions from EM-3 were checked at 48 kph as tested at 80,500 km and with a spare (but used) vacuum amplifier. The spare vacuum amplifier test resulted in $NO_x$ emissions of 250 ppm compared with 380 ppm with the vacuum amplifier used during the 80,500 km tests. The vacuum amplifier used during the distance accumulation from 32,200 to 80,500 km was checked for proper operation and it was ascertained that the diaphram had not failed. However, it is felt that vacuum amplifier deterioration must be at least partially responsible for the increase in $NO_x$ emissions from EM-3 following the 48,300 km test.

In general, the emissions from the SET-7 tests and HFET tests presented in Figures 23 and 24, show the same trends as the FTP tests. The increase in CO emissions from car EM-1 after the 24,100 km test, and from car EM-2 after the 48,300 km test are more pronounced in both the SET-7 and HFET tests than in the FTP test.

The $SO_2$ and sulfate emissions from each test type at each distance interval are shown in Tables 17 to 20 for cars EM-1 to EM-4, respectively. As an aid to understanding the comparative magnitudes and trends of the emissions, these emissions in terms of m/km have been plotted as histograms in Figures 25 to 31.

Each figure shows the $SO_2$ and sulfate emissions at all distance intervals for one test type on all four cars. This allows cars to be compared on the basis of both catalyst type and whether or not there is air injection.

In comparing the sulfate emission results from these cars, it must be kept in mind that several factors not measured in this study have been shown to have direct influence on the amount of sulfate produced by a catalyst.[12, 13] These factors include amount of oxygen in the exhaust, catalyst temperature, and space velocity of the catalyst system. Some conclusions about effects of oxygen can be drawn by comparing the air-injected and nonair-injected systems. However, it would be inappropriate to draw conclusions about the relative sulfate producing ability of monolith or pelleted catalyst without knowing the catalyst temperatures, oxygen levels and space velocities of each system during each test type. Thus, in the discussion that follows, where one car produced more or less sulfates than another car, it is the total catalyst system operation that should be compared, not just the form of the catalyst substrate.

The results are presented in the order in which the tests were run in the test sequence; i.e., FTP, SET-7, HFET, acceleration to 48 kph, steady-

TABLE 17. SULFUR DIOXIDE AND SULFATE EMISSIONS
AT DISTANCE INTERVALS - CAR EM-1
1975 Federal Plymouth Gran Fury
Monolithic Catalyst, Without Air Pump

| Test Type | Kilometers | mg/km $SO_2$ | mg/km $H_2SO_4$ | % Fuel "S" as $SO_2$ | % Fuel "S" as $H_2SO_4$ | Total Sulfur Recovery |
|---|---|---|---|---|---|---|
| FTP | 0 | 68 | 0.98 | 46.70 | 0.45 | 47.20 |
| | 3200 | 86 | 0.27 | 58.82 | 0.14 | 58.98 |
| | 8050 | 89 | 0.86 | 70.70 | 0.43 | 71.14 |
| | 16100 | 127 | 0.82 | 98.32 | 0.41 | 98.72 |
| | 24100 | 113 | 2.18 | 98.60 | 1.23 | 99.83 |
| | 32200 | 137 | 0.69 | 105.36 | 0.36 | 105.70 |
| | 48300 | 169 | 1.47 | 125.43 | 0.71 | 126.14 |
| | 48300* | 110 | 1.80 | 79.96 | 0.86 | 80.82 |
| | 64400 | 159 | 2.77 | 120.93 | 1.37 | 122.30 |
| | 80500 | 167 | 1.80 | 126.33 | 0.89 | 127.22 |
| | 80500 | 88 | 1.22 | 64.63 | 0.58 | 65.22 |
| SET-7 | 8050 | 100 | 0.33 | 113.13 | 0.24 | 113.37 |
| | 16100 | 95 | 0.29 | 108.52 | 0.22 | 108.77 |
| | 24100 | 86 | 0.42 | 100.13 | 0.32 | 100.45 |
| | 32200 | 125 | 0.80 | 137.84 | 0.57 | 138.41 |
| | 48300 | 75 | 0.49 | 78.95 | 0.34 | 79.29 |
| | 48300* | 60 | 0.59 | 62.91 | 0.41 | 63.31 |
| | 64400 | 73 | 0.63 | 72.59 | 0.41 | 73.00 |
| | 80500 | 92 | 0.41 | 93.44 | 0.27 | 93.71 |
| | 80500 | 54 | 0.41 | 53.60 | 0.27 | 53.87 |
| FET | 8050 | 65 | 0.25 | 86.68 | 0.23 | 86.91 |
| | 16100 | 93 | 0.51 | 130.89 | 0.48 | 131.37 |
| | 24100 | 88 | 0.54 | 130.60 | 0.53 | 131.13 |
| | 32200 | 123 | 0.99 | 152.95 | 0.81 | 153.76 |
| | 48300 | 59 | 0.23 | 75.99 | 0.19 | 76.18 |
| | 48300* | 28 | 0.20 | 35.73 | 0.17 | 35.90 |
| | 64400 | 63 | 0.86 | 73.52 | 0.65 | 74.29 |
| | 80500 | 62 | 0.31 | 74.94 | 0.25 | 75.19 |
| | 80500 | 28 | 0.19 | 32.15 | 0.15 | 32.30 |
| 48 kph accel | 0 | 26 | 0.54 | 37.80 | 0.54 | 38.50 |
| | 3200 | 27 | 0.12 | 41.75 | 0.12 | 41.87 |
| | 8050 | 17 | 0.26 | 27.18 | 0.11 | 27.29 |
| | 16100 | 23 | 0.85 | 39.18 | 0.97 | 40.15 |
| | 24100 | 26 | 0.37 | 46.04 | 0.43 | 46.47 |
| | 32200 | 7 | 0.01 | 11.15 | 0.00 | 11.15 |
| | 48300 | 16 | 0.56 | 27.96 | 0.65 | 28.60 |
| | 48300* | 19 | 0.46 | 32.15 | 0.51 | 32.66 |
| | 64400 | 18 | 0.48 | 29.25 | 0.51 | 29.76 |
| | 80500 | 21 | 0.15 | 35.66 | 0.17 | 35.83 |
| | 80500 | 19 | 0.14 | 32.70 | 0.16 | 32.86 |

*after maintenance

TABLE 17. (Cont'd.) SULFUR DIOXIDE AND SULFATE EMISSIONS AT DISTANCE INTERVALS - CAR EM-1
1975 Federal Plymouth Gran Fury
Monolithic Catalyst, Without Air Pump

| Test Type | kilometers | mg/km $SO_2$ | mg/km $H_2SO_4$ | % Fuel "S" as $SO_2$ | % Fuel "S" as $H_2SO_4$ | Total Sulfur Recovery |
|---|---|---|---|---|---|---|
| 48 kph S/S | 0 | 8 | 0.32 | 12.89 | 0.32 | 13.22 |
| | 3200 | 11 | 2.40 | 17.27 | 2.56 | 19.83 |
| | 8050 | 8 | 0.34 | 22.34 | 0.39 | 22.86 |
| | 16100 | 12 | 0.83 | 20.44 | 0.99 | 21.43 |
| | 24100 | 11 | 1.39 | 20.03 | 1.74 | 21.77 |
| | 32200 | 14 | 1.07 | 24.07 | 1.22 | 25.29 |
| | 48300 | 11 | 1.20 | 19.57 | 1.39 | 20.97 |
| | 48300* | 21 | 1.20 | 36.69 | 1.38 | 38.07 |
| | 64400 | 14 | 0.75 | 29.51 | 0.84 | 25.35 |
| | 80500 | 9 | 0.67 | 16.47 | 0.78 | 17.25 |
| | 80500 | 9 | 0.51 | 15.62 | 0.51 | 16.20 |
| 96 kph accel | 0 | 237 | 13.10 | 323.67 | 11.68 | 335.35 |
| | 3200 | 208 | 2.00 | 273.56 | 3.15 | 276.71 |
| | 8050 | 96 | 2.64 | 141.12 | 2.45 | 145.98 |
| | 16100 | 157 | 13.51 | 267.77 | 14.32 | 282.10 |
| | 24100 | 90 | 62.84 | 143.80 | 64.11 | 207.92 |
| | 32200 | 151 | 6.68 | 185.03 | 5.36 | 190.39 |
| | 48300 | 132 | 1.77 | 173.85 | 1.52 | 175.37 |
| | 48300* | 116 | 1.39 | 155.19 | 1.21 | 156.40 |
| | 64400 | 106 | 2.14 | 132.19 | 1.75 | 133.94 |
| | 80500 | 111 | 1.11 | 150.39 | 0.98 | 151.37 |
| | 80500 | 83 | .76 | 102.31 | 0.61 | 102.92 |
| 96 kph S/S | 0 | 76 | 0.18 | 109.83 | 0.16 | 109.99 |
| | 3200 | 94 | 0.20 | 131.06 | 0.18 | 131.25 |
| | 8050 | 64 | 0.31 | 94.16 | 0.29 | 96.76 |
| | 16100 | 59 | 1.38 | 103.39 | 1.56 | 104.96 |
| | 24100 | 75 | 18.75 | 121.23 | 15.83 | 137.06 |
| | 32200 | 107 | 0.68 | 133.06 | 0.55 | 133.61 |
| | 48300 | 67 | 0.24 | 91.98 | 0.22 | 92.20 |
| | 48300* | 40 | 0.21 | 54.61 | 0.19 | 54.61 |
| | 64400 | 76 | 0.12 | 95.16 | 0.09 | 95.25 |
| | 80500 | 43 | 0.16 | 52.51 | 0.13 | 52.64 |
| | 80500 | 42 | 0.08 | 53.01 | 0.07 | 53.08 |

* after maintenance

TABLE 18. SULFUR DIOXIDE AND SULFATE EMISSIONS AT DISTANCE INTERVALS - CAR EM-2
1975 Federal Chevrolet Impala
Pelleted Catalyst, Without Air Pump

| Test Type | kilometers | mg/km | | % Fuel "S" as | | Total Sulfur Recovery |
|---|---|---|---|---|---|---|
| | | $SO_2$ | $H_2SO_4$ | $SO_2$ | $H_2SO_4$ | |
| FTP | 0 | - | 0.58 | - | 0.27 | - |
| | 3200 | 56 | 0.11 | 45.84 | 0.06 | 45.88 |
| | 8050 | 101 | 0.13 | 80.19 | 0.10 | 80.29 |
| | 16100 | 86 | 1.00 | 66.31 | 0.50 | 66.81 |
| | 24100 | 105 | 1.26 | 82.46 | 0.65 | 83.10 |
| | 32200 | 123 | 2.39 | 95.42 | 1.21 | 96.63 |
| | 48300 | 107 | 1.31 | 80.93 | 0.65 | 81.58 |
| | 48300* | 78 | 0.78 | 63.45 | 0.42 | 63.87 |
| | 64400 | 115 | 0.90 | 88.86 | 0.46 | 89.31 |
| | 80500 | 120 | 1.13 | 89.94 | 0.55 | 90.49 |
| | 80500 | 170 | 1.56 | 122.61 | 0.73 | 123.34 |
| SET-7 | 8050 | 117 | 0.40 | 130.60 | 0.29 | 130.89 |
| | 16100 | 92 | 0.30 | 100.40 | 0.22 | 100.62 |
| | 24100 | 87 | 0.77 | 96.47 | 0.56 | 97.03 |
| | 32200 | 97 | 1.18 | 102.78 | 0.81 | 103.59 |
| | 48300 | 115 | 1.33 | 120.16 | 0.90 | 121.06 |
| | 48300* | 105 | 1.88 | 117.13 | 1.37 | 118.50 |
| | 64400 | 115 | 0.52 | 117.97 | 0.35 | 118.32 |
| | 80500 | 102 | 1.89 | 101.31 | 1.24 | 102.55 |
| | 80500 | 126 | 1.09 | 128.76 | 0.73 | 129.49 |
| HWFET | 8050 | 110 | 1.51 | 137.09 | 1.24 | 138.33 |
| | 16100 | 87 | 0.76 | 113.94 | 0.63 | 114.51 |
| | 24100 | 96 | 1.34 | 115.44 | 1.03 | 116.47 |
| | 32200 | 130 | 1.91 | 170.00 | 1.63 | 171.63 |
| | 48300 | 137 | 3.03 | 148.67 | 2.15 | 150.82 |
| | 48300* | 100 | 2.70 | 128.80 | 2.28 | 131.08 |
| | 64400 | 143 | 0.83 | 158.10 | 0.60 | 158.70 |
| | 80500 | 111 | 1.03 | 126.58 | 0.77 | 127.35 |
| | 80500 | 87 | 1.64 | 98.94 | 1.22 | 100.16 |
| 48 kph accel | 0 | - | 0.44 | - | 0.31 | - |
| | 3200 | 45 | 0.44 | 60.62 | 0.36 | 61.08 |
| | 8050 | - | 0.09 | - | 0.08 | - |
| | 16100 | 22 | 0.04 | 30.91 | 0.04 | 30.95 |
| | 24100 | 37 | 0.14 | 54.36 | 0.14 | 54.50 |
| | 32200 | 28 | 0.54 | 39.96 | 0.51 | 40.47 |
| | 48300 | 18 | 0.20 | 27.20 | 0.20 | 27.40 |
| | 48300* | 15 | 0.01 | 23.12 | 0.01 | 23.13 |
| | 64400 | 57 | 0.98 | 80.35 | 0.89 | 81.24 |
| | 80500 | 28 | 0.36 | 38.83 | 0.33 | 39.16 |
| | 80500 | 27 | 0.38 | 41.24 | 0.37 | 41.61 |



* after maintenance

TABLE 18 (Cont'd.) SULFUR DIOXIDE AND SULFATE EMISSIONS
AT DISTANCE INTERVALS - CAR EM-2
1975 Federal Chevrolet Impala
Pelleted Catalyst, Without Air Pump

| Test Type | kilometers | mg/km $SO_2$ | mg/km $H_2SO_4$ | % Fuel "S" as $SO_2$ | % Fuel "S" as $H_2SO_4$ | Total Sulfur Recovery |
|---|---|---|---|---|---|---|
| 48 kph S/S | 0 | - | 0.09 | - | 0.07 | - |
| | 3200 | 10 | 8.29 | 13.75 | 7.32 | 21.05 |
| | 8050 | 18 | 2.93 | 12.05 | 2.97 | 15.02 |
| | 16100 | 35 | 3.55 | 51.92 | 3.42 | 55.34 |
| | 24100 | 10 | 2.39 | 15.67 | 2.44 | 18.11 |
| | 32200 | 16 | 1.46 | 19.46 | 1.18 | 20.63 |
| | 48300 | 6 | 2.29 | 8.49 | 2.16 | 10.65 |
| | 48300* | 10 | 0.87 | 16.50 | 0.93 | 17.43 |
| | 64400 | 57 | 0.10 | 83.53 | 0.10 | 83.63 |
| | 80500 | 13 | 0.96 | 19.58 | 0.99 | 20.56 |
| | 80500 | 17 | 0.28 | 26.04 | 0.28 | 26.32 |
| 96 kph accel | 0 | - | 6.23 | - | 4.62 | - |
| | 3200 | 119 | 4.28 | 160.32 | 5.73 | 166.03 |
| | 8050 | 140 | 5.50 | 177.93 | 4.63 | 182.57 |
| | 16100 | 116 | 8.01 | 142.37 | 6.59 | 148.96 |
| | 24100 | 115 | 34.30 | 145.10 | 27.78 | 172.87 |
| | 32200 | 169 | 12.07 | 186.39 | 8.72 | 195.11 |
| | 48300 | 177 | 16.01 | 208.81 | 12.37 | 221.18 |
| | 48300* | 145 | 23.05 | 186.02 | 19.26 | 205.28 |
| | 64400 | 209 | 2.22 | 249.52 | 1.74 | 251.25 |
| | 80500 | 130 | 13.36 | 152.19 | 10.25 | 162.44 |
| | 80500 | 77 | 12.31 | 101.86 | 10.63 | 112.49 |
| 96 kph S/S | 0 | - | 3.16 | - | 2.52 | - |
| | 3200 | 119 | 1.82 | 157.36 | 1.44 | 158.80 |
| | 8050 | 138 | 4.41 | 176.82 | 3.60 | 180.42 |
| | 16100 | 115 | 4.59 | 149.69 | 3.75 | 151.89 |
| | 24100 | 73 | 5.47 | 85.55 | 4.13 | 89.68 |
| | 32200 | 137 | 3.51 | 172.65 | 2.88 | 175.53 |
| | 48300 | 113 | 1.07 | 130.14 | 0.80 | 130.95 |
| | 48300* | 123 | 3.01 | 166.80 | 2.67 | 169.46 |
| | 64400 | 105 | 0.26 | 127.02 | 0.20 | 127.23 |
| | 80500 | 28 | 1.53 | 33.35 | 1.19 | 34.55 |
| | 80500 | 65 | 5.58 | 81.94 | 4.62 | 86.56 |

* after maintenance

TABLE 19. SULFUR DIOXIDE AND SULFATE EMISSIONS
AT DISTANCE INTERVALS - CAR EM-3
1975 California Plymouth Gran Fury
Monolithic Catalyst, With Air Pump

| Test Type | kilometers | mg/km SO2 | mg/km H2SO4 | % Fuel "S" as SO2 | % Fuel "S" as H2SO4 | Total Sulfur Recovery |
|---|---|---|---|---|---|---|
| FTP | 0 | 147 | 1.61 | 93.76 | 0.70 | 94.32 |
| | 3200 | 237 | 6.16 | 120.92 | 2.89 | 123.80 |
| | 8050 | 113 | 4.43 | 88.08 | 2.59 | 90.66 |
| | 16100 | 98 | 5.74 | 65.02 | 2.50 | 67.52 |
| | 24100 | 186 | 5.67 | 121.62 | 2.44 | 124.05 |
| | 32200** | 224 | 11.35 ** | 178.76 | 5.91 | 184.67 |
| | 48300 | 116 | 2.84 | 83.31 | 1.33 | 84.65 |
| | 48300* | 169 | 4.12 | 122.10 | 1.94 | 124.04 |
| | 64400 | 100 | 4.37 | 72.75 | 2.08 | 74.83 |
| | 80500 | 140 | 6.92 | 91.76 | 2.95 | 94.71 |
| SET-7 | 8050 | 72 | 29.09 | 76.86 | 20.23 | 97.09 |
| | 16100 | 68 | 26.67 | 69.21 | 17.81 | 87.02 |
| | 24100 | 81 | 15.27 | 81.18 | 9.91 | 91.09 |
| | 32200** | 85 | 44.59 ** | 95.88 | 33.01 | 128.89 |
| | 48300 | 96 | 6.62 | 101.31 | 4.55 | 105.86 |
| | 48300 | 101 | 7.05 | 100.27 | 4.56 | 104.83 |
| | 64400 | 153 | 7.47 | 152.62 | 4.87 | 157.49 |
| | 80500 | 101 | 5.67 | 96.04 | 3.52 | 99.56 |
| HWFET | 8050 | 61 | 44.59 | 78.07 | 38.31 | 116.38 |
| | 16100 | 54 | 51.92 | 64.56 | 40.82 | 105.38 |
| | 24100 | 46 | 38.01 | 53.60 | 29.46 | 83.06 |
| | 32200** | 75 | 45.08 ** | 99.88 | 39.33 | 139.21 |
| | 48300 | 59 | 12.93 | 70.75 | 10.11 | 80.87 |
| | 48300* | 45 | 14.55 | 54.25 | 11.42 | 65.67 |
| | 64400 | 67 | 11.41 | 72.64 | 8.14 | 80.79 |
| | 80500 | 72 | 10.34 | 80.96 | 7.60 | 88.56 |
| 48 kph accel | 0 | 17 | 0.23 | 25.10 | 0.22 | 25.33 |
| | 3200 | 36 | 0.10 | 56.89 | 0.10 | 56.99 |
| | 8050 | 23 | 0.37 | 36.90 | 0.41 | 37.31 |
| | 16100 | 13 | 0.07 | 22.01 | 0.07 | 22.08 |
| | 24100 | 14 | 0.17 | 21.46 | 0.17 | 21.63 |
| | 32200** | 7 | 0.64 ** | 11.82 | 0.68 | 12.50 |
| | 48300 | 13 | 0.40 | 22.43 | 0.46 | 22.89 |
| | 48300* | 19 | 0.37 | 33.35 | 0.42 | 33.77 |
| | 64400 | 33 | 3.18 | 40.33 | 2.55 | 42.89 |
| | 80500 | 27 | 4.90 | 32.46 | 3.87 | 36.33 |
| | 80500 | 18 | 0.25 | 30.74 | 0.27 | 31.01 |

*after maintenance
**EGR system inoperative

TABLE 19 (Cont'd.) SULFUR DIOXIDE AND SULFATE EMISSIONS AT DISTANCE INTERVALS - CAR EM-3
1975 California Plymouth Gran Fury
Monolithic Catalyst, With Air Pump

| Test Type | kilometers | mg/km | | % Fuel "S" as | | Total Sulfur Recovery |
|---|---|---|---|---|---|---|
| | | $SO_2$ | $H_2SO_4$ | $SO_2$ | $H_2SO_4$ | |
| 48 kph S/S | 0 | 13 | 8.43 | 20.25 | 8.76 | 29.00 |
| | 3200 | 19 | 4.42 | 30.69 | 4.78 | 35.46 |
| | 8050 | 17 | 3.42 | 29.19 | 3.86 | 33.05 |
| | 16100 | 10 | 1.75 | 16.88 | 1.94 | 18.82 |
| | 24100 | 15 | 2.63 | 25.36 | 2.96 | 28.32 |
| | 32200** | 24 | 8.02 ** | 38.69 | 8.38 | 47.07 |
| | 48300 | 16 | 0.91 | 27.71 | 1.04 | 28.75 |
| | 48300* | 22 | 0.66 | 39.56 | 0.77 | 40.33 |
| | 64400 | 29 | 35.44 | 36.92 | 29.68 | 66.60 |
| | 80500 | 33 | 26.62 | 42.92 | 22.29 | 65.20 |
| | 80500 | 22 | 1.17 | 36.41 | 1.29 | 37.69 |
| 96 kph accel | 0 | 135 | 28.07 | 167.24 | 23.04 | 190.27 |
| | 3200 | 151 | 23.66 | 200.31 | 20.44 | 220.75 |
| | 8050 | 106 | 61.74 | 150.87 | 57.29 | 208.16 |
| | 16100 | 65 | 62.98 | 86.85 | 54.82 | 141.67 |
| | 24100 | 110 | 26.01 | 140.12 | 19.90 | 160.02 |
| | 32200** | 69 | 77.11 ** | 94.43 | 68.69 | 163.11 |
| | 48300 | 82 | 24.80 | 111.41 | 22.00 | 133.41 |
| | 48300* | 88 | 7.25 | 118.92 | 6.43 | 125.35 |
| | 64400 | 53 | 49.32 | 64.85 | 39.72 | 104.58 |
| | 80500 | 89 | 18.44 | 107.87 | 14.65 | 122.52 |
| 96 kph S/S | 0 | 24 | 20.01 | 30.13 | 16.77 | 46.90 |
| | 3200 | 28 | 43.65 | 41.06 | 41.96 | 83.02 |
| | 8050 | 24 | 27.99 | 33.60 | 26.26 | 59.86 |
| | 16100 | 22 | 46.11 | 32.44 | 43.70 | 76.15 |
| | 24100 | 26 | 24.83 | 32.36 | 20.68 | 53.03 |
| | 32200** | 25 | 32.53 ** | 29.28 | 33.97 | 63.24 |
| | 48300 | 30 | 21.22 | 43.86 | 20.14 | 64.00 |
| | 48300 | 30 | 19.66 | 39.68 | 17.08 | 56.76 |
| | 64400 | 42 | 19.76 | 53.60 | 16.62 | 70.22 |
| | 80500 | 34 | 14.83 | 44.90 | 12.59 | 57.48 |

* after maintenance
**EGR system inoperative

TABLE 20. SULFUR DIOXIDE AND SULFATE EMISSIONS AT DISTANCE INTERVALS - CAR EM-4
1975 California Chevrolet Impala
Pelleted Catalyst, With Air Pump

| | | mg/km | | % Fuel "S" as | | Total Sulfur |
|---|---|---|---|---|---|---|
| Test Type | kilometers | $SO_2$ | $H_2SO_4$ | $SO_2$ | $H_2SO_4$ | Recovery |
| FTP | 0 | 120 | 2.42 | 75.45 | 1.01 | 76.45 |
| | 3200 | 59 | 8.89 | 44.14 | 4.24 | 48.37 |
| | 8050** | 105 | 0.52 | 78.83 | 0.33 | 79.15 |
| | 16100** | 140 | 0.72 | 95.93 | 0.32 | 96.25 |
| | 24100 | 106 | 3.23 | 72.40 | 1.45 | 73.65 |
| | 32200 | 56 | 16.15 | 41.50 | 7.87 | 49.37 |
| | 48300 | 103 | 11.08 | 77.78 | 5.48 | 83.26 |
| | 48300* | 72 | 7.58 | 53.06 | 3.64 | 56.70 |
| | 64400 | 137 | 6.27 | 91.43 | 2.73 | 94.15 |
| | 80500 | 116 | 2.80 | 79.82 | 1.28 | 81.10 |
| SET-7 | 8050** | 79 | 1.01 | 83.27 | 0.69 | 83.96 |
| | 16100** | 78 | 2.33 | 81.76 | 1.59 | 83.35 |
| | 24100 | 77 | 9.63 | 76.90 | 6.35 | 83.25 |
| | 32200 | 58 | 26.9 | 62.00 | 18.93 | 80.93 |
| | 48300 | 70 | 16.93 | 71.81 | 11.38 | 83.19 |
| | 48300* | 66 | 10.88 | 66.79 | 7.14 | 73.93 |
| | 64400 | 97 | 8.34 | 88.72 | 4.99 | 93.71 |
| | 80500 | 75 | 6.80 | 73.21 | 4.45 | 77.66 |
| HWFET | 8050** | 60 | 4.19 | 73.55 | 3.39 | 76.94 |
| | 16100** | 53 | 4.48 | 63.03 | 3.51 | 66.54 |
| | 24100 | 60 | 9.75 | 67.30 | 7.12 | 74.42 |
| | 32200 | 64 | 16.41 | 79.75 | 13.39 | 93.15 |
| | 48300 | 62 | 13.83 | 73.53 | 10.65 | 84.17 |
| | 48300* | 58 | 14.81 | 67.72 | 11.23 | 78.95 |
| | 64400 | 90 | 12.87 | 91.91 | 8.56 | 100.48 |
| | 80500 | 48 | 2.79 | 45.65 | 2.03 | 47.69 |
| 48 kph accel | 0 | 22 | 4.72 | 22.08 | 3.10 | 26.16 |
| | 3200 | 20 | 13.30 | 23.44 | 10.18 | 33.61 |
| | 8050** | 68 | 13.44 | 82.06 | 10.73 | 92.79 |
| | 16100** | 13 | 1.87 | 16.09 | 1.52 | 17.60 |
| | 24100 | 11 | 6.69 | 12.69 | 5.27 | 17.96 |
| | 32200 | 31 | 8.26 | 41.36 | 7.22 | 48.58 |
| | 48300 | 26 | - | 39.47 | - | - |
| | 48300* | 19 | 7.41 | 28.21 | 7.30 | 35.50 |
| | 64400 | 23 | ----- | 34.20 | ---- | ---- |
| | 80500 | 28 | 4.23 | 35.53 | 3.58 | 39.11 |

* after maintenance
** Leak in air injection system

TABLE 20 (Cont'd.) SULFUR DIOXIDE AND SULFATE EMISSIONS AT DISTANCE INTERVALS - CAR EM-4
1975 California Chevrolet Impala
Pelleted Catalyst, With Air Pump

| Test Type | kilometers | mg/km | | % Fuel "S" as | | Total Sulfur Recovery |
|---|---|---|---|---|---|---|
| | | $SO_2$ | $H_2SO_4$ | $SO_2$ | $H_2SO_4$ | |
| 48 kph S/S | 0 | 20 | 35.55 | 20.82 | 24.21 | 45.03 |
| | 3200 | 11 | 32.23 | 13.45 | 25.60 | 39.05 |
| | 8050** | 26 | 13.75 | 32.47 | 11.43 | 43.90 |
| | 16100** | 9 | 7.81 | 13.97 | 8.03 | 22.00 |
| | 24100 | 14 | 30.78 | 18.57 | 26.01 | 44.58 |
| | 32200 | 29 | 26.63 | 38.61 | 23.48 | 62.08 |
| | 48300 | 16 | 3.72 | 25.01 | 3.72 | 28.74 |
| | 48300* | 16 | 9.70 | 23.59 | 9.40 | 32.99 |
| | 64400 | 12 | 2.92 | 17.05 | 2.75 | 19.80 |
| | 80500 | 18 | 10.70 | 24.48 | 9.18 | 33.66 |
| 96 kph accel | 0 | 60 | 17.03 | 62.25 | 11.79 | 80.63 |
| | 3200 | 56 | 27.77 | 66.27 | 21.71 | 87.97 |
| | 8050** | 65 | 16.10 | 81.58 | 13.24 | 94.81 |
| | 16100** | 60 | 8.35 | 77.76 | 7.04 | 84.80 |
| | 24100 | 71 | 35.63 | 75.95 | 24.86 | 100.80 |
| | 32200 | 50 | 66.98 | 55.57 | 49.05 | 104.63 |
| | 48300 | 103 | 45.90 | 124.13 | 45.90 | 160.31 |
| | 48300* | 72 | 17.92 | 85.80 | 13.94 | 99.74 |
| | 64400 | 78 | 24.02 | 89.15 | 18.01 | 107.16 |
| | 80500 | 36 | 24.48 | 42.99 | 19.11 | 62.10 |
| 96 kph S/S | 0 | 63 | 15.70 | 71.71 | 11.84 | 84.37 |
| | 3200 | 22 | 17.87 | 28.71 | 15.99 | 39.49 |
| | 8050** | 53 | 10.17 | 68.95 | 8.76 | 77.71 |
| | 16100** | 53 | 13.79 | 72.90 | 12.20 | 85.09 |
| | 24100 | 46 | 24.28 | 52.93 | 18.23 | 71.16 |
| | 32200 | 17 | 27.20 | 21.73 | 22.55 | 44.28 |
| | 48300 | 70 | 17.85 | 86.57 | 14.50 | 101.06 |
| | 48300* | 62 | 18.70 | 75.64 | 15.02 | 90.66 |
| | 64400 | 65 | 8.74 | 75.05 | 6.63 | 81.68 |
| | 80500 | 40 | 9.10 | 48.04 | 7.36 | 55.39 |

* after maintenance
** Leak in air injection system

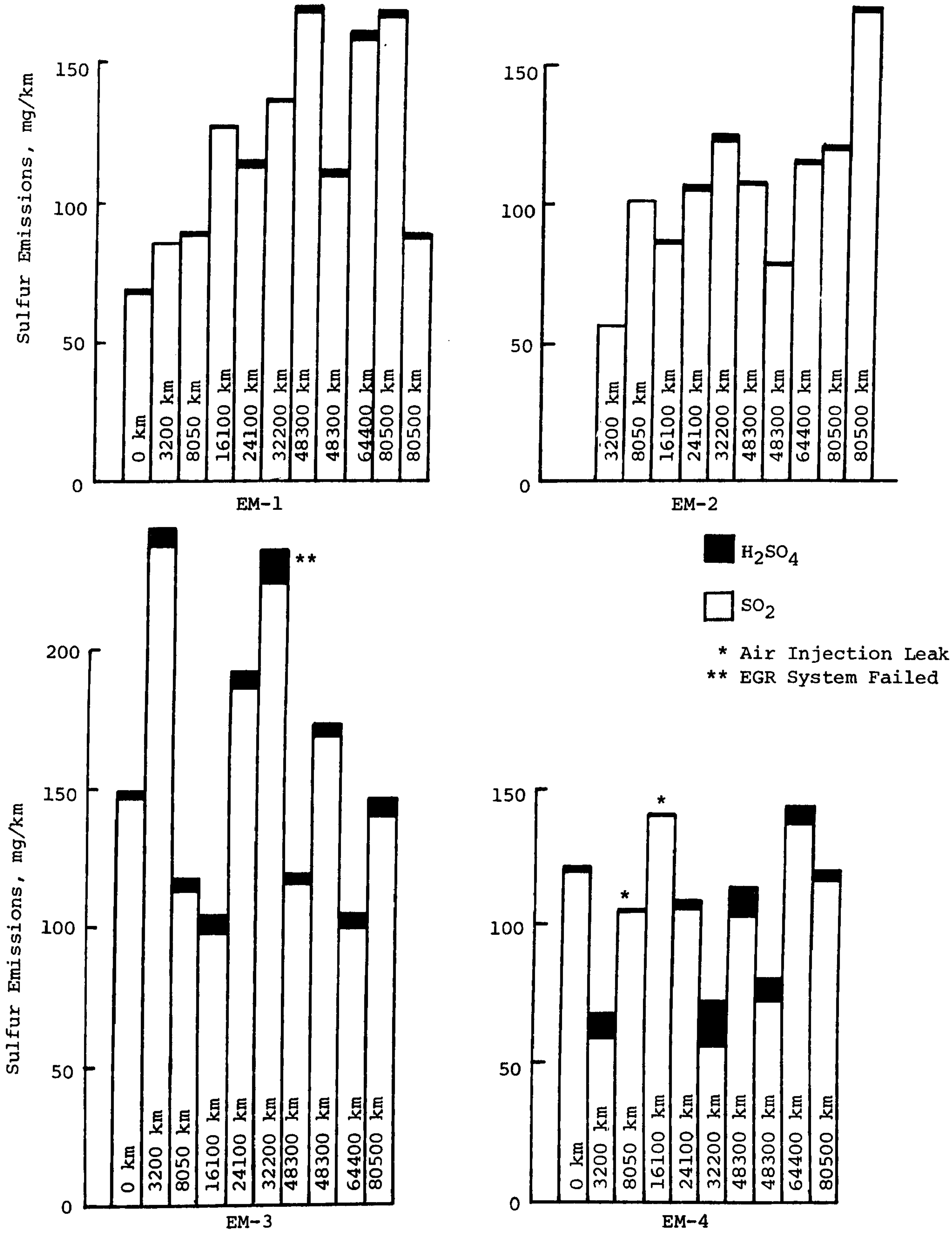



FIGURE 25. SULFATE AND SULFUR DIOXIDE EMISSIONS FROM FTP TESTS AT DISTANCE INTERVALS FOR FOUR CARS

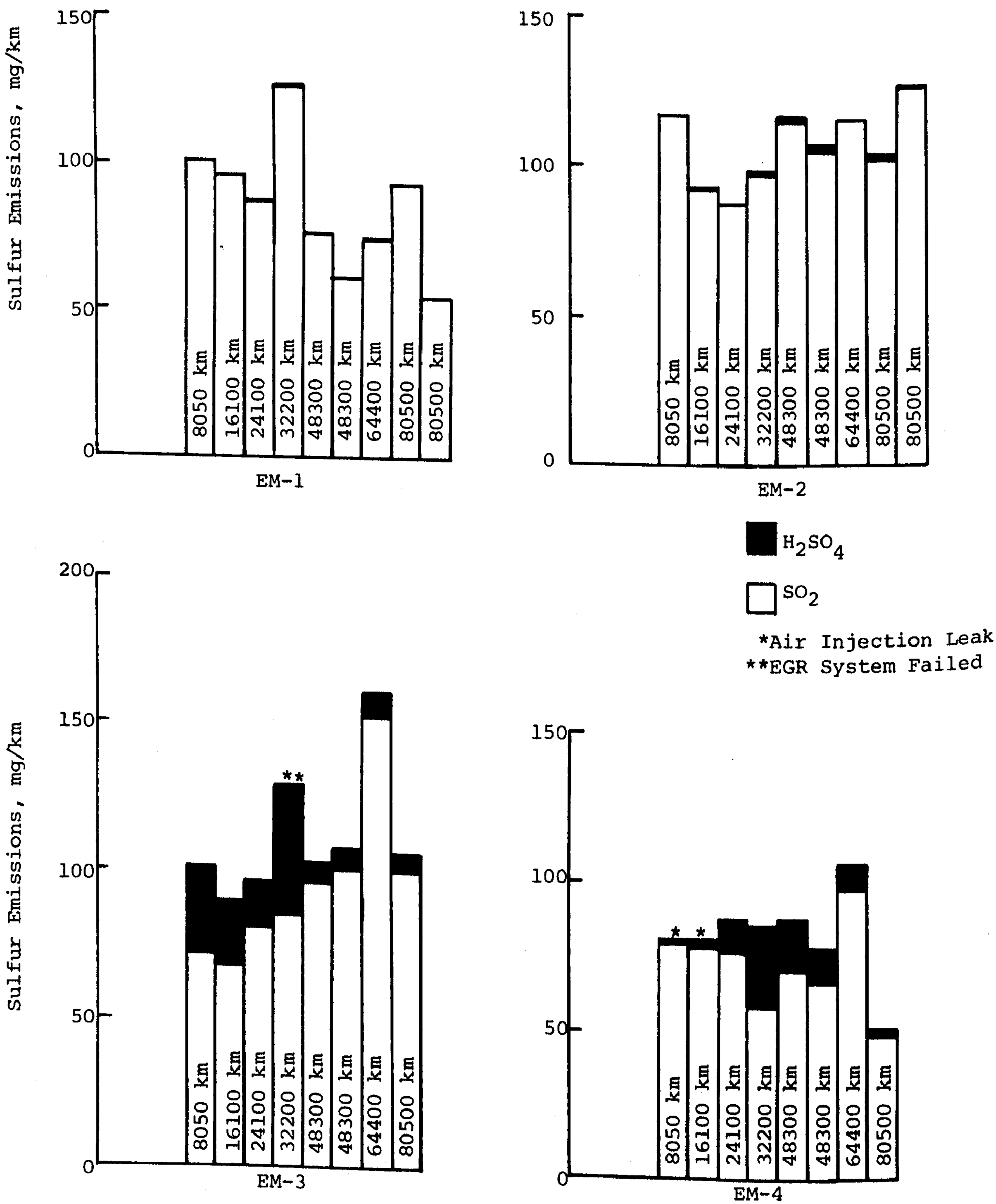



FIGURE 26. SULFATE AND SULFUR DIOXIDE EMISSIONS FROM SET-7 TESTS AT DISTANCE INTERVALS FOR FOUR CARS

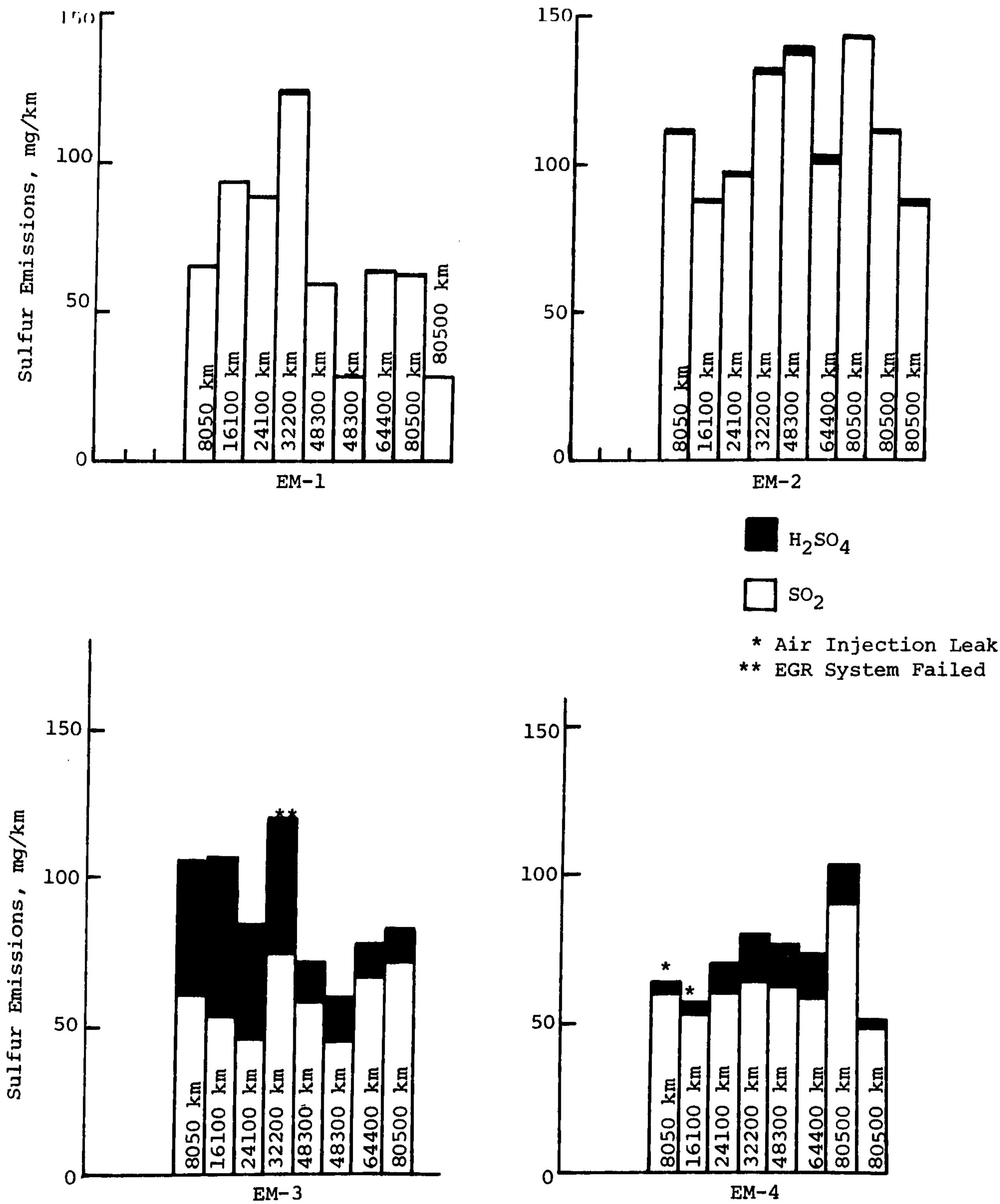



FIGURE 27. SULFATE AND SULFUR DIOXIDE EMISSIONS FROM HFET TESTS AT DISTANCE INTERVALS FOR FOUR CARS

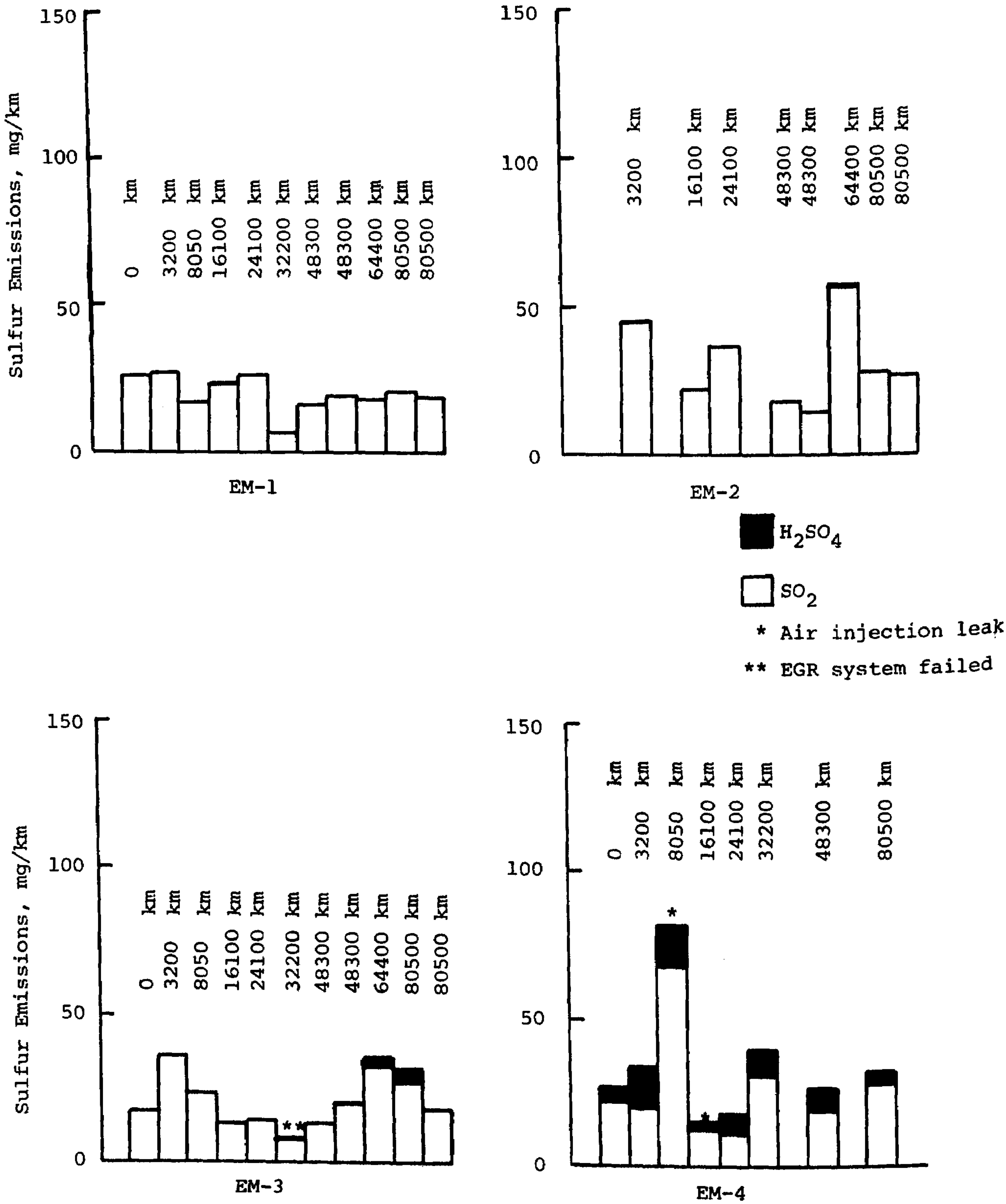



FIGURE 28. SULFATE AND SULFUR DIOXIDE EMISSIONS FROM ACCELERATION TO 48 kph TESTS AT DISTANCE INTERVALS FOR FOUR CARS

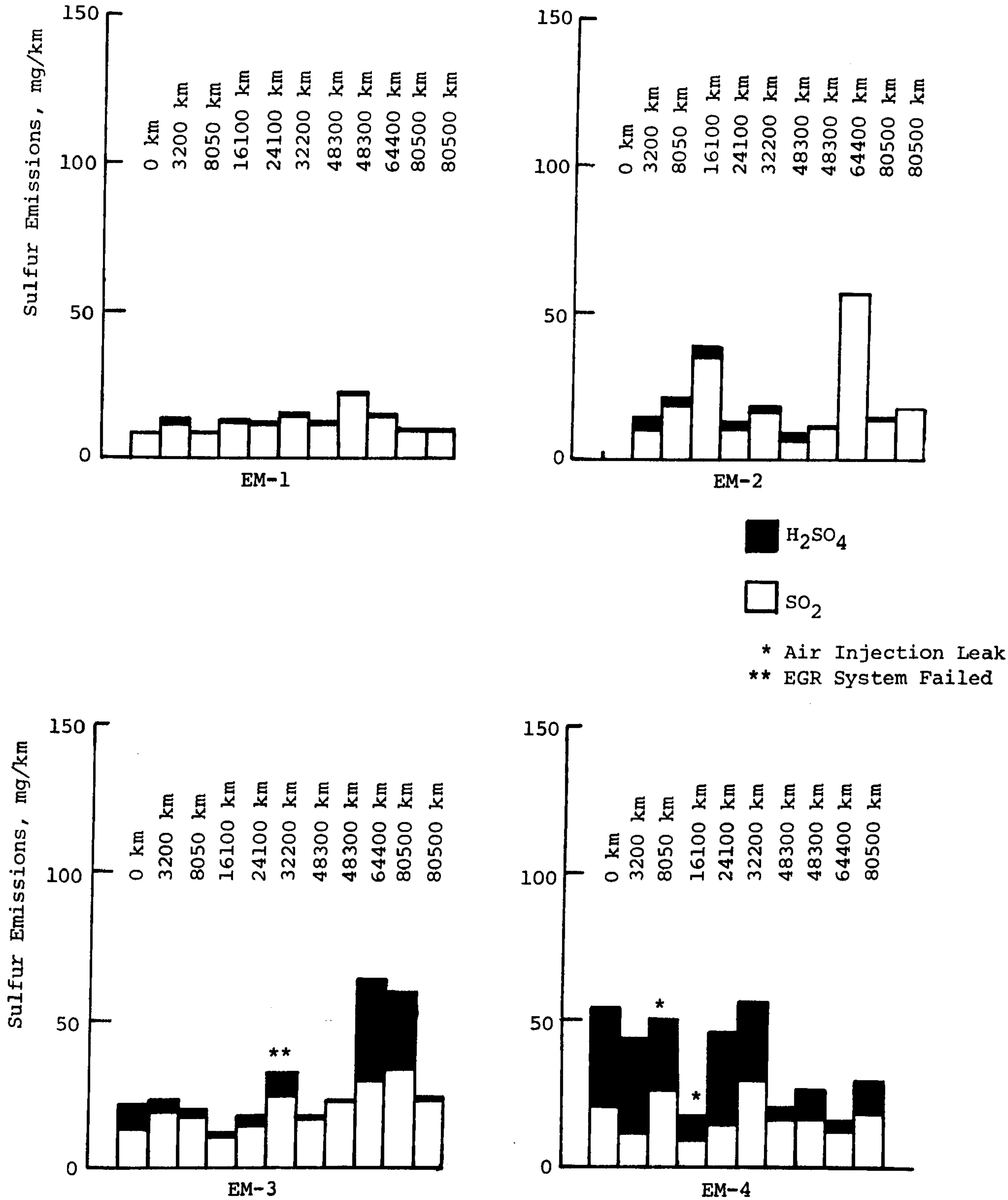



FIGURE 29. SULFATE AND SULFUR DIOXIDE EMISSIONS FROM 48 kph STEADY STATE TESTS AT DISTANCE INTERVALS FOR FOUR CARS

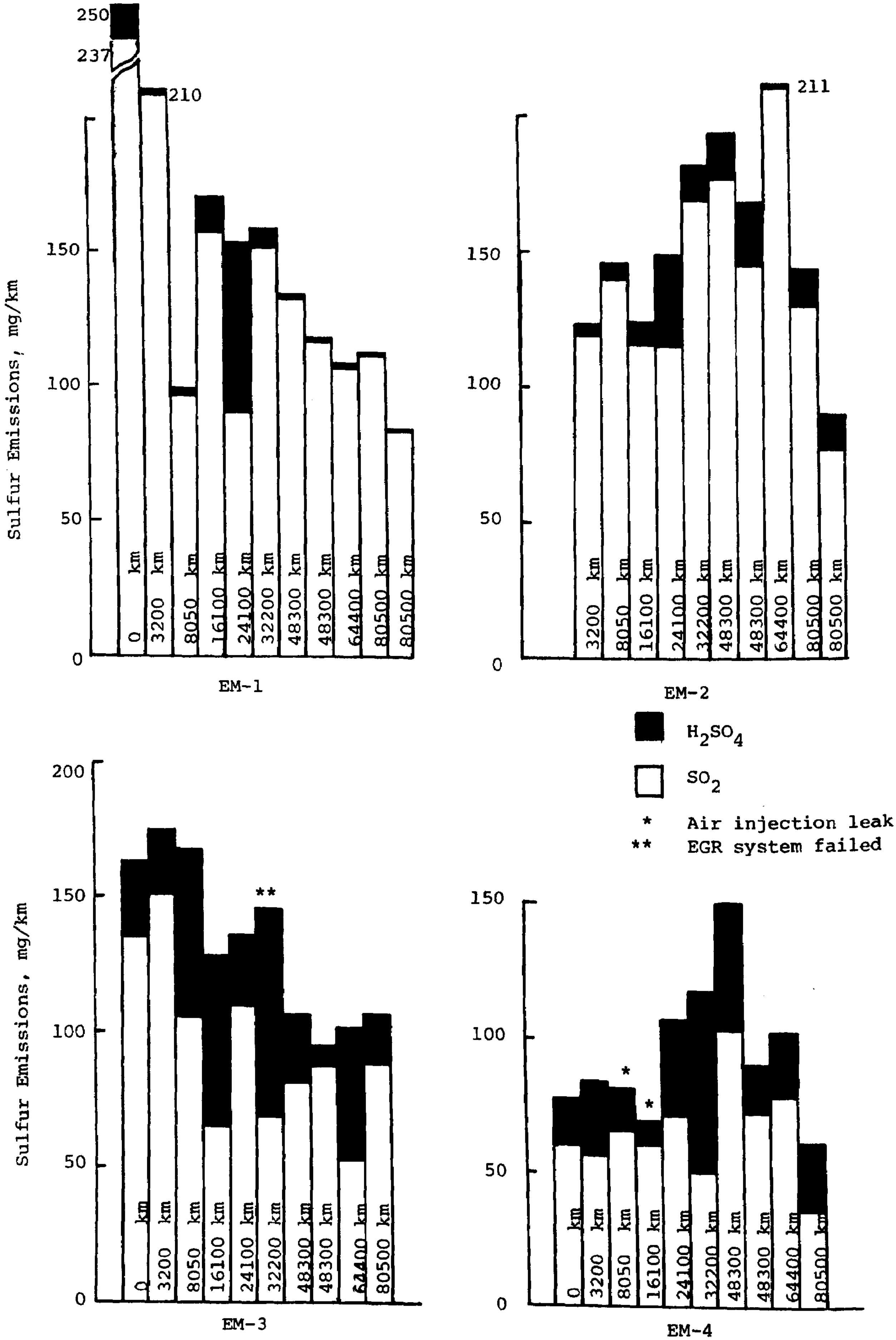



FIGURE 30. SULFATE AND SULFUR DIOXIDE EMISSIONS FROM ACCELERATION TO 96 kph TESTS AT DISTANCE INTERVALS ON FOUR CARS

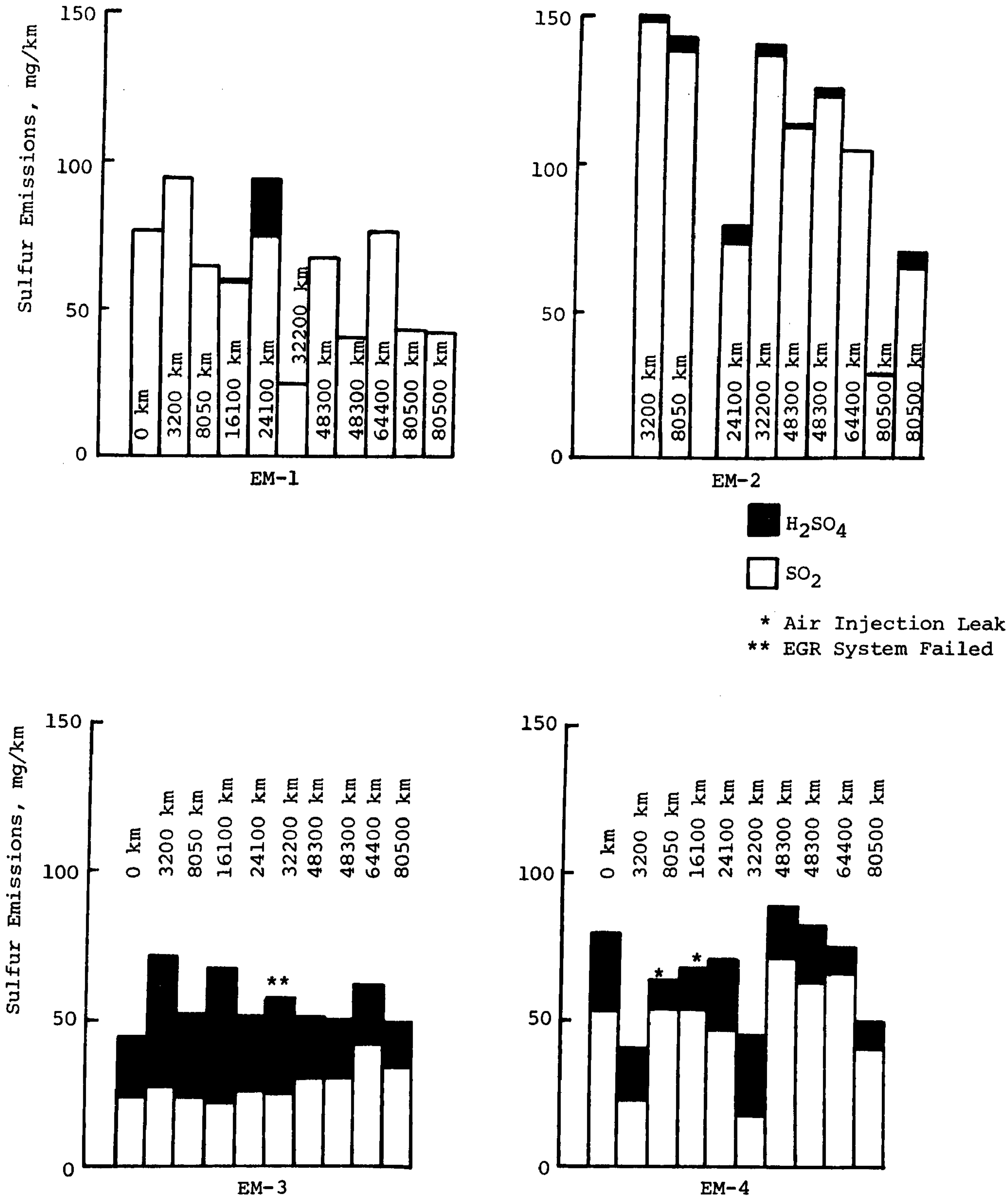



FIGURE 31. SULFATE AND SULFUR DIOXIDE EMISSIONS FROM 96 kph STEADY STATE TESTS AT DISTANCE INTERVALS ON FOUR CARS

state 48 kph, acceleration from 0 to 96 kph and steady-state 96 kph. For the nonair-injected cars, the most sulfur emissions, regardless of specie, n general were produced during the acceleration from 0 to 96 kph. The FTP produces the next highest, then the SET-7, HFET, 96 kph steady-state, and then the acceleration to 48 kph. The lowest sulfur emissions were from the 48 kph steady-state tests.

The rank order for the air-injected cars was somewhat different. For these two cars, the highest sulfur emissions were from the FTP. The acceleration from 0 to 96 kph produced the next highest emissions, then the SET-7, HFET test, 96 kph steady-state, and the 48 kph steady-state. The lowest sulfur compound emissions were from the acceleration to 48 kph.

It is interesting to note that the 48 kph steady-state sulfur emissions were either the lowest or next lowest sulfur emissions. In fact, the total sulfur emissions at 48 kph (30 mph) were on the order of one-tenth of the total sulfur emissions from the FTP.

For the FTP tests, cars EM-1 and EM-3 produced, on the average, more total sulfur emissions than EM-2 and EM-4. The air-injected monolith catalyst (EM-3) appeared to produce more total sulfur emissions during the FTP tests than the nonair-injected monolith (EM-1). The air-injected pelleted catalyst (EM-4) appeared to produce approximately the same total sulfur emissions as the nonair-injected pelleted catalyst (EM-2).

A comparison of average SET-7 total sulfur emissions for the nonair-injected cars shows that car EM-2 produced somewhat more total sulfur emissions than car EM-1. For the air-injected cars, EM-4 produces less total sulfur than EM-3. The air-injected monolith (EM-3) appeared to produce somewhat more total sulfur emissions during the SET-7 test than the nonair-injected (EM-1). However, the air-injected pelleted catalyst (EM-4) produced less total sulfur emissions than the nonair-injected pelleted catalyst (car EM-2.) The comparisons between the various catalyst configurations made for the SET-7 tests also hold for the HFET tests.

The total sulfur emissions from the acceleration to 48 kph and the 48 kph steady-state were too low to make meaningful comparisons; however, it appears that car EM-4 had the highest total sulfur emissions at both conditions.

The sulfur emissions from the acceleration from 0 to 96 kph were the highest of all tests for the nonair-injected cars. It is not surprising then, that at this condition, the nonair-injected cars produced more total sulfur emissions than the air-injected cars, comparing like models (i.e., EM-1 to EM-3 and EM-2 to EM-4). When the total sulfur emissions from the nonair-injected cars are compared, the pelleted system (EM-2) had greater emissions than the monolith system (EM-1). However, when the air-injected car sulfur emissions are compared, the pelleted system had lower emissions than the monolith system.

At the 96 kph conditions, car EM-2 produced the highest total sulfur emissions. The two cars with monolith catalyst (cars EM-1 and EM-3) produced approximately the same total sulfur emissions. The nonair-injected pelleted catalyst car (EM-2) produced greater total sulfur emissions than the air-injected pelleted catalyst car (EM-4).

The main purpose of this study, of course, is to investigate the exhaust sulfate emissions. While the histograms provide a good means to visualize the fraction of the sulfur emissions emitted as sulfuric acid, they provide only a gross comparison of sulfate emissions between tests and cars. This is because for some of the tests, the sulfate emissions from the non air-injected cars were too small to be represented accurately on the scale used for the histograms. Therefore, the sulfate emissions for each test type were averaged over the 80,500 km and presented in Table 21.

As can be seen from the table, the highest average sulfate emission from all cars is 33.6 mg/km from the acceleration from 0 to 96 kph for EM-3, the smallest average sulfate emission is 0.31 mg/km from the acceleration to 48 kph for EM-2. However, the rank order of sulfate emissions by test type is different for each car. This is a somewhat curious finding since sulfate emissions might reasonably to expected to be a function of the type of driving. Apparently, there are enough differences in the operations of the total emission control system on each car to cause these differences in rank order. The SET-7 test fell in the middle of the sulfate emission ranking for all four cars. Table 21 also shows that air-injected cars (EM-3 and EM-4) produced more sulfate emissions from each test type than the nonair-injected cars (EM-1 and EM-2).

From the tables, large variations in sulfate emissions from car-to-car for each type of test may be noted. The largest variation is for the 96 kph steady-state test where the highest average sulfate value is approximately 76 times the lowest. The acceleration to 96 kph test has the smallest variation, the highest sulfate value being 3.2 times the lowest value. Car EM-1 had the lowest average sulfate emissions for 5 of the 7 test types. Car EM-2 had the lowest average sulfate emissions from 2 of the test types. The highest sulfate emissions for each test type were more evenly divided between cars EM-3 and EM-4, with EM-3 having the highest emissions on 4 of the test types and EM-4 on 3 of the test types.

As mentioned before, the scale of the histograms in Figures 25 to 31 makes it difficult to determine the changes in sulfate emissions with distance accumulation. Therefore, the sulfate emissions in mg/km have been plotted versus distance traveled in kilometres and presented in Figures 32 to 38 for each test type. As explained, emissions control system malfunctions occurred during certain tests of EM-3 and EM-4. These malfunctions were corrected as discovered. However, for the tests at which the malfunctions occurred, the sulfate emissions were affected. This fact should be taken into consideration when evaluating the results presented in Figures 32 to 38. In the case of EM-4, which had an air-injection system leak at the 8,050 km and and 16,100 km tests, it appeared that this leak may have affected the sulfate conditioning of the catalyst, causing lower sulfates at the 24,100 km test than would have been seen had the air-injection system not leaked at all.

As a general rule, the sulfate emissions from the nonair-injected cars showed little change over the 80,500 km distance accumulation. The

TABLE 21. AVERAGE SULFATE EMISSIONS BY TEST TYPE FROM DISTANCE INTERVAL TEST ON FOUR CARS

| | Sulfate Emissions | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | EM-1 | | EM-2 | | EM-3** | | EM-4* | |
| Test Type | mg/km | Rank Order | mg/km | Rank Order | mg/km | Rank Order | mg/km | Rank Order |
| FTP | 1.35 | 3 | 1.01 | 6 | 4.65 | 6 | 7.30 | 7 |
| SET-7 | 0.49 | 5 | 1.04 | 5 | 13.98 | 4 | 13.25 | 4 |
| HFET | 0.45 | 6 | 1.63 | 4 | 26.25 | 3 | 11.74 | 5 |
| Accel to 48 kph | 0.36 | 7 | 0.31 | 7 | 1.00 | 7 | 19.03 | 2 |
| 48 kph | 0.97 | 4 | 2.11 | 3 | 8.55 | 5 | 17.43 | 3 |
| Accel to 96 kph | 9.81 | 1 | 12.49 | 1 | 33.59 | 1 | 7.49 | 6 |
| 96 kph | 2.03 | 2 | 3.13 | 2 | 26.26 | 2 | 28.42 | 1 |

*excluding 8050 and 16100 km tests with leaking air injection system
**excluding 32200 km test with failed EGR

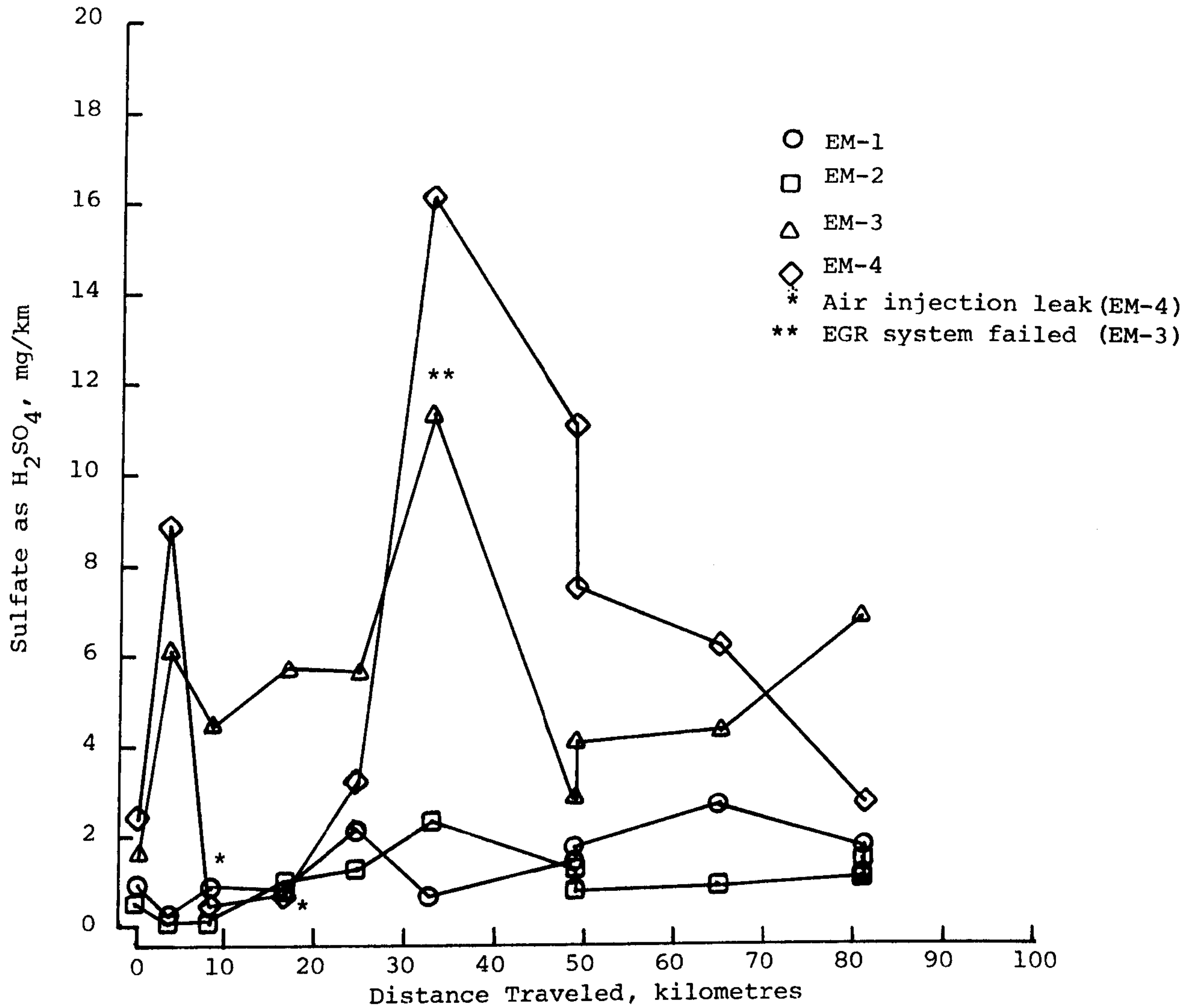



FIGURE 32. SULFATE EMISSIONS FROM FTP TESTS AS A FUNCTION OF DISTANCE TRAVELED FOR FOUR CARS

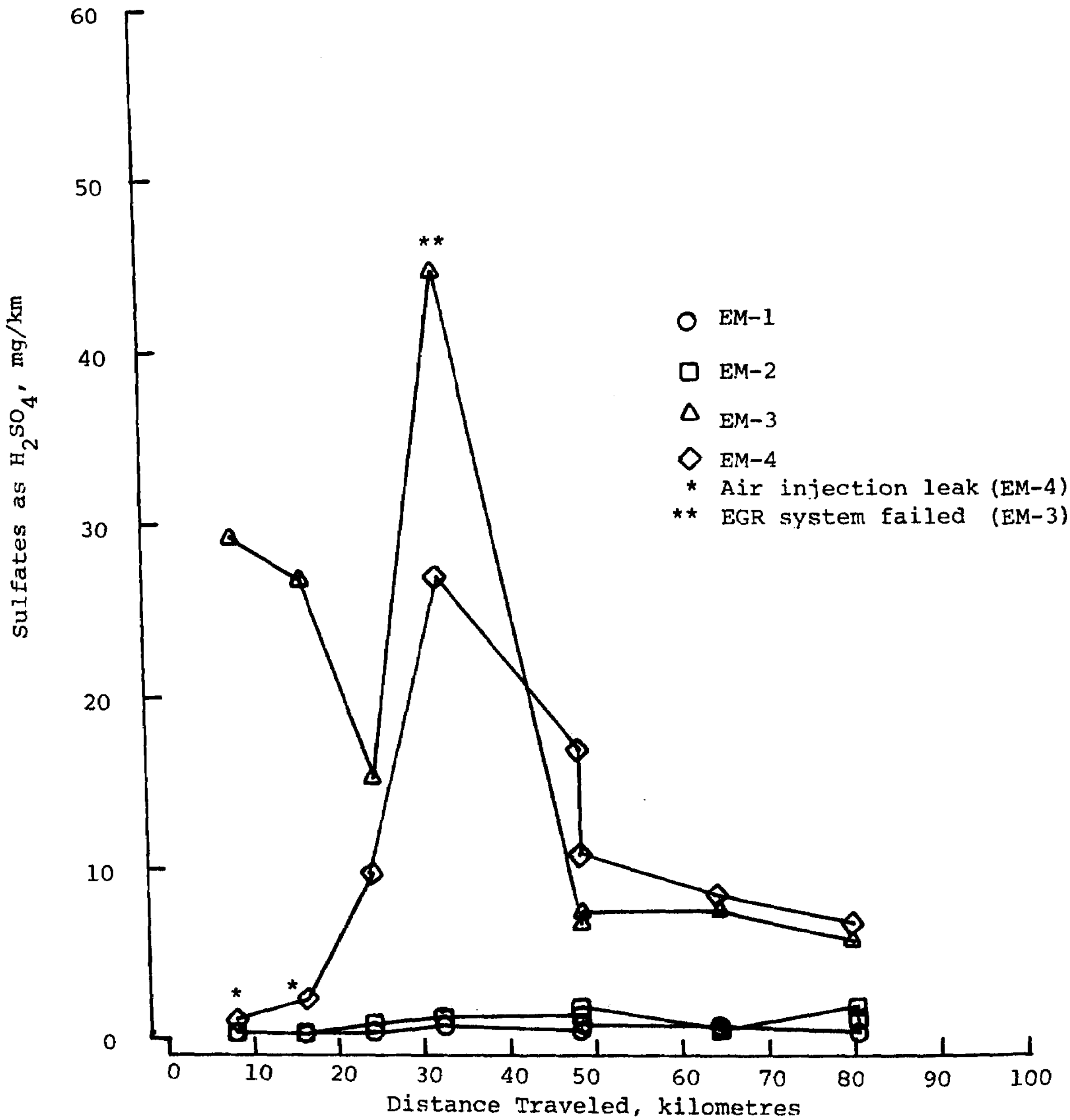



FIGURE 33. SULFATE EMISSIONS FROM SET-7 TESTS AS A FUNCTION OF DISTANCE TRAVELED FOR FOUR CARS

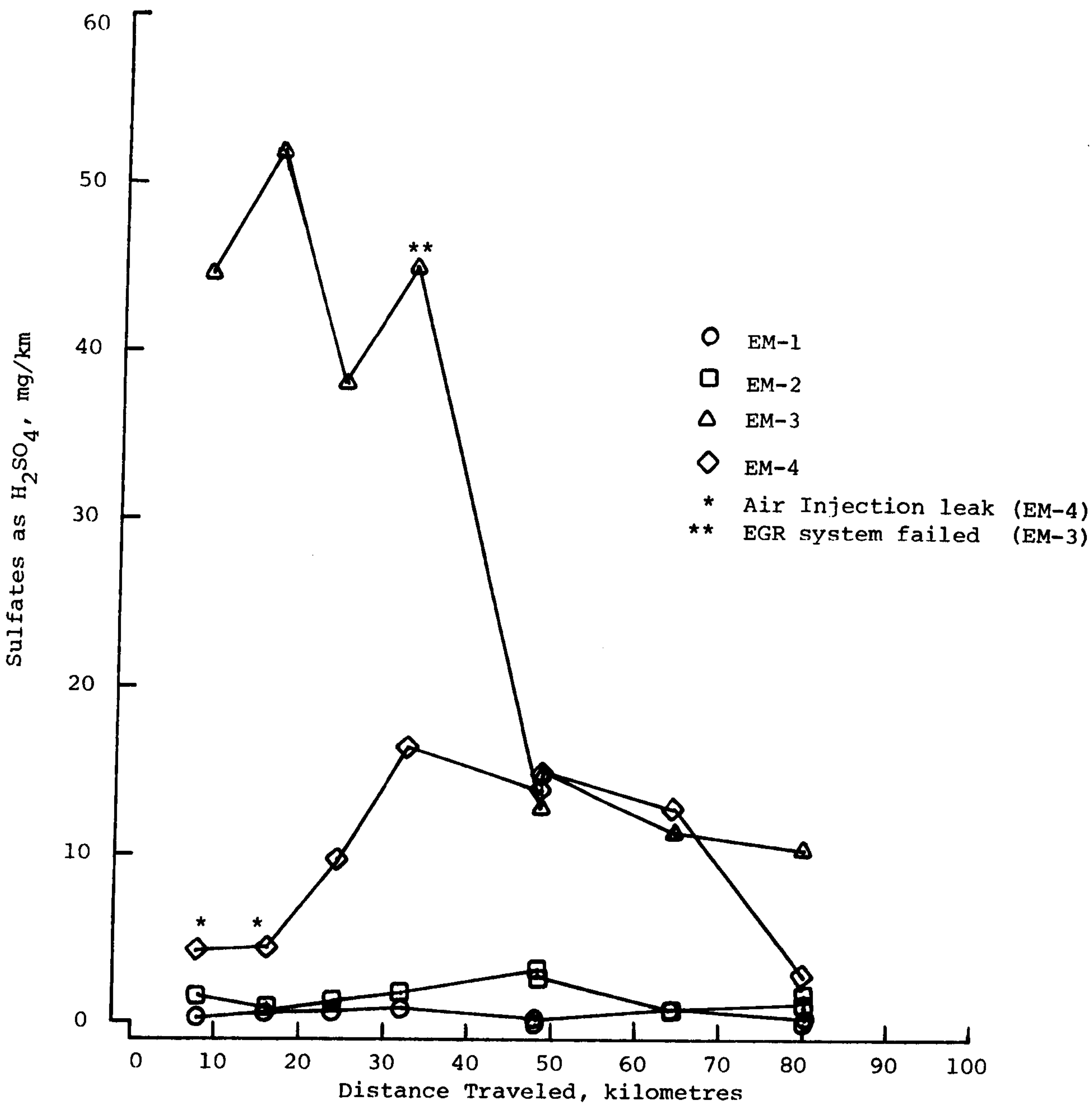



FIGURE 34. SULFATE EMISSIONS FROM HFET TESTS AS A FUNCTION OF DISTANCE TRAVELED FOR FOUR CARS

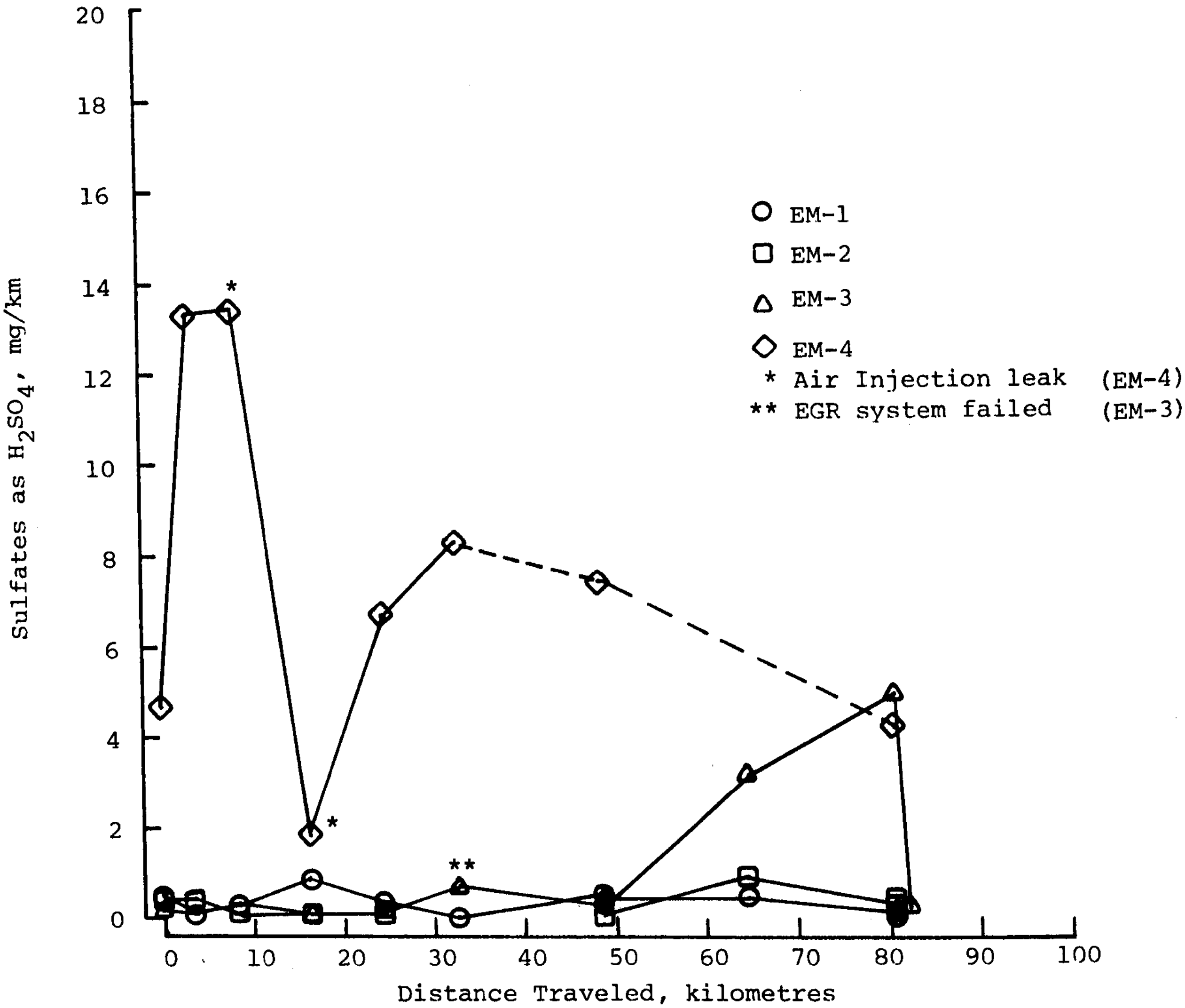



FIGURE 35. SULFATE EMISSIONS FROM ACCELERATION TO 48 KPH TESTS AS A FUNCTION OF DISTANCE TRAVELED FOR FOUR CARS

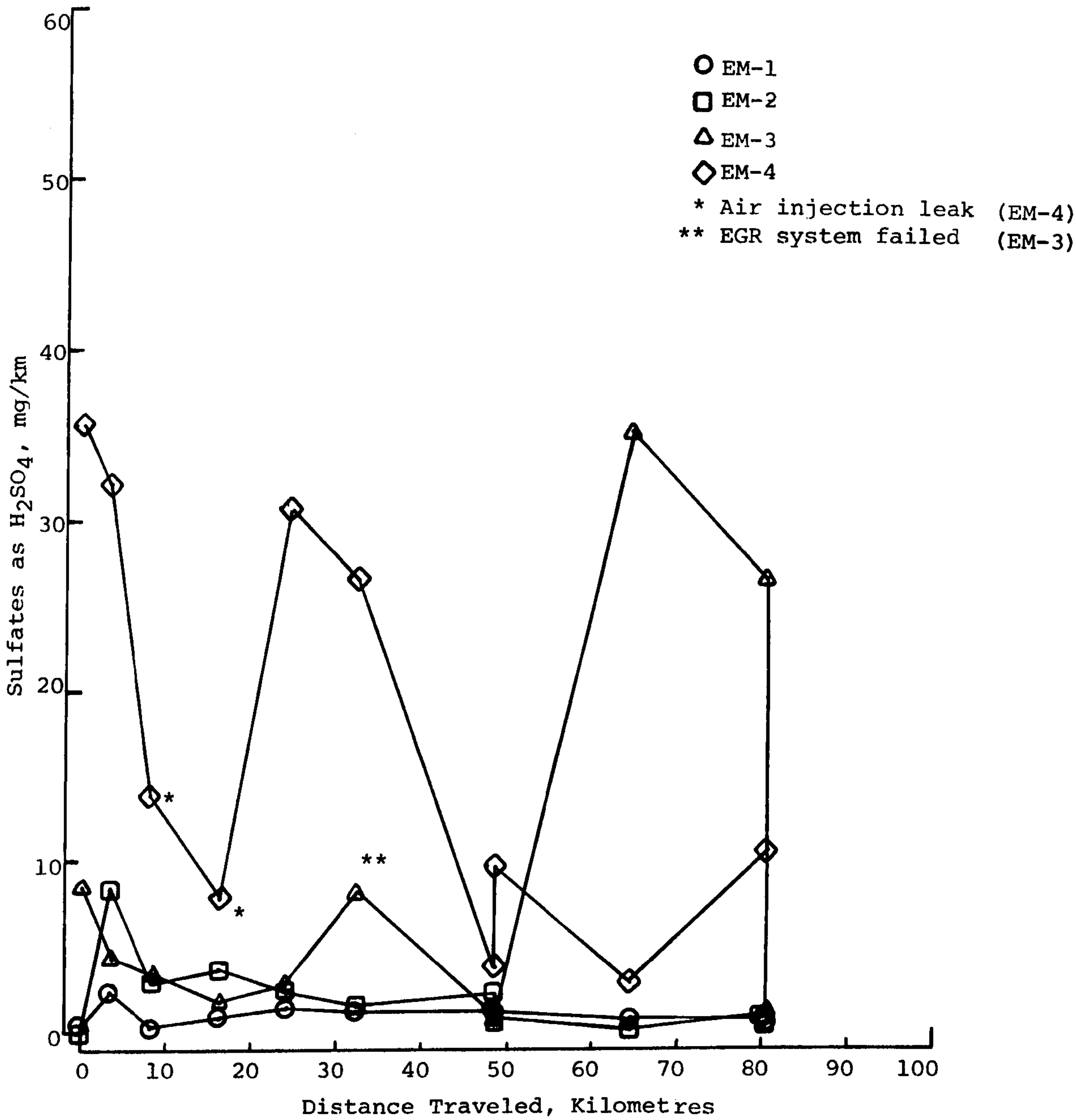



FIGURE 36. SULFATE EMISSIONS FROM 48 KPH STEADY STATE TESTS AS A FUNCTION OF DISTANCE TRAVELED FOR FOUR CARS

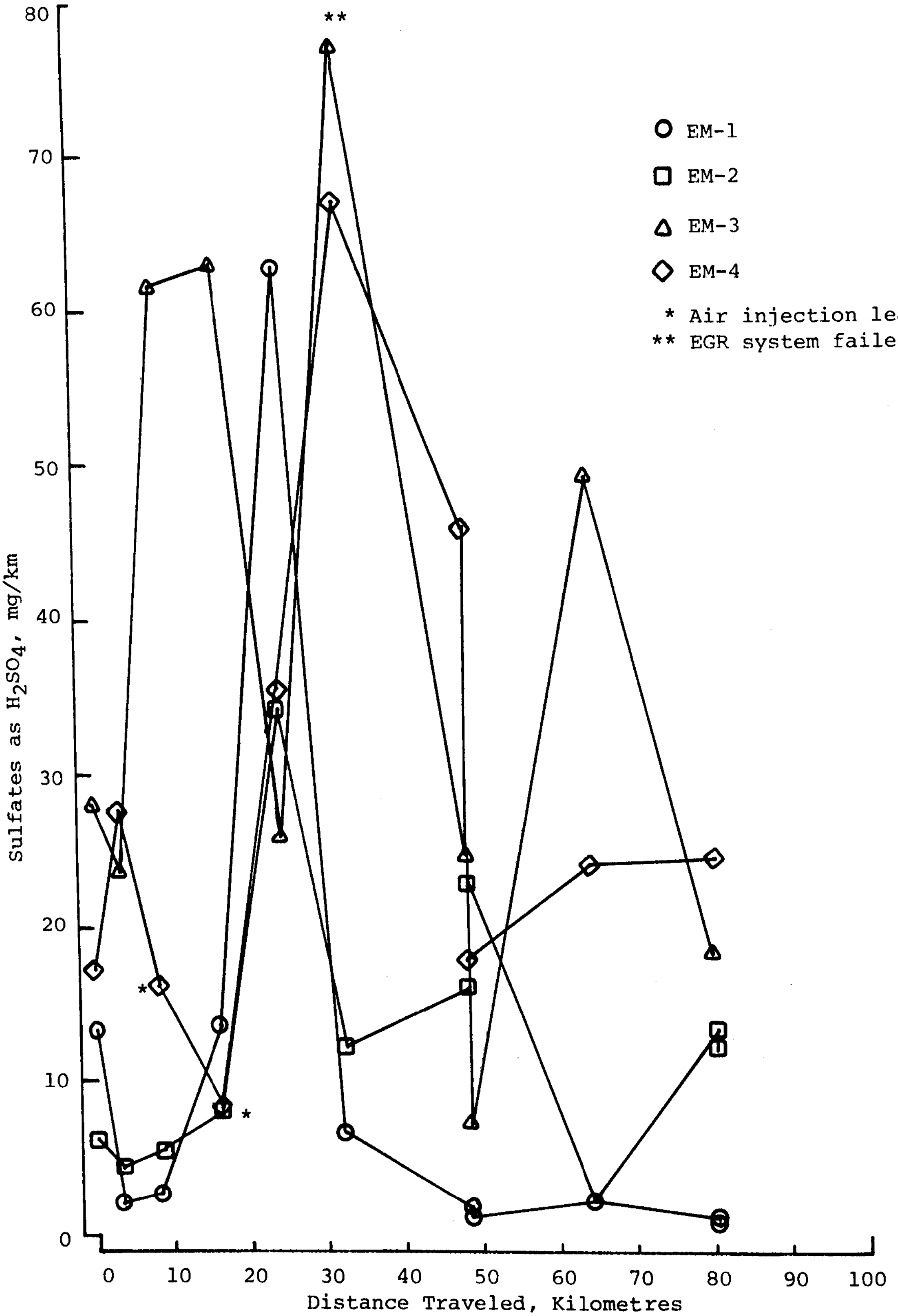



FIGURE 37. SULFATE EMISSIONS FROM ACCELERATION TO 96 KPH TESTS AS A FUNCTION OF DISTANCE TRAVELED FOR FOUR CARS

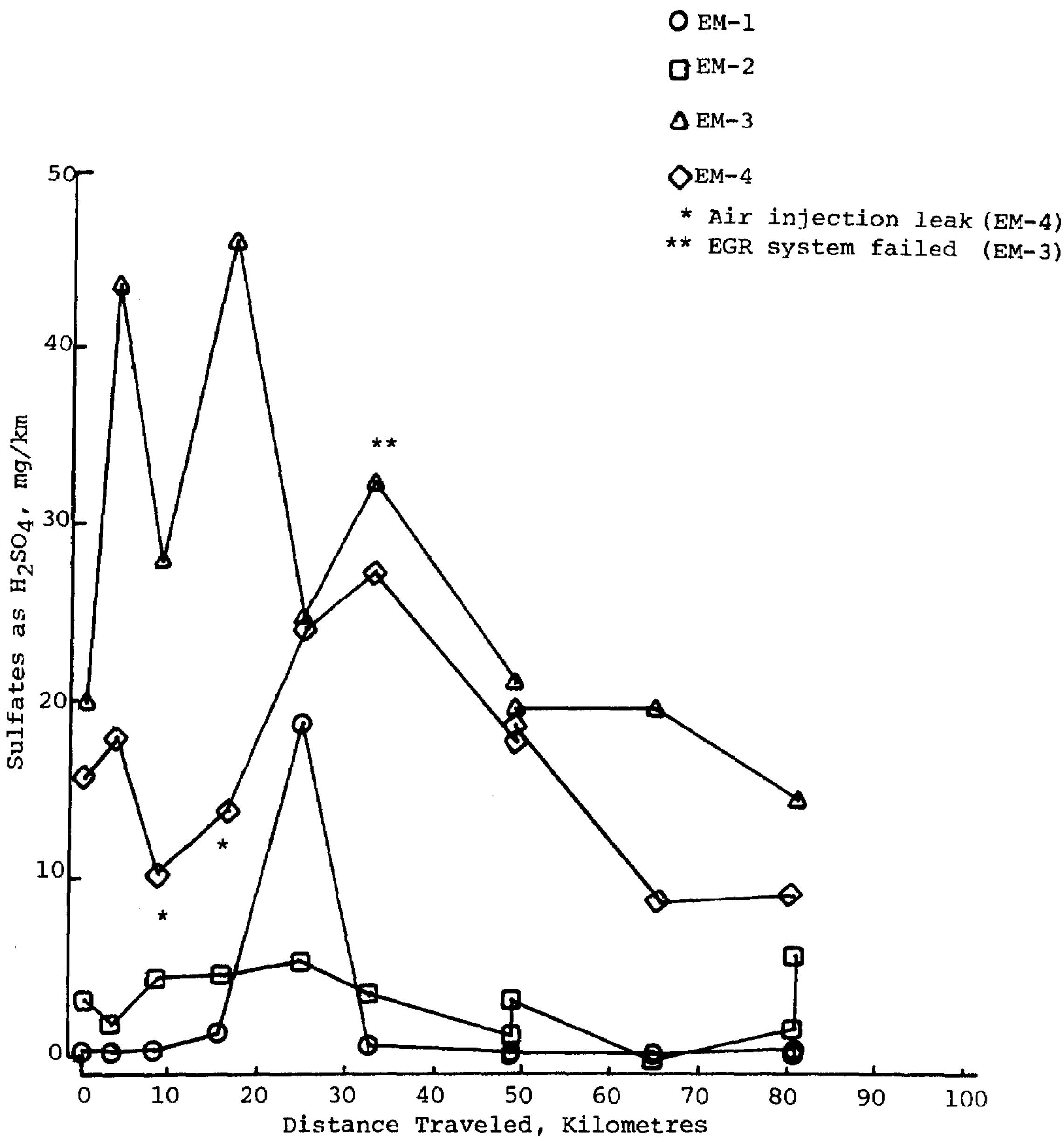



FIGURE 38. SULFATE EMISSIONS FROM 96 KPH STEADY STATE TESTS AS A FUNCTION OF DISTANCE TRAVELED FOR FOUR CARS

exception is the acceleration to 96 kph. The sulfate emissions from this test for all cars varies widely over the 80,500 km. The sulfate emissions for car EM-1 from the 24,100 km test at 96 kph, were considerably higher than any of the other kilometre test points at 96 kph. It is felt, however, that this is a valid value considering that it is from replicate tests. It is also interesting to note that the CO emissions from EM-1 are much lower for the 96 kph test at this kilometre point. This is perhaps an indication of a higher oxygen feed level to the catalyst during this particular test. What would have caused this higher oxygen level is not known.

The sulfate emissions from the two air-injected cars, EM-3 and EM-4, do not follow similar patterns with distance. As mentioned previously, this may be caused by the emission control system malfunctions at various points in the distance accumulation of the two cars.

For car EM-3, the higher speed tests (SET-7, HFET, accel to 96 kph, and 96 kph steady-state) show a similar pattern of sulfate emissions. As the distance traveled increases from 0 to between 8,000 and 16,000 km, the sulfate emissions increase. Thereafter, as distance traveled increased from 16,000 km to 80,500 km, the sulfate emissions decreased. For the FTP, the sulfate emissions from EM-3 increased as distance increased to about 3,200 km. From 3,200 km to 80,500 km, the sulfate emissions were essentially constant. The sulfate emissions from the acceleration to 48 kph and the 48 kph steady-state tests were essentially constant at a level corresponding to the nonair-injected cars to a distance of approximately 50,000 km. From 50,000 km to 80,000 km the sulfate emissions increased, then abruptly decreased to the pre-50,000 km level during the replicate 80,500 km test.

The sulfate emissions for EM-4, from all tests except the acceleration to 48 kph and 48 kph steady-state tests, increased between 0 and 32,000 km, then decreased between 32,000 km and 80,500 km. It is possible that the peak sulfate emission level might have been reached prior to 32,000 km if the air injection system had not been leaking between approximately 6,000 km and 19,000 km. For the acceleration to 46 kph and the 46 kph steady-state tests of EM-4, the sulfate emissions apparently reached their peak within the first 3,000 km of operation, and decreased continuously thereafter.

Since the SET-7 test cycle represents the driving mode where the highest level of sulfate would be expected, the sulfate emissions from the SET-7 deserve special attention. A regression analysis was performed on the SET-7 sulfate emissions for each car separately. First, a linear regression equation was obtained and a deterioration factor calculated using the procedure for light duty certification deterioration factors[14] from the equation values at 8,050 and 80,500 km. The linear equations and deterioration factor calculated from these equations together with the coefficient of determination ($r^2$) for each equation are shown in Table 22. Also shown are the minimum, maximum and average value of the SET-7 sulfate emissions for each car with indications at which distance test point the minimum and maximum occurred.

From this table, it can be seen that both EM-1 and EM-2 have deterioration factors greater than 1.0, indicating the SET-7 emissions increased with distance. However, the $r^2$ values for the regression equations

TABLE 22. REGRESSION ANALYSIS AND DETERIORATION FACTORS FOR SET-7 TESTS AT DISTANCE INTERVALS ON FOUR CARS

Linear Regression: Sulfate in mg/km = a + b (km)

| Car | Distance Used | a | b | Coeff. of Determination ($r^2$) |
|---|---|---|---|---|
| EM-1 | 3200 to 80500 | 0.40 | $+2.24 \times 10^{-6}$ | 0.106 |
| EM-2 | 3200 to 80500 | 0.46 | $+13.02 \times 10^{-6}$ | 0.342 |
| EM-3[1] | 8050 to 80500 | 27.96 | $-337.85 \times 10^{-6}$ | 0.794 |
| EM-4[2] | 32200 to 80500 | 35.48 | $-392.98 \times 10^{-6}$ | 0.775 |

Exponential Regression: Sulfates in mg/km $= a\,e^{b(km)}$

| Car | Distance Used | a | b | Coeff. of Determination ($r^2$) |
|---|---|---|---|---|
| EM-3[1] | 8050 to 80500 | 30.79 | $-24.23 \times 10^{-6}$ | 0.858 |
| EM-4[2] | 32200 to 80500 | 57.37 | $-28.14 \times 10^{-6}$ | 0.866 |

| Car | Average SET-7 Sulfates, mg/km | | | Linear Deterioration Factor | Exp. Deterioration Factor |
|---|---|---|---|---|---|
| | Minimum | Maximum | Mean | | |
| EM-1 | 0.29(16100 km)[3] | 0.80(32200 km) | 0.49 | 1.384 | - |
| EM-2 | 0.30(16100 km) | 1.89(80500 km) | 1.04 | 2.677 | - |
| EM-3[1] | 5.67(80500 km) | 29.09(8050 km) | 13.98 | 0.030 | 0.173 |
| EM-4[2] | 6.80(80500 km) | 26.90(32200 km) | 13.25 | 0.119 | 0.130 |

(1) excluding failed EGR test at 32200 km

(2) excluding tests with leaking air injection system

(3) numbers in parentheses are distances at which max or min occurs

of these two vehicles indicate that the data fit the equation poorly. This fact and the consideration of low absolute levels of the sulfate emissions themselves, should be considered when drawing conclusions from these deterioration factors. The deterioration factors for cars EM-3 and EM-4 are less than 1.0, indicating that the SET-7 sulfate emissions decreased with distance traveled. Examination of Figure 33, the plot of SET-7 sulfate emissions versus distance, indicates that an exponential curve might fit the SET-7 sulfate emissions from EM-3 and EM-4 better than a linear equation. An exponential regression analysis was performed on these sulfate emissions using an equation of the form $y = ae^{bx}$. The results of the analysis are also shown in Table 22. Comparing the coefficients of determination of the exponential curve with those obtained from the linear regression, it can be seen that the exponential equation does indeed give a better fit ($r^2$ closer to 1.0 for the exponential equations). A new deterioration factor was then calculated using the 8,050 and 80,500 km values from the exponential equations for each car. These deterioration factors are also shown in Table 22.

Apparently then, SET-7 sulfate emissions from nonair-injected cars changed little, if any, during 80,500 km of distance accumulation. SET-7 sulfate emissions from air-injected cars decreased significantly in an exponential fashion from 8,050 km (5,000 miles) to 80,500 km (50,000 miles).

It should be remembered that in the above analysis, certain data from EM-3 and EM-4 were not used because of malfunctions in the emission control of the car during those certain tests. While it was not one of the purposes of this study, one of the significant findings is that emission control system malfunctions have a definite effect on sulfate emissions.

Once the fact that the air-injected catalyst cars had higher sulfate emissions than non air-injected cars was established, it was obvious that any leak in the air injection system would lower the sulfate emissions. This is what happened at the 8,050 and 16,100 km test points on EM-4. In fact, the lower sulfate emissions were one of the causes of the investigation for a leak. Another malfunction that affects sulfate emissions was not so obvious. After the 32,200 km test of EM-3, a check of the $NO_x$ emissions indicated a malfunction of the EGR system. As explained earlier, this malfunction was caused by a failure of the vacuum amplifier in the EGR system. The sulfate emissions were also high, but the two facts were not connected at the time, since except for the FTP and SET-7 tests, sulfate emissions at the same, or higher, levels had been observed on previous tests.

It was not until a similar situation occurred during the 48,300 km "after maintenance" tests on EM-3 that the two facts were connected. While reviewing the $NO_x$ emissions as each test was completed, it became obvious that the EGR system was not functioning. The EGR system had been visually inspected prior to testing and appeared to be operational. However, after the test each line was traced to insure there were no leaks. Finally, an almost inaccessible connection to a solenoid in the system was found to be loose. It is perhaps fortunate that the leak developed since it revealed an unexpected relationship between EGR and sulfate emissions.

The hose was connected and proper operation of the EGR system verified. The car was operated for 500 km on the modified AMA cycle and then retested. It is this test series on February 19, 1976, that is reported as the "after maintenance" tests for the 48,300 kilometre test point.

The sulfate filters from the tests with the inoperative EGR were processed to compare sulfate emissions with and without EGR. Table 23 shows the $NO_x$ and sulfur emissions from both the 48,300 km after maintenance FTP, SET-7 and FET tests, together with the $NO_x$ and sulfur emissions from the 24,100 and 32,200 km tests for comparison. Note that for 5 of the 6 tests, when the EGR system was inoperative, the sulfate emissions were considerably higher than the sulfate emissions from tests with the EGR functioning. Thus, while the results are not 100 percent consistent, it does appear that an EGR system failure increases sulfate emissions as well as $NO_x$ emissions.

To further investigate this phenomenon, a series of two tests were run on each car at the conclusion of the 80,500 km tests. The test series consisted of two 80 kph steady-state tests, 10 to 15 minutes long. For one of the two tests, the EGR system was disabled by disconnecting the vacuum actuation line at the EGR valve. The other test was run with the EGR system functioning normally. On car EM-4, a third test was run with the vacuum line disconnected and plugged. With the line unplugged, there was a vacuum "leak", as well as an inoperative EGR system; with the line plugged, the integrity of the vacuum system was preserved and only the EGR system was inoperative.

Table 24 shows the results of these tests. In addition to the usual gaseous emission and sulfates, the temperature at the inlet to the catalyst and the oxygen level at the exit of the catalyst are also shown. For each car, the test with the EGR valve disabled showed an increase in $NO_x$. This increase varied from approximately 10 percent for EM-1 to approximately 200 percent for EM-4. The sulfate emissions also increased for the EGR disabled test except for car EM-1. Thus, the changes in sulfate emissions ranged from negligible for car EM-1 to approximately 170 percent for the test with the vacuum line plugged on car EM-4.

For 3 of the 4 cars, when the EGR system was disabled, the exhaust gas temperature into the catalyst decreased. On two of the cars, the $O_2$ content at the exit of the catalyst decreased when the EGR was disconnected, one one car there was no change and on one car the oxygen increased. It has been shown in several studies[12, 13] that decreasing catalyst temperature increases the amount of sulfates formed. Thus, it is not surprising that the car with the largest temperature decrease, (EM-4), also had the largest sulfate increase.

This series of tests was not intended to be a thorough investigation of this phenomenon. Rather, they were to be a verification that a malfunctioning EGR system could lead to increased sulfate emissions. It is felt that the test accomplished this purpose and has defined an area that requires further study.

To summarize the sulfate emissions results from the four distance accumulation cars, the air-injected catalyst cars have significantly higher sulfate emissions than the nonair-injected catalyst cars for all test cycles. The reason for this cannot be stated with certainty, since as explained previously, some important parameters were not measured. However, it is felt

TABLE 23. $NO_x$ AND SULFUR EMISSIONS FROM SELECTED TESTS ON SwRI CAR EM-3

| Miles | Date(s) | Test Type | EGR Operative? | g/km $NO_x$ | g/km $SO_2$ | mg/km $H_2SO_4$ | % Fuel S as $H_2SO_4$ | % Fuel S as $SO_2$ | Total Recovery |
|---|---|---|---|---|---|---|---|---|---|
| 15,000 | 11/3, 11/5/76 | FTP | Yes | 1.10 | 0.186 | 5.67 | 2.44 | 121.62 | 124.05 |
| 20,000 | 12/19/75 | FTP | No | 3.26 | 0.224 | 11.35 | 5.91 | 178.76 | 184.67 |
| 30,000 | 2/6/76 | FTP | Yes | 1.07 | 0.116 | 2.84 | 1.33 | 83.31 | 84.65 |
| 30,000 | 2/18/76 | FTP | No | 2.46 | 0.086 | 3.66 | 1.89 | 68.33 | 70.23 |
| 30,000 | 2/19/76 | FTP | Yes | 0.93 | 0.169 | 4.12 | 1.94 | 122.10 | 124.04 |
| 15,000 | 11/3, 11/5/75 | SET-7 | Yes | 0.86 | 0.081 | 15.27 | 9.91 | 81.18 | 91.09 |
| 20,000 | 12/19/75 | SET-7 | No | 3.00 | 0.085 | 44.59 | 33.01 | 95.88 | 128.89 |
| 30,000 | 2/6/76 | SET-7 | Yes | 0.81 | 0.096 | 6.62 | 4.55 | 101.31 | 105.86 |
| 30,000 | 2/18/76 | SET-7 | No | 2.67 | 0.063 | 49.09 | 35.46 | 69.89 | 105.35 |
| 30,000 | 2/19/76 | SET-7 | Yes | 0.80 | 0.101 | 7.05 | 4.56 | 100.27 | 104.83 |
| 15,000 | 11/3, 11/5/75 | FET | Yes | 0.75 | 0.046 | 38.01 | 29.46 | 53.60 | 83.06 |
| 20,000 | 12/19/75 | FET | No | 3.38 | 0.075 | 45.08 | 39.33 | 99.88 | 139.21 |
| 30,000 | 2/6/76 | FET | Yes | 0.87 | 0.059 | 12.93 | 10.11 | 70.75 | 80.87 |
| 30,000 | 2/18/76 | FET | No | 2.87 | 0.040 | 62.79 | 55.93 | 54.79 | 110.72 |
| 30,000 | 2/19/76 | FET | Yes | 0.85 | 0.045 | 14.55 | 11.42 | 54.25 | 65.67 |

Note: SET-7 is average of 4 sets

TABLE 24. RESULTS OF EMISSION TESTS AT 80 kph STEADY STATE ON FOUR CARS WITH EGR SYSTEM OPERATING NORMALLY AND DISABLED

| Test No. | Car No. | Operative EGR | g/km HC | CO | $NO_x$ | $SO_2$ | mg/km $H_2SO_4$ | % Fuel as $H_2SO_4$ | % fuel as $SO_2$ | Total Recovery | Avg.Cat. Inlet Temp °F | $O_2$ % Out of Cat. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11 | EM-1 | yes | 0.06 | 0.21 | 3.03 | 0.054 | 0.01 | 0.00 | 81.49 | 81.50 | 888° | 1.00% |
| 12 | EM-1 | no (1) | 0.05 | 0.27 | 3.31 | 0.079 | 0.01 | 0.00 | 123.86 | 123.86 | 939° | .75% |
| 11 | EM-2 | yes | 0.03 | 0.12 | 1.36 | 0.033 | 1.27 | 1.15 | 45.33 | 46.48 | 1143°F | 1.13% |
| 12 | EM-2 | no | 0.04 | 0.11 | 2.33 | 0.042 | 1.59 | 1.41 | 57.09 | 58.50 | 1119°F | 0.83% |
| 11 | EM-3 | yes | 0.07 | 0.02 | 1.58 | 0.020 | 44.16 | 46.74 | 32.13 | 78.87 | 881°F | 6.00% |
| 12 | EM-3 | no | 0.06 | 0.02 | 4.36 | 0.019 | 55.60 | 60.72 | 31.56 | 92.27 | 831°F | 6.00% |
| 11 | EM-4 | yes | 0.02 | 0.02 | 0.42 | 0.030 | 10.72 | 9.12 | 38.83 | 47.95 | 1081°F | 5.50% |
| 12 | EM-4 | no | 0.01 | 0.03 | 1.24 | 0.022 | 17.15 | 16.35 | 32.55 | 48.90 | 974°F | 6.00% |
| 13 | EM-4 | no (2) | 0.02 | 0.04 | 1.28 | 0.020 | 29.28 | 27.36 | 28.68 | 56.04 | 976°F | 6.13% |

Notes: (1) Except where noted when EGR system is inoperative, the vacuum line to the EGR valve was disconnected, but not plugged.

(2) For this test vacuum line to EGR valve was disconnected and plugged.

that the higher oxygen level in the air-injected catalyst was the cause of the higher sulfates. For the air-injected catalyst cars, the sulfate emissions from the SET-7 test increased as distance traveled increased from 0 to between 8,000 and 16,000 km. The SET-7 sulfate emissions then decreased exponentially as distance traveled increased to 80,500 km. The reason for this decrease is only speculative, but one possibility is that the catalyst efficiency is decreasing, so that along with its decreasing ability to oxidize CO and HC, it also decreases in ability to oxidize $SO_2$ to $SO_3$. The SET-7 sulfate emissions from the non air-injected catalyst cars showed little change with distance traveled for the entire 80,500 km.

The smallest sulfate emission observed during this study was less than 0.01 mg/km. This occurred on the accelerations to 48 kpm during the 32,000 km test series on EM-1. The largest sulfate emission observed was 77.11 mg/km. This occurred on the acceleration to 96 kpm during the 32,200 km test series on EM-3. The highest sulfate emissions from each car occurred during the acceleration to 96 kph test. The lowest occurred during the acceleration to 48 kph test for three of the four cars. Sulfate emission variations were noted (1) with whether or not air was injected, (2) with distance traveled, and (3) with test cycle. These findings indicate that there are large differences in sulfate emissions from cars in actual operation on the road.

## 2. Storage of Sulfur Compounds

One of the objectives of this study was to investigate, where possible, the storage and release of sulfur compounds from the catalyst systems. This storage and release of sulfur on a test cycle basis can easily be seen if the exhaust sulfur emissions are expressed in terms of percent by weight of the sulfur consumed with the fuel. If there is no net storage or release of sulfur from the catalyst, the exhaust sulfur emissions should equal 100 percent of the fuel sulfur consumed during the test. Recovery of sulfur in the exhaust in excess of 100 percent indicates a net release of sulfur during the test. A recovery of less than 100 percent indicates a net storage during the test. For purposes of these discussions, the term "total recovery" means the sum of the exhaust sulfur in $SO_2$ expressed as percent of fuel sulfur and the exhaust sulfur in sulfate (as $H_2SO_4$) expressed as percent of fuel sulfur.

Tables 17 to 20 contain the values of sulfur in $SO_2$ as percent of fuel sulfur, sulfur in sulfate as percent of fuel sulfur, and total recovery for each test type at all distance intervals for each of the four cars. This information is plotted by test type in Figures 39 to 45 to aid in interpreting the data. The results from all four cars are shown in each figure to facilitate comparison between cars.

An examination of the figures shows that the storage or release of sulfates is not necessarily the same for all cars on a particular test. There are also apparent changes in storage with distance traveled for some cars on some tests.

Before discussing the sulfate storage of each car on each test cycle, it should be pointed out that the $SO_2$ collection procedure is a wet chemistry procedure that requires considerable sample handling and thus is more prone to errors than the other emission measurements made during this study. Thus,

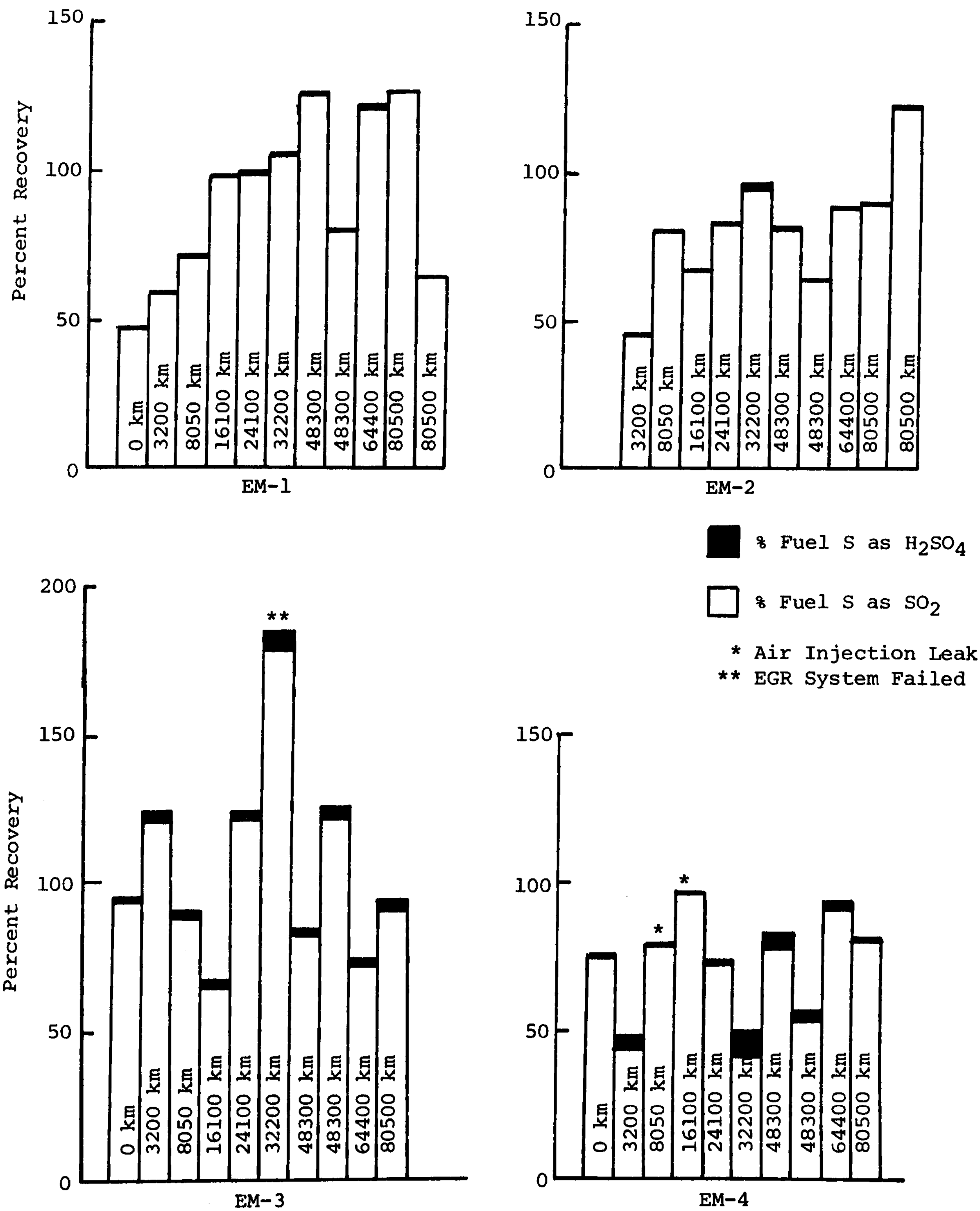



FIGURE 39. EXHAUST SULFUR RECOVERY FROM FTP TESTS AT DISTANCE INTERVALS FOR FOUR CARS

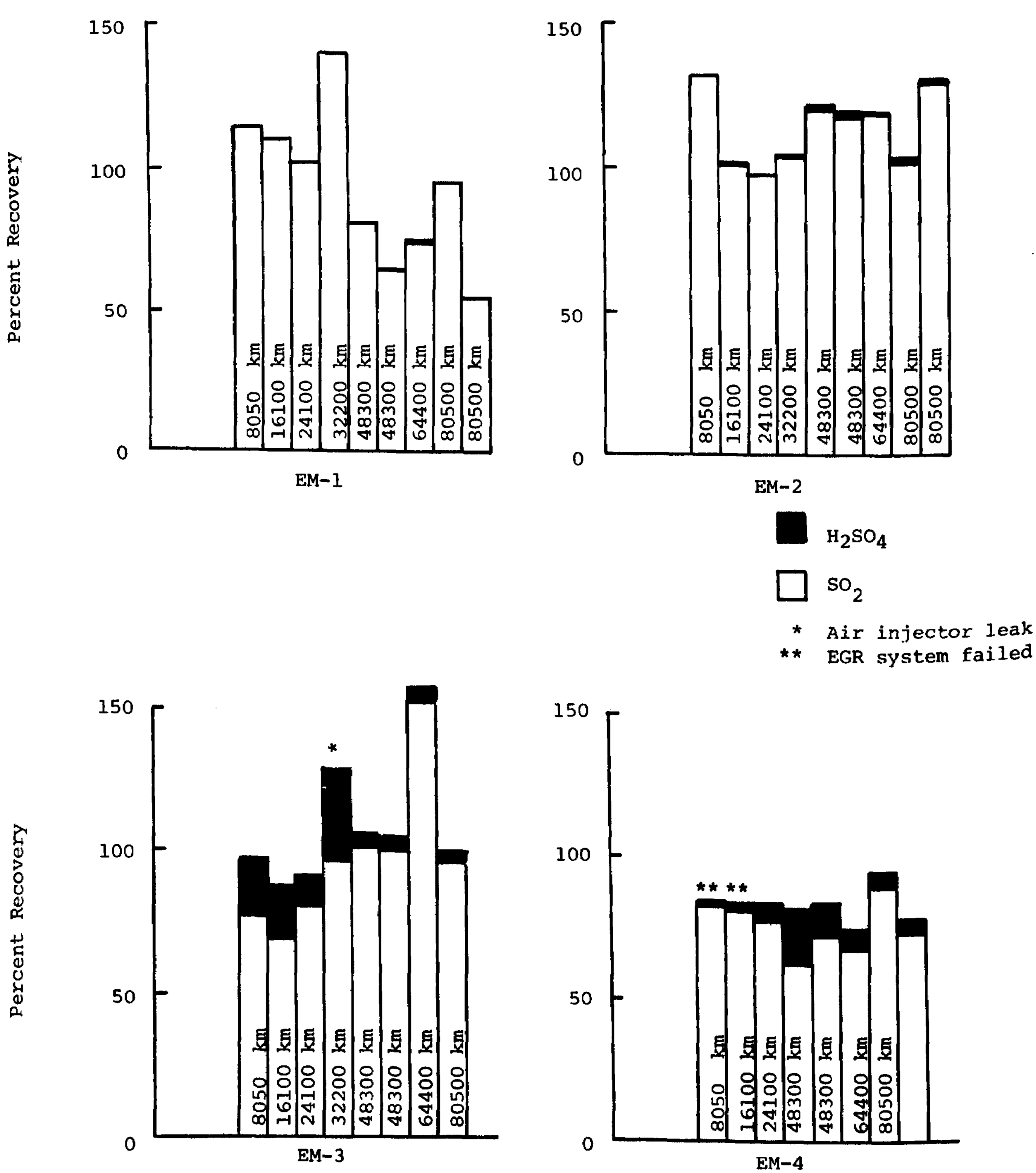



FIGURE 40. EXHAUST SULFUR RECOVERY FROM SET-7 TESTS AT DISTANCE INTERVALS FOR FOUR CARS

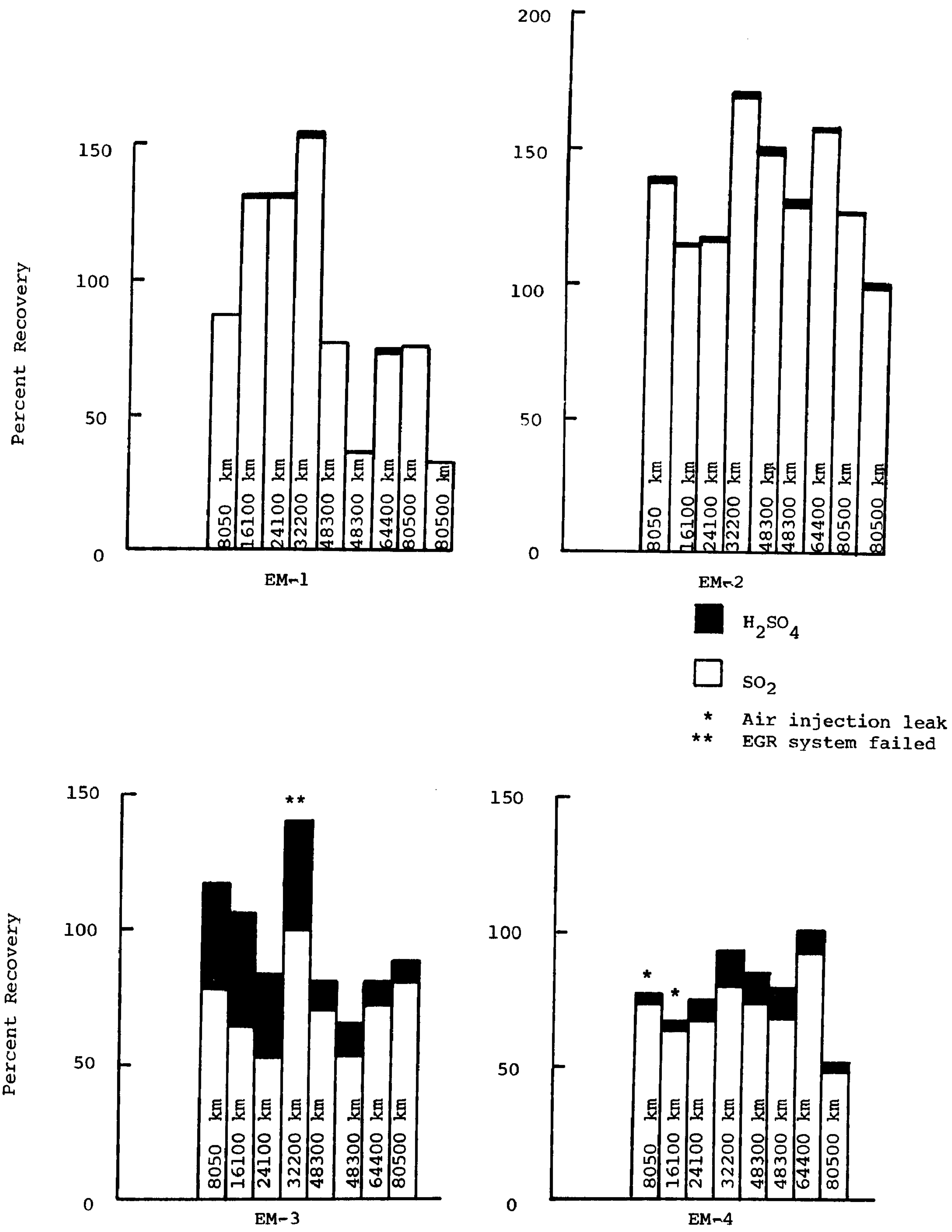



FIGURE 41. EXHAUST SULFUR RECOVERY FOR HFET TESTS AT DISTANCE INTERVALS FOR FOUR CARS

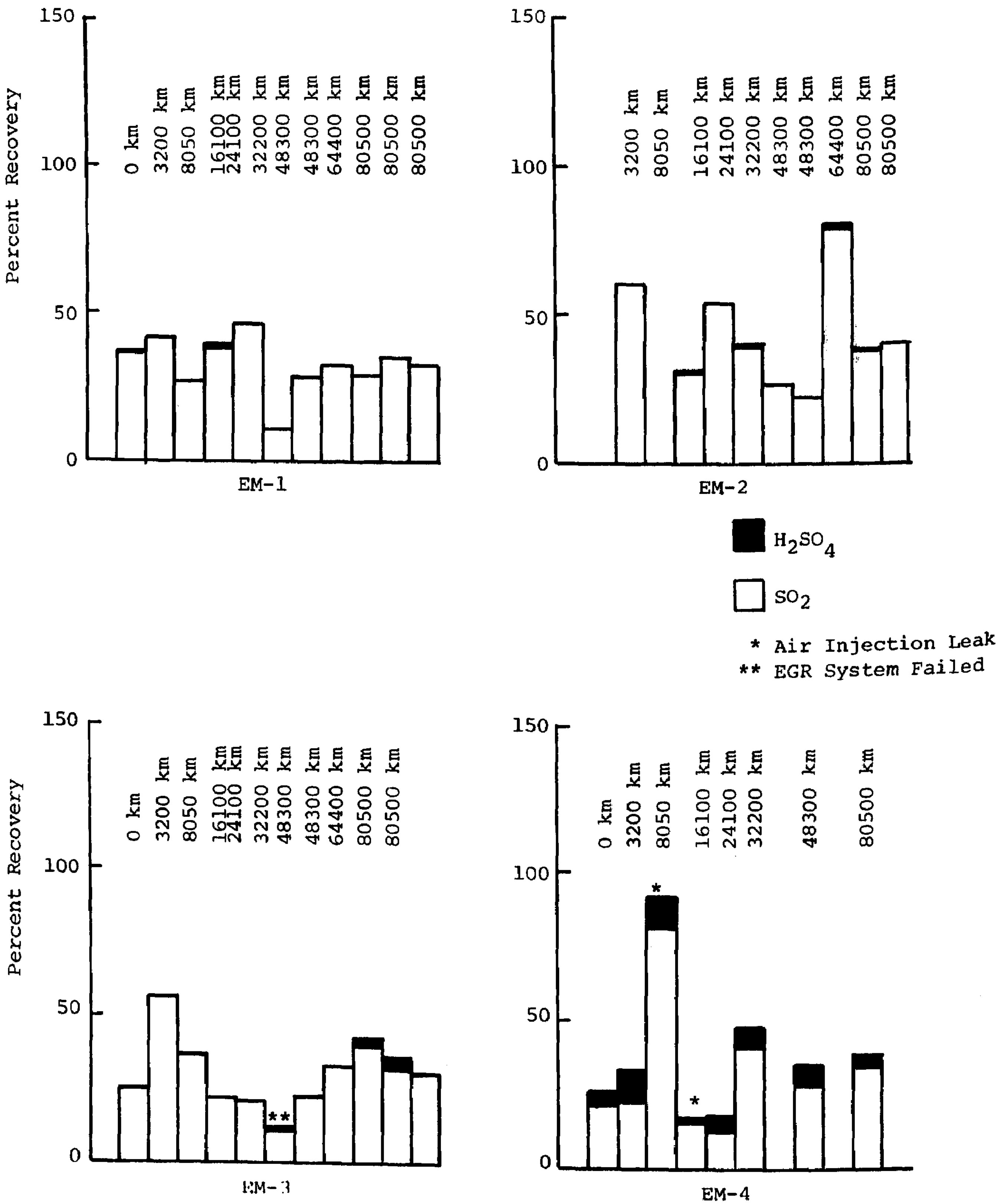



FIGURE 42. EXHAUST SULFUR RECOVERY FOR ACCELERATION TO 48 kph TESTS AT DISTANCE INTERVALS FOR FOUR CARS

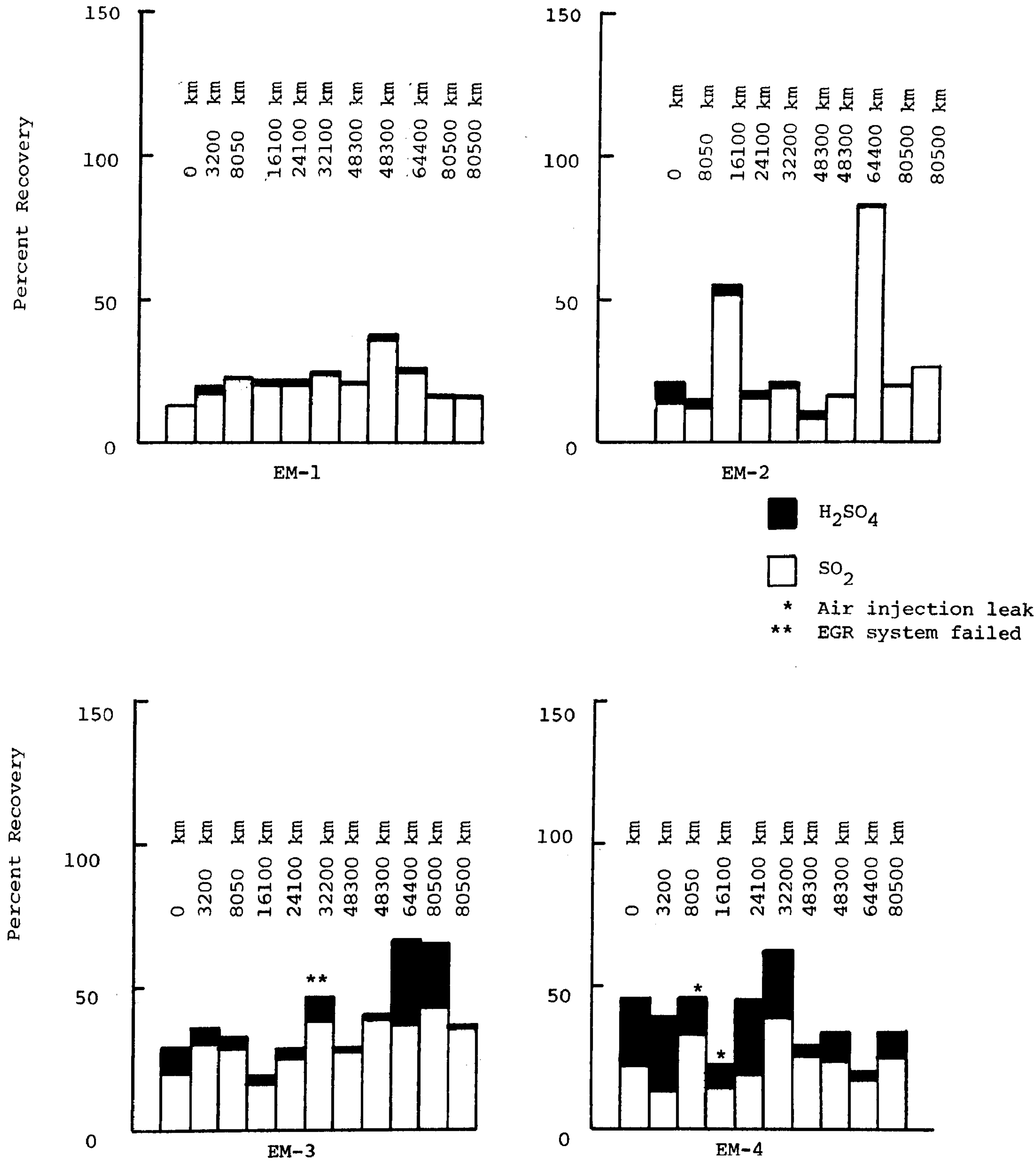



FIGURE 43. EXHAUST SULFUR RECOVERY FOR 48 kph STEADY STATE TESTS AT DISTANCE INTERVALS FOR FOUR CARS

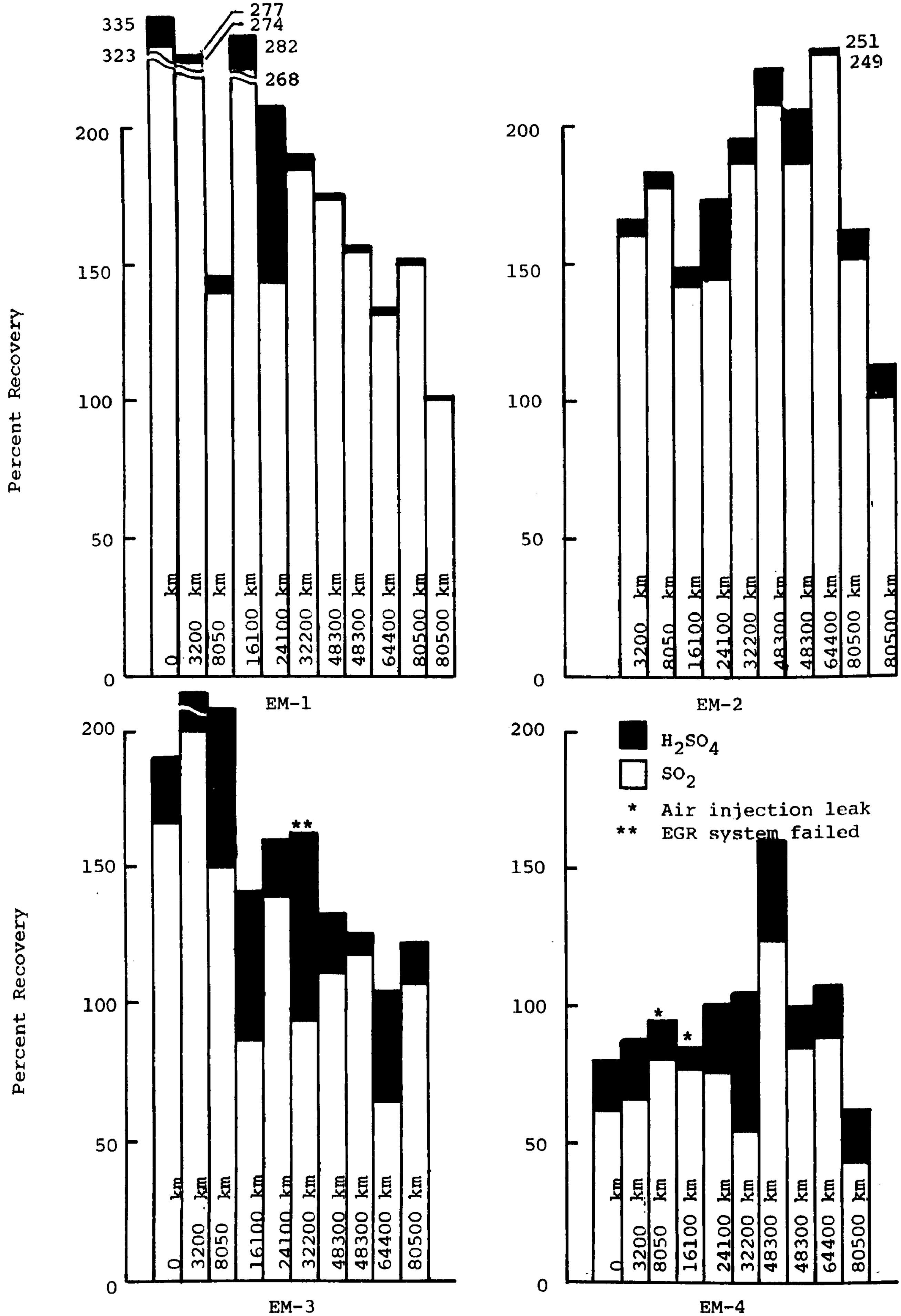



FIGURE 44. EXHAUST SULFUR RECOVERY FOR ACCELERATION TO 96 kph TESTS AT DISTANCE INTERVALS FOR FOUR CARS

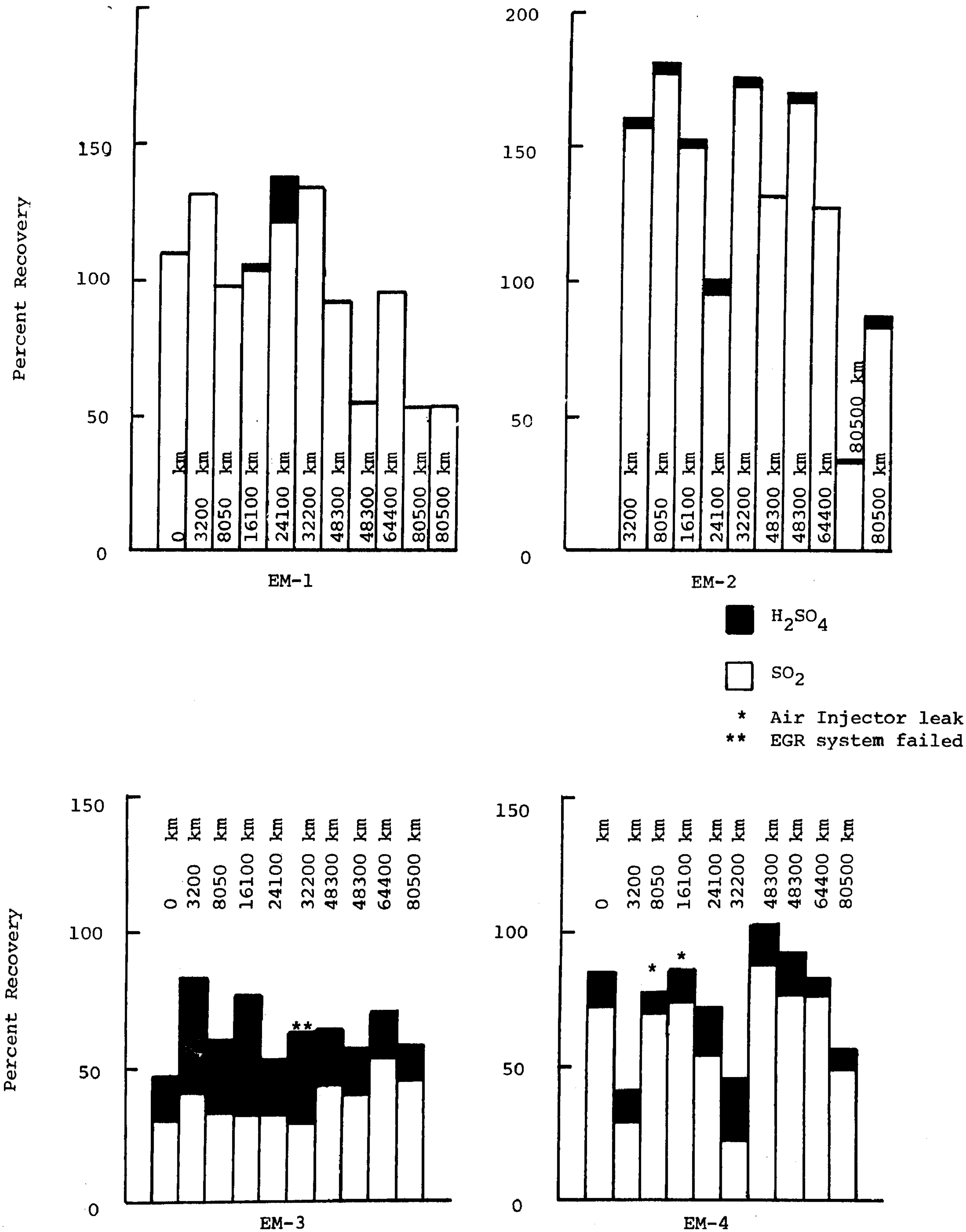



FIGURE 45. EXHAUST SULFUR RECOVERY FOR 96 kph STEADY STATE TESTS AT DISTANCE INTERVALS FOR FOUR CARS

$SO_2$ differences between two tests of less than ±10 percent may not be significant. However, if the data for each car is considered over the complete 80,500 km distance accumulation, the trend and total recovery level should be sufficiently valid to draw correct conclusions.

For the FTP tests, car EM-1 apparently stored sulfur compounds at a decreasing rate as distance traveled increased. At zero kilometres EM-1 had a net storage of about half of the sulfur consumed with fuel. As distance traveled increased, the net storage decreased. After approximately 50,000 km, there was an apparent release of sulfur compounds from the catalyst during the FTP test. Car EM-2 showed the same trend, except that it apparently was just at the equilibrium condition (no net storage or release) by the end of the 80,500 km accumulation. Thus, both the non air-injected cars stored sulfur during the FTP at zero kilometres, but by the time 80,500 km had been accumulated, they were no longer storing sulfur during the FTP test.

As was pointed out earlier, the data from the replicate tests of 80,500 km of cars EM-1 and EM-2 were not averaged because of the erratic emissions results obtained. This is most obvious in total sulfur recovery from the three nonsteady-state tests (FTP, FET, and SET-7) on car EM-1. The test data was checked throughly for errors, but none were found. While the catalyst was obviously storing more sulfur during the replicate tests, the reasons for this are not known.

The total recovery for car EM-3 was close enough to 100 percent for the total distance accumulated (neglecting the test with failed EGR) to indicate that there is no net storage or release of sulfur compounds during the FTP and that there was no change with distance traveled. The FTP is apparently a net storage test for car EM-4, since it never reached 100 percent recovery (neglecting the two tests with air leaks) during the entire distance accumulation. However, from 3,200 km to 80,500 km, there is an increase in total recovery, indicating that less sulfur was being stored as distance traveled increased. Just how the leak in the air injection system affected the change in sulfur storage with distance traveled is not known. The two air-injected cars then, displayed different sulfur storage characteristics during the FTP tests.

For the SET-7 tests, car EM-1 had generally decreasing total recovery over the 80,500 km. It may have actually been releasing a small amount of stored sulfur at the 8,050 km accumulation, however by 80,500 km the total recovery was approximately 50 percent. It should be noted that the SET-7 results shown in Figure 40 are the average of all SET-7 tests run at the particulate distance accumulation point. Both the number and sequence of the SET-7 tests changed during the lower distances on all cars. However, the test sequence was the same from 24,100 km onward for all cars. For car EM-2, the total recovery never dropped below essentially 100 percent, it can be concluded that the SET-7 test is one of net release of stored sulfates for car EM-2. Thus, for the SET-7 test, the two non air-injected cars showed opposite trends with distance accumulation

The total recovery from car EM-3 in general shown little variation from 100 percent over the entire 80,500 km accumulation. If the tests with the failed EGR system are neglected, the average recovery for EM-3 is 106 percent. The total recovery for car EM-4 also shows little change between 24,100 km and 80,500 km. The data 80,510 and 16,100 km are neglected because of the leak in the air injection system at that time. However, the average total recovery of 84 percent indicates that EM-4 was operating in a storage mode during the SET-7 tests.

The HFET tests have total recovery patterns that are somewhat difficult to ascertain. The total recovery from car EM-1 appears to increase from near 100 percent to around 154 percent between 8,050 km and 32,200 km. During this distance interval, car EM-1 was operating in a net release mode during the HFET. After 32,200 km, the total recovery for EM-1 dropped to between 30 and 70 percent by 80,500 km. In this distance interval, EM-1 stored sulfur during the HFET. Car EM-2 exhibited a somewhat similar pattern of increasing then decreasing total recovery. However the total recovery was always over 100 percent indicating that EM-2 was always releasing stored sulfur during the HFET. Again for this test, the two non air-injected cars have somehwat different patterns of total recovery.

Car EM-3 operated in a release mode, with recoveries slightly over 100 percent for the 8,050 and 16,100 km tests. After that the car stored sulfur during the HFET at a constant rate for the remaining tests to 80,500 km. The average total recovery (excluding the test with failed EGR) was approximately 80 percent. It is difficult to determine, given the accuracy of the $SO_2$ method, whether the total recovery from EM-4 remained constant from 24,100 to 80,500 km or whether it decreased somewhat. In either case, the total recovery was always at or below 100 percent, indicating that the HFET was a storage mode for EM-4.

The acceleration to 48 kph test and the 48 kph steady-state test are sulfur storage modes for all cars. However, there is no obvious pattern with distance traveled for any of the four cars. For the acceleration to 48 kph, cars EM-1, EM-3 and EM-4 had average total recoveries of approximately 35 percent. Car EM-2 had an average total recovery of approximately 45 percent. For the 48 kph steady tests, the two non air-injected cars, EM-1 and EM-2 had average total recoveries of approximately 22 and 29 percent respectively. The air-injected cars, EM-3 and EM-4, had somewhat higher total recoveries during the 48 kph steady state tests. Both of these cars averaged approximately 40 percent recovery.

The acceleration to 96 kph test was definitely a sulfur release mode for EM-1, EM-2 and EM-3. Cars EM-1 and EM-3 appear to have had declining total recoveries as the distance traveled increased from 0 to 80,500 km. However, even at the 80,500 km test the recoveries from both these cars were above 100 percent, indicating that their catalysts were still releasing stored sulfur. Car EM-2, while always operating in the release mode, had increasing total recoveries from 0 to approximately 64,000 km. After this, the total recovery apparently dropped. However, it was still above 100 percent at 80,500 km. Car EM-4 had a total recovery of 80 percent at the zero kilometre tests, indicating that it was storing sulfur at this time. The total recovery for EM-4 continued to increase as distance traveled increased to 48,300 km. From approximately 24,100 km, the total recovery was above 100 percent, indicating that the catalyst was releasing stored sulfur. The total recovery for EM-4 decreased as distance traveled increased from 48,300 to 80,500 km. At the 80,500 km test the recovery was approximately 60 percent, indicating that the catalyst was once again storing sulfur.

At 96 kph, the two nonair-injected cars, EM-1 and EM-2, exhibited similar patterns of total recovery. Both cars had recoveries above 100 percent at zero kilometres indicating the release of stored sulfur. The total recovery for EM-1 started to drop after 32,200 kilometers of distance traveled. From the 48,300 km test on, the total recovery was below 100 percent indicating the storage of sulfur in the catalyst. While the total recovery from car EM-2 started to decline at the 48,300 km test, it did not go below 100 percent until the 80,500 km test.

The air-injected cars, EM-3 and EM-4, showed little change in total recovery from the 96 kph test over the entire 80,500 km. The average total recovery for EM-3 was 63 percent, indicating that 96 kph was a storage mode for this car. The total recovery at 96 kph for car EM-4 varied considerably from test to test, but there is no apparent pattern. The average total recovery was 72 percent, indicating for this car also, 96 km was a storage mode.

Throughout the tests, various patterns of storage and release have been seen. In every case where the pattern changed abruptly in mganitude or direction, the test data and vehicle were checked. Occasionally, as with the air injection leaks on EM-4 and the failed EGR system on EM-3, a reason for the change was found. For the remainder of the cases no errors or malfunctions were found. The test plan did not provide for any more detailed investigation of the causes of the storage and release phenomena.

In summary then, it appears that whether a given vehicle operating condition is a storage or release mode, is dependent not only on what the condition is, but also the distance accumulated on the vehicle. Cars EM-1, 2 and 3 stored sulfur during some test cycles and released sulfur during other test cycles. However, EM-4 apparently stored sulfur during all test cycles except for the acceleration to 96 kph test at 24,100, 32,200 and 48,300 km.

As mentioned earlier, the recoveries shown in Figures 39 and 45 are often averages of repetitive test sequences. In the case of the SET-7 and HFET tests, they are also the average of repetitive tests within a given test sequence. Thus, the histograms do not show if, for instance, a SET-7 has a different total recovery following an FTP, than it would following a HFET. Nor do the histograms indicate whether there is a net storage or release of sulfur over the entire test sequence performed at each distance interval.

As means of examining both of these cases, the cumulative exhaust sulfur recovered from each test sequence was calculated to allow comparison with the cumulative fuel sulfur consumed. This can be done, since, except for 5 minute periods at idle conditions between tests, the exhaust was sampled during the entire test sequence. Plots of cumulative exhaust sulfur as a function of cumulative fuel sulfur are shown in Figures 46 to 57 for the test sequences through 24,100 km distance accumulation. The three different test sequences used are shown for each car. The test sequences after 24,100 km are not shown, since to do so would make it difficult to follow any one test sequence due to a confusion of lines and data points.

The plots are presented without discussion, except to point out that the total sulfur recovery for the entire test sequence is generally within 80 to 120 percent except for EM-4. Car EM-4 shows the trend noted earlier of continual net sulfur storage. Table 25 shows the total recovery for each test sequence for all four cars.

3. Particulate Weights

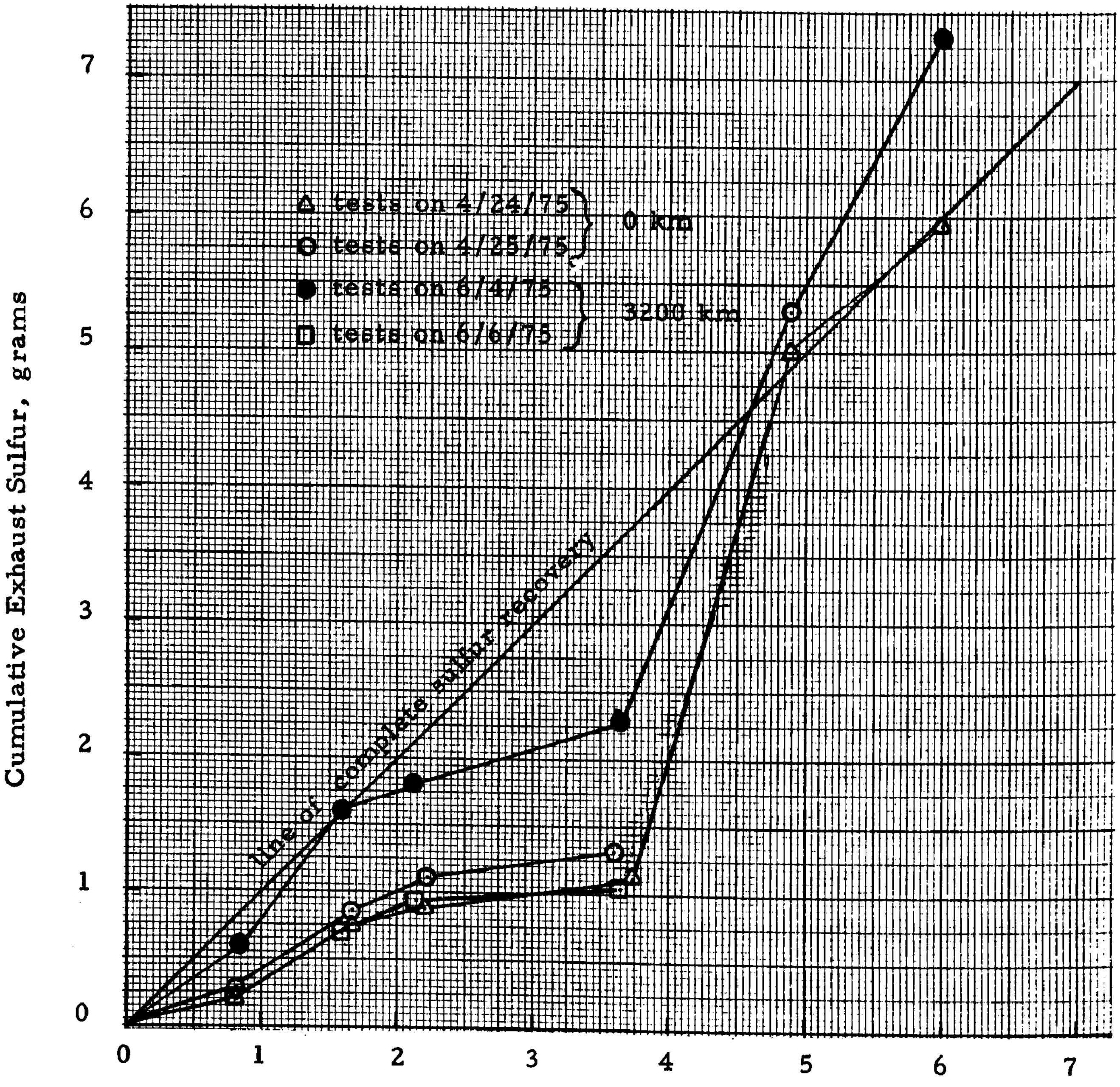
One of the objectives of this study was to determine the relationship between the total collected weight of particulates and the weight of sulfate from the BCA analysis on each of the filters. As part of the test procedure, each filter was weighed on a microgram balance before and after use and the increase in weight calculated. The weight of sulfates on the filter from the BCA analysis was multiplied by 1.3757 to convert from weight as sulfate ion ($SO_4^{=}$) to weight as ammonium sulfate, $(NH_4)_2SO_4$. This was necessary since the sulfate on the filter at the time it was weighed was in the form of ammonium sulfate.

Plots of the BCA sulfate weight versus the balance weight are shown as Figures 58 to 61. Since a preliminary analysis indicated that there might be a different relationship between the weighed and BCA sulfates for the FTP tests than for the other tests, the FTP test results were plotted separately. In addition, the non air-injected cars have been separated from the air-injected cars to examine any differences that might occur between the two different types of catalyst systems.

From an examination of the plots, it is difficult to determine if there is a difference in the correlation of the filter weight and BCA sulfate weight between the air-injected and non air-injected cars on either the FTP and non FTP tests. To better quantify the relationships between filter weight and BCA weight and the differences between air-injected and non air-injected cars, a linear regression was performed on each group. The resulting regression equations are shown on each figure together with a plot of the equation. The correlation coefficient is also shown for each equation.

While there is some scatter in the data, for the non-FTP tests, the correlation coefficients are sufficiently high to indicate good linear fit. The fit is slightly better for the air-injected cars than the non air-injected cars. However, the intercepts and slopes of the two equations are close enough to conclude that there is probably no difference in the balance weight-BCA relationship for the two sets of cars. The FTP tests show considerable scatter and corresponding poorer correlation coefficients. Also, the intercepts and slopes of the air-injected and non air-injected groups are different enough to suspect there is a difference in the balance weight-BCA relationship for the FTP tests on the two sets of cars. Thus, it appears

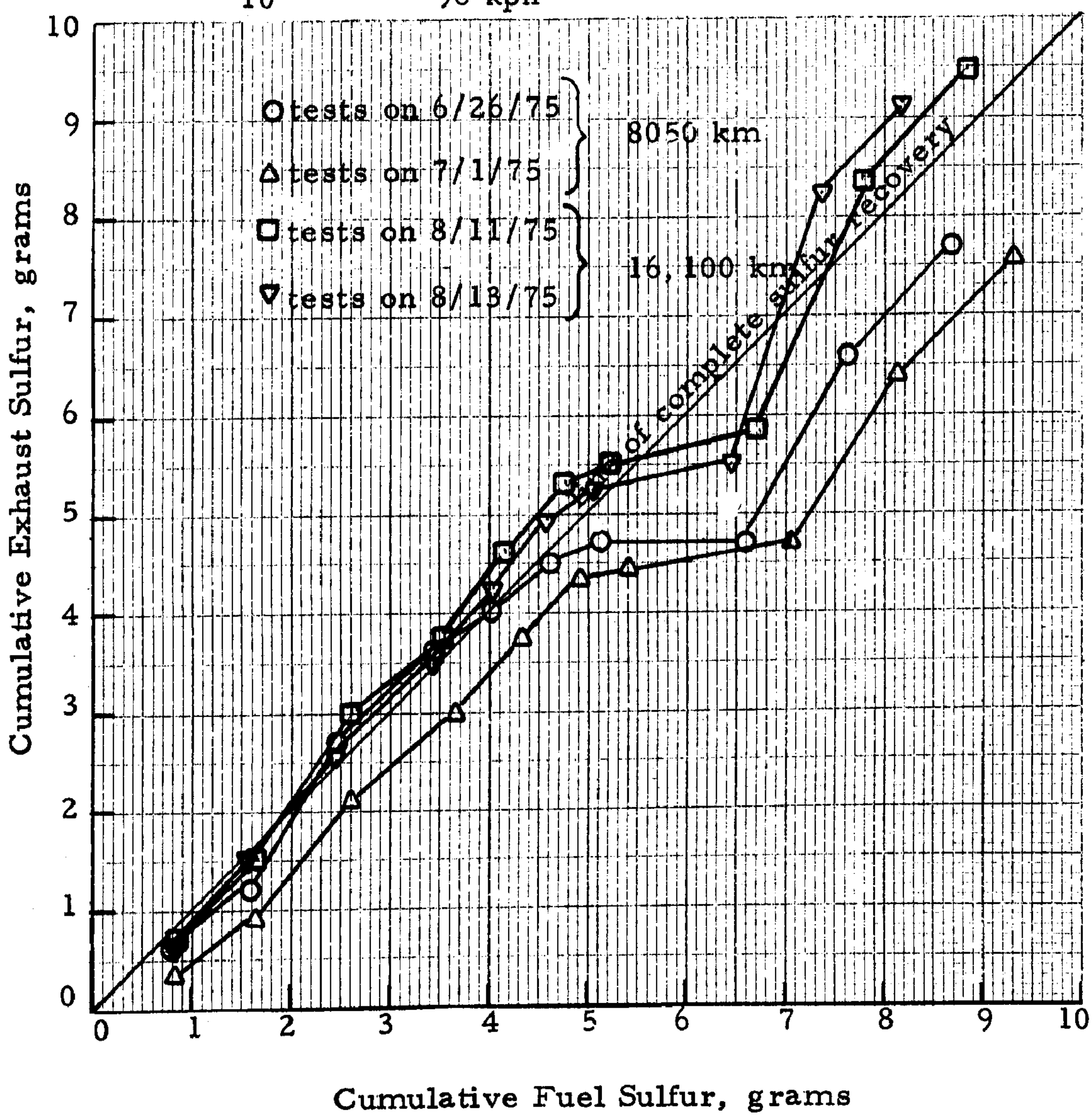
| Test No. | Test Type |
|---|---|
| 1 | Cold LA-4 |
| 2 | Hot LA-4 |
| 3 | Accel to 48 kph |
| 4 | 48 kph |
| 5 | Accel to 96 kph |
| 6 | 96 kph |




1975 Federal Plymouth Gran Fury
Monolithic Catalyst, no air injection
0.0415% fuel Sulfur

FIGURE 46. CUMULATIVE SULFUR RECOVERED IN EXHAUST AS A FUNCTION OF SULFUR CONSUMED, EM-1 AT 0 AND 3200 km

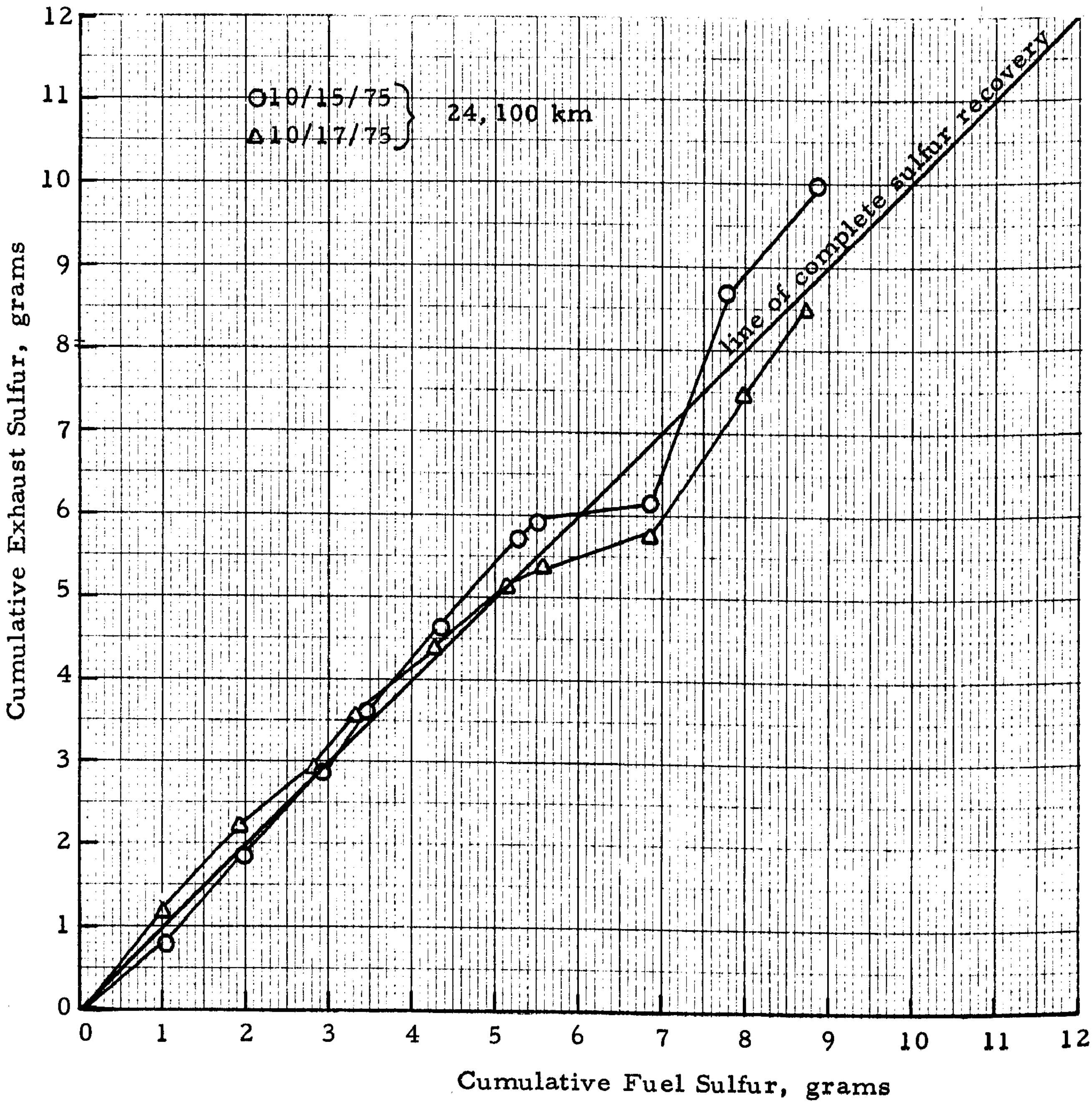
| Test No. | Test Type |
|---|---|
| 1 | Cold LA-4 |
| 2 | Hot LA-4 |
| 3 | SET-7 |
| 4 | SET-7 |
| 5 | HWFET |
| 6 | HWFET |
| 7 | Accel to 48 kph |
| 8 | 48 kph |
| 9 | Accel to 96 kph |
| 10 | 96 kph |




1975 Federal Plymouth Gran Fury
Monolithic Catalyst, no air injection
0.0415% fuel Sulfur

FIGURE 47. CUMULATIVE SULFUR RECOVERED IN EXHAUST AS A FUNCTION OF SULFUR CONSUMED, EM-1 AT 8050 AND 16,100 km

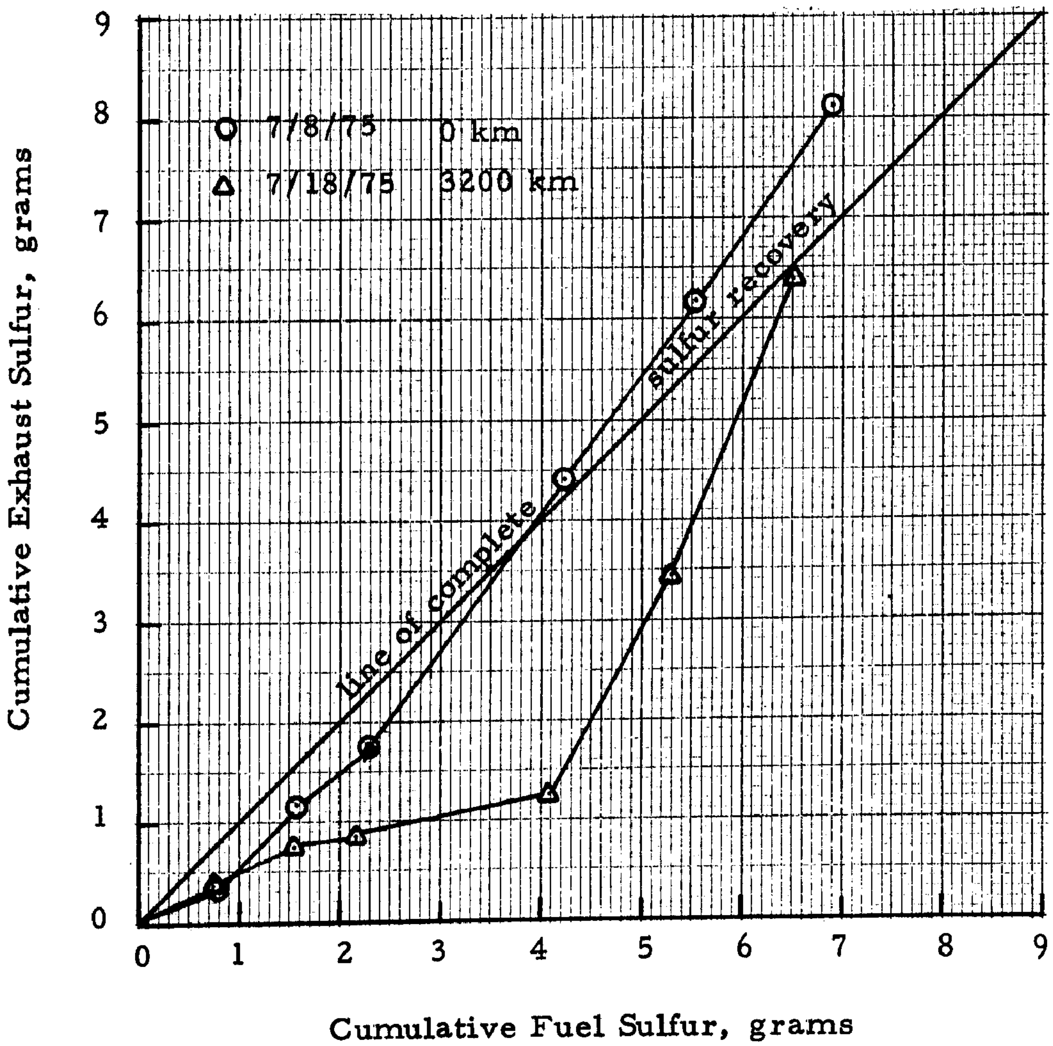
| Test No. | Test Type | Test No. | Test Type |
|---|---|---|---|
| 1 | FTP | 6 | SET-7 |
| 2 | SET-7 | 7 | accel to 48 kph |
| 3 | SET-7 | 8 | 48 kph |
| 4 | HWFET | 9 | accel to 96 kph |
| 5 | SET-7 | 10 | 96 kph |




1975 Federal Plymouth Gran Fury
Monolithic Catalyst, no air injection
0.0415% fuel Sulfur

FIGURE 48. CUMULATIVE SULFUR RECOVERED IN EXHAUST AS A FUNCTION OF SULFUR CONSUMED, EM-1 AT 24,100 km

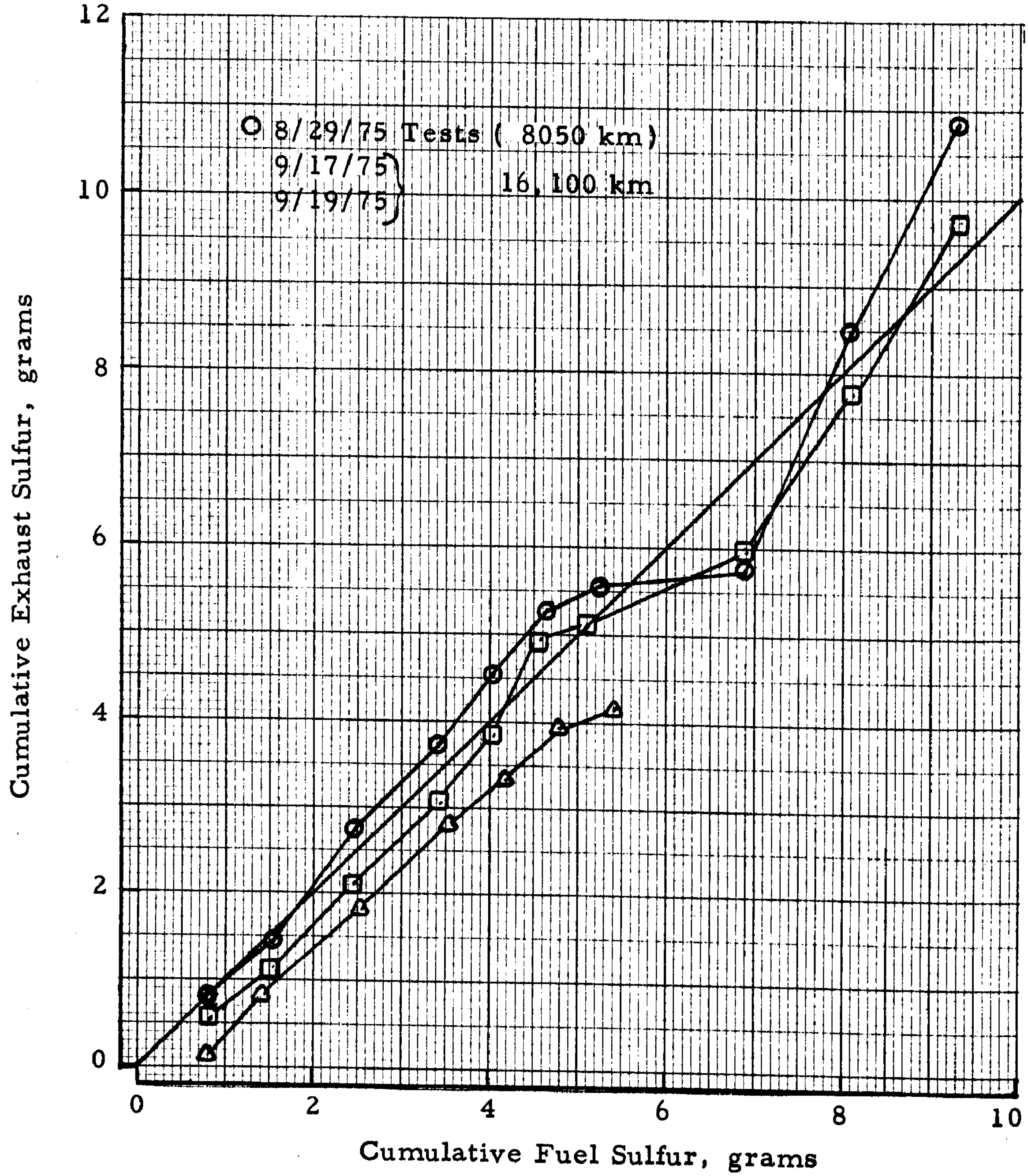
| Test No. | Test Type |
|---|---|
| 1 | Cold LA-4 |
| 2 | Hot LA-4 |
| 3 | Accel to 48 kph |
| 4 | 48 kph |
| 5 | Accel to 96 kph |
| 6 | 96 kph |




1975 Federal Chevrolet Impala
Pelleted Catalyst, no air injection
0.0415% fuel Sulfur

FIGURE 49. CUMULATIVE SULFUR RECOVERED IN EXHAUST AS A FUNCTION OF SULFUR CONSUMED, EM-2 AT 0 AND 3200 km

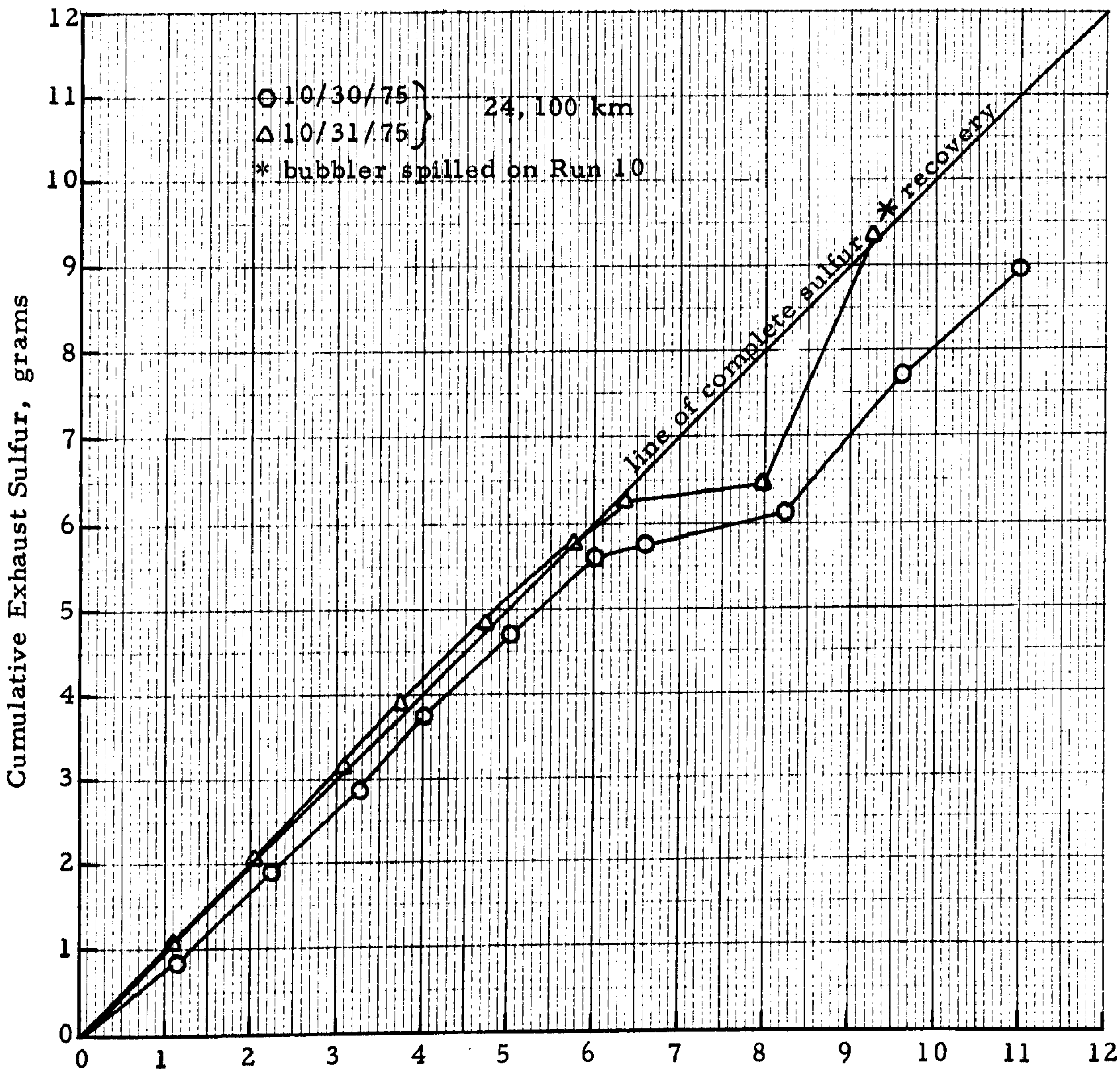
| Test No. | Test Type |
|---|---|
| 1 | Cold LA-4 |
| 2 | Hot LA-4 |
| 3 and 4 | SET-7 |
| 5 and 6 | HWFET |
| 7 | Accel to 48 kph |
| 8 | 48 kph Steady |
| 9 | Accel to 96 kph |
| 10 | 96 kph Steady |




1975 Federal Chevrolet Impala
Pelleted Catalyst, no air injection
0.0415% fuel Sulfur

FIGURE 50. CUMULATIVE SULFUR RECOVERED IN EXHAUST AS A FUNCTION OF SULFUR CONSUMED, EM-2 AT 8050 AND 16,100 km

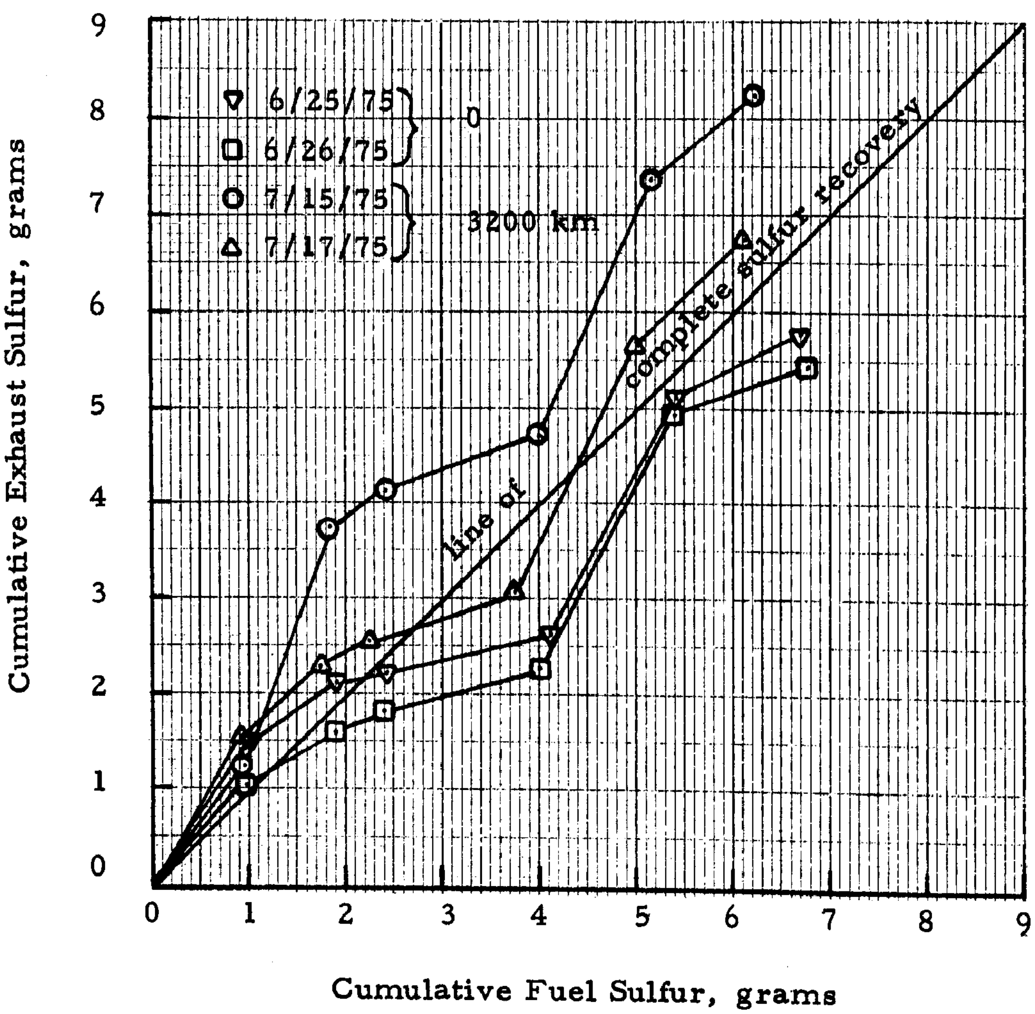
| Test No. | Test Type | Test No. | Test Type |
|---|---|---|---|
| 1 | FTP | 6 | SET-7 |
| 2 | SET-7 | 7 | accel to 48 kph |
| 3 | SET-7 | 8 | 48 kph |
| 4 | HWFET | 9 | accel to 96 kph |
| 5 | SET-7 | 10 | 96 kph |




1975 Federal Chevrolet Impala
Pelleted Catalyst, no air injection
0.0415% fuel Sulfur

FIGURE 51. CUMULATIVE SULFUR RECOVERED IN EXHAUST AS A FUNCTION OF SULFUR CONSUMED, EM-2 AT 24,100 km

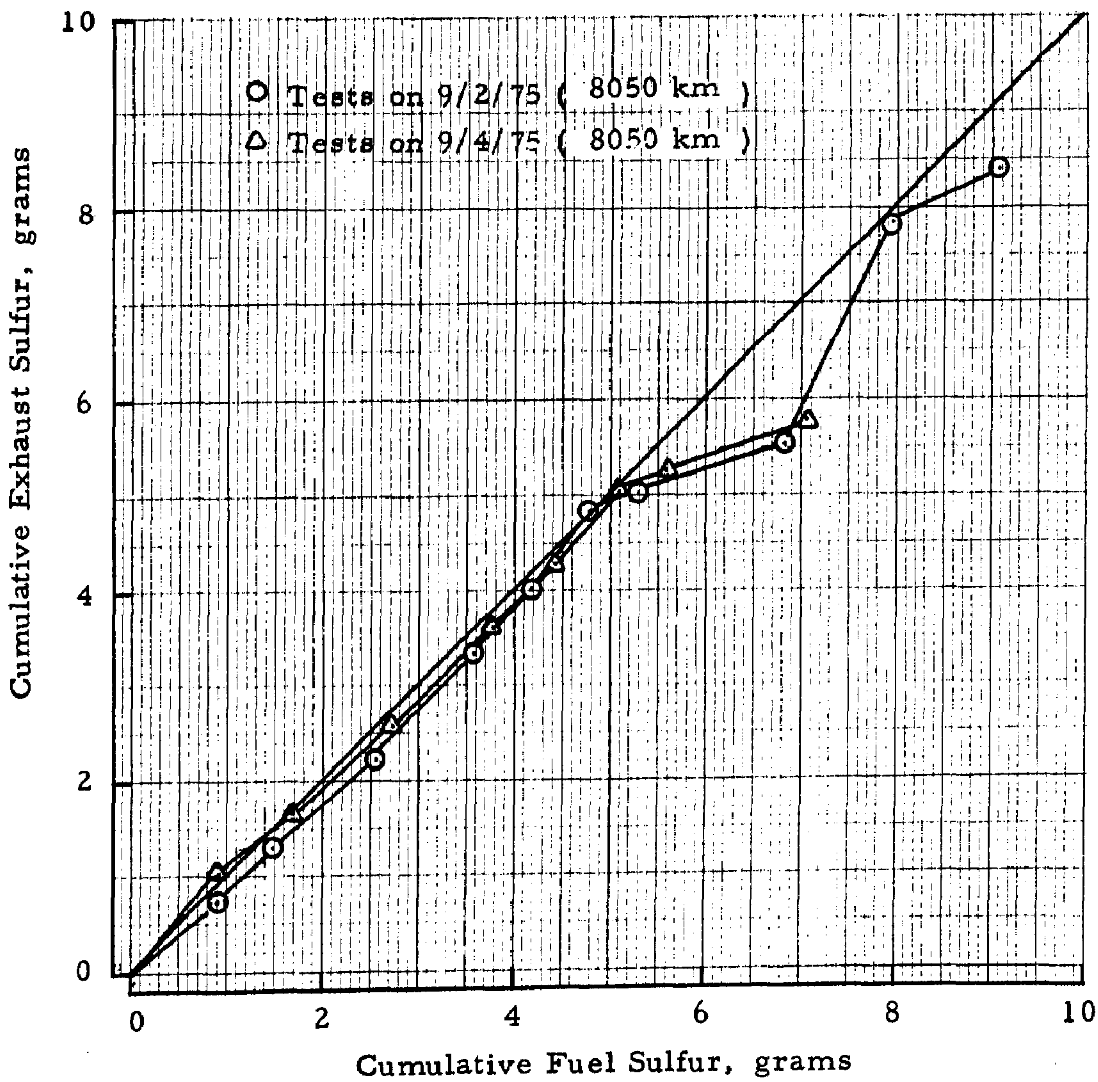
| Test No. | Test Type |
|---|---|
| 1 | Cold LA-4 |
| 2 | Hot LA-4 |
| 3 | Accel to 48 kph |
| 4 | 48 kph |
| 5 | Accel to 96 kph |
| 6 | 96 kph |




1975 California Plymouth Gran Fury
Monolithic Catalyst, with air injection
0.0415% fuel Sulfur

FIGURE 52. CUMULATIVE SULFUR RECOVERED IN EXHAUST AS A FUNCTION OF SULFUR CONSUMED, EM-3 AT 0 AND 3200 km

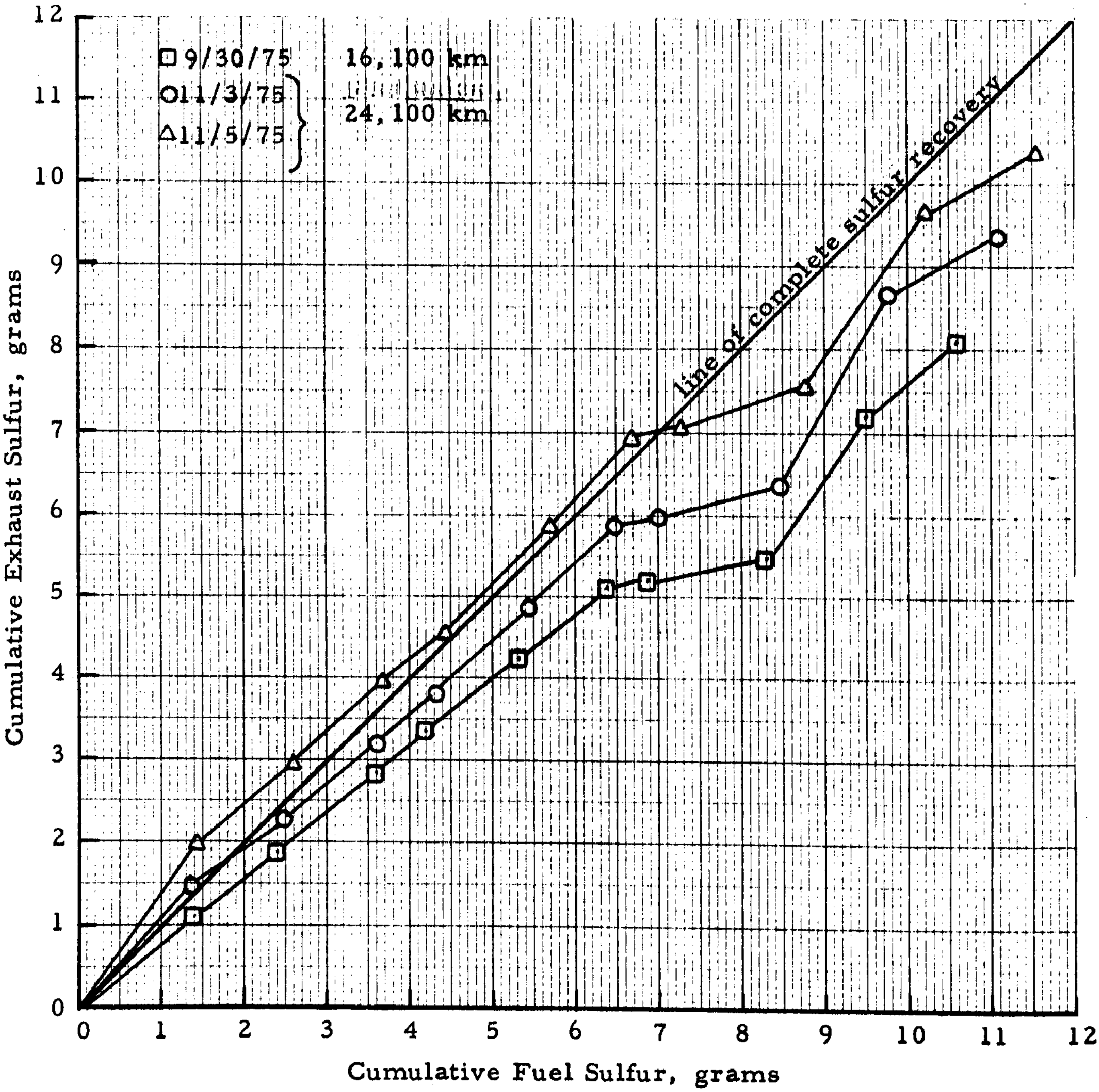
| Test No. | Test Type |
|---|---|
| 1 | Cold LA-4 |
| 2 | Hot LA-4 |
| 3 and 4 | SET-7 |
| 5 and 6 | HWFET |
| 7 | Accel to 48 kph |
| 8 | 48 kph Steady |
| 9 | Accel to 96 kph |
| 10 | 96 kph Steady |




1975 California Plymouth Gran Fury
Monolithic Catalyst, with air injection
0.0415% fuel Sulfur

FIGURE 53. CUMULATIVE SULFUR RECOVERED IN EXHAUST AS A FUNCTION OF SULFUR CONSUMED, EM-3 AT 8050 km

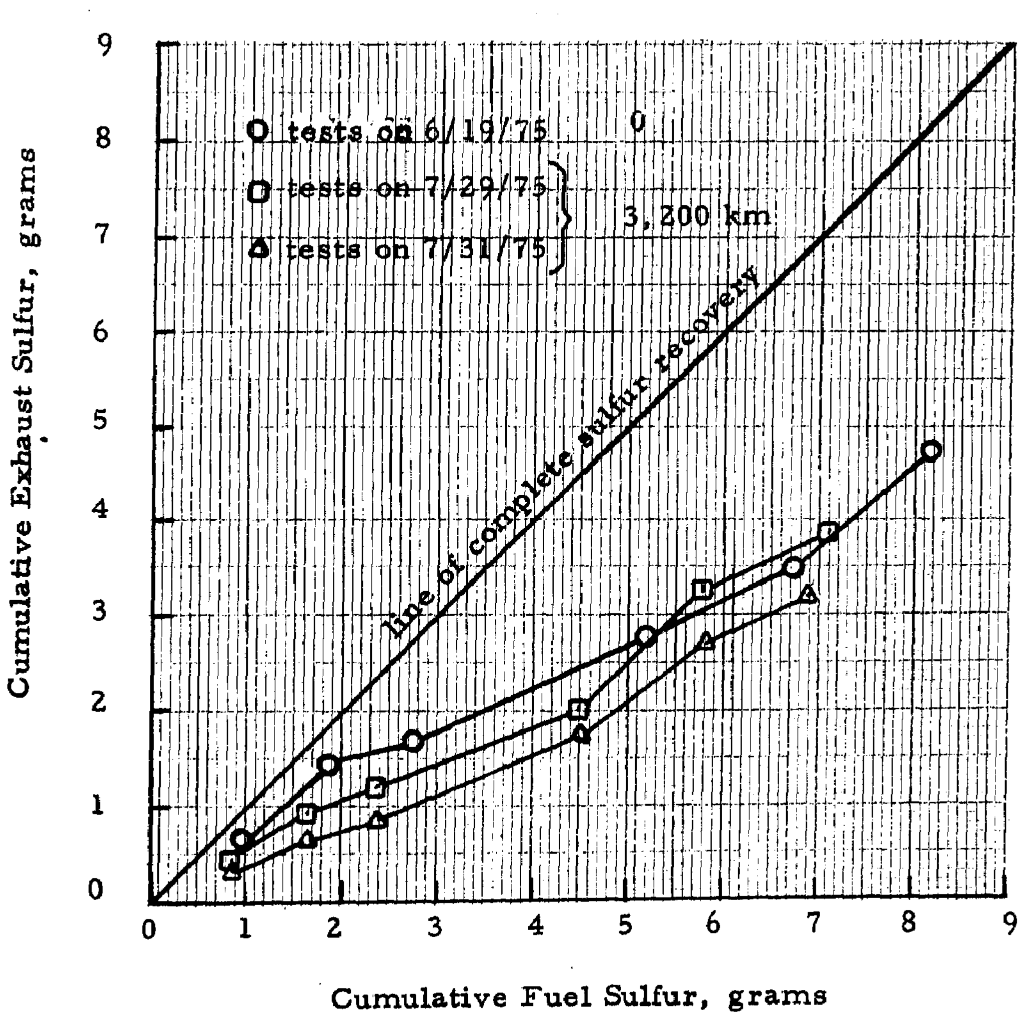
| Test No. | Test Type | Test No. | Test Type |
|---|---|---|---|
| 1 | FTP | 6 | SET-7 |
| 2 | SET-7 | 7 | accel to 48 kph |
| 3 | SET-7 | 8 | 48 kph |
| 4 | HWFET | 9 | accel to 96 kph |
| 5 | SET-7 | 10 | 96 kph |




1975 California Plymouth Gran Fury
Monolithic Catalyst, with air injection
0.0415% fuel Sulfur

FIGURE 54. CUMULATIVE SULFUR RECOVERED IN EXHAUST AS A FUNCTION OF SULFUR CONSUMED, EM-3 AT 16,100 AND 24,100 km

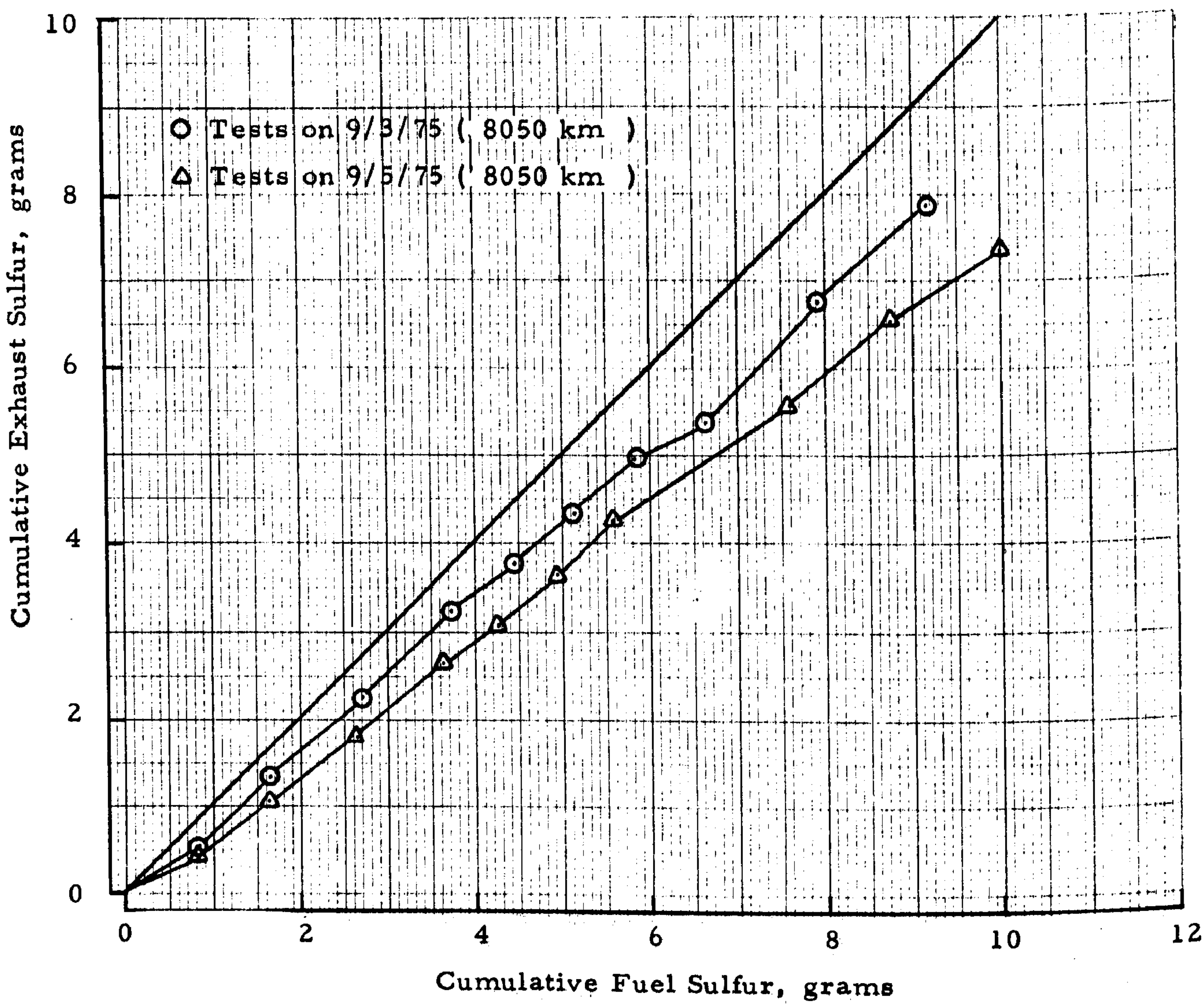
| Test No. | Test Type |
|---|---|
| 1 | Cold LA-4 |
| 2 | Hot LA-4 |
| 3 | Accel to 48 kph |
| 4 | 48 kph |
| 5 | Accel to 96 kph |
| 6 | 96 kph |




1975 California Chevrolet Impala
Pelleted Catalyst, with air injection
0.0415% fuel Sulfur

FIGURE 55. CUMULATIVE SULFUR RECOVERIES IN EXHAUST AS A FUNCTION OF SULFUR CONSUMED, EM-4 AT 0 AND 3200 km

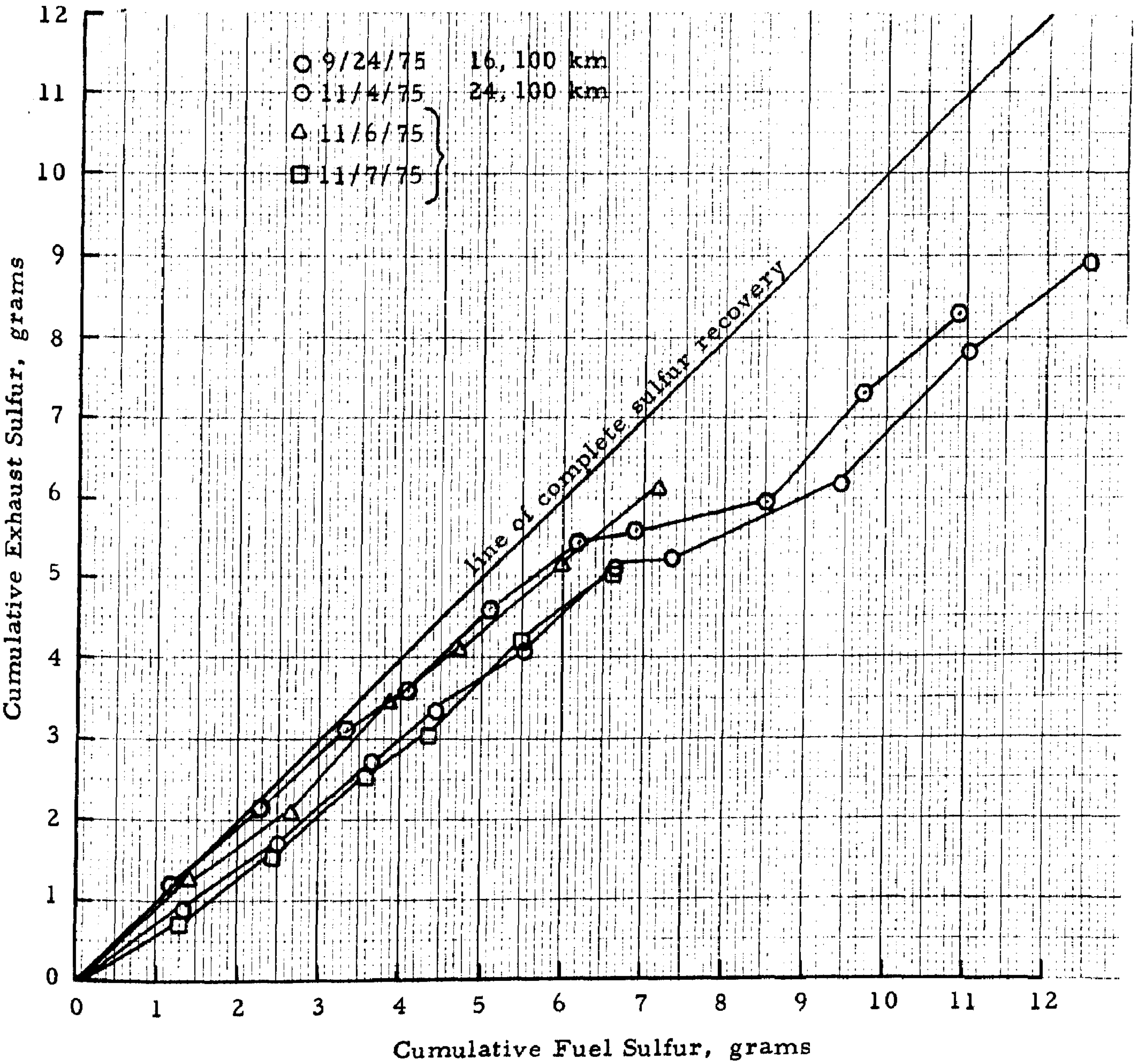
| Test No. | Test Type |
|---|---|
| 1 | Cold LA-4 |
| 2 | Hot LA-4 |
| 3 and 4 | SET-7 |
| 5 and 6 | HWFET |
| 7 | Accel to 48 kph |
| 8 | 48 kph Steady |
| 9 | Accel to 96 kph |
| 10 | 96 kph Steady |




1975 California Chevrolet Impala
Pelleted Catalyst, with air injection
0.0415% fuel Sulfur

FIGURE 56. CUMULATIVE SULFUR RECOVERIES IN EXHAUST AS A FUNCTION OF SULFUR CONSUMED, EM-4 AT 8050 km

| Test No. | Test Type | Test No. | Test Type |
|---|---|---|---|
| 1 | FTP | 6 | SET-7 |
| 2 | SET-7 | 7 | accel to 48 kph |
| 3 | SET-7 | 8 | 48 kph |
| 4 | HWFET | 9 | accel to 96 kph. |
| 5 | SET-7 | 10 | 96 kph |




1975 California Chevrolet Impala
Pelleted Catalyst, with air injection
0.0415% fuel Sulfur

FIGURE 57. CUMULATIVE SULFUR RECOVERIES IN EXHAUST AS A FUNCTION OF SULFUR CONSUMED, EM-4 AT 16,100 AND 24,100 km

TABLE 25. TEST SEQUENCE TOTAL SULFUR RECOVERY

| Distance Test Point | Percent of Fuel Sulfur Recovered in Exhaust | | | |
|---|---|---|---|---|
| | EM-1 | EM-2 | EM-3 | EM-4 |
| 0 km | 99 | 163 | 87 | - |
| 0 km | - | 141 | 81 | 58 |
| 3200 km | 122 | 138 | 132 | 54 |
| 3200 km | - | 98 | 111 | 46 |
| 8050 km | 89 | 117 | 92 | 84 |
| 8050 km | 81 | - | - | 75 |
| 16100 km | 107 | 104 | 76 | 76 |
| 16100 km | 112 | - | - | - |
| 24100 km | 109 | - | 84 | 71 |
| 24100 km | 97 | 82 | 90 | - |
| 32200 km | 122 | 119 | 119 | 73 |
| 48300 km | 93 | 119 | 90 | 89 |
| 48300 km (after maint) | 72 | 118 | - | - |
| 64400 km | 84 | 133 | 109 | - |
| 80500 km | 90 | 92 | 88 | - |
| 80500 km | 57 | 105 | 89 | 60 |
| Average | 95 | 118 | 96 | 69 |

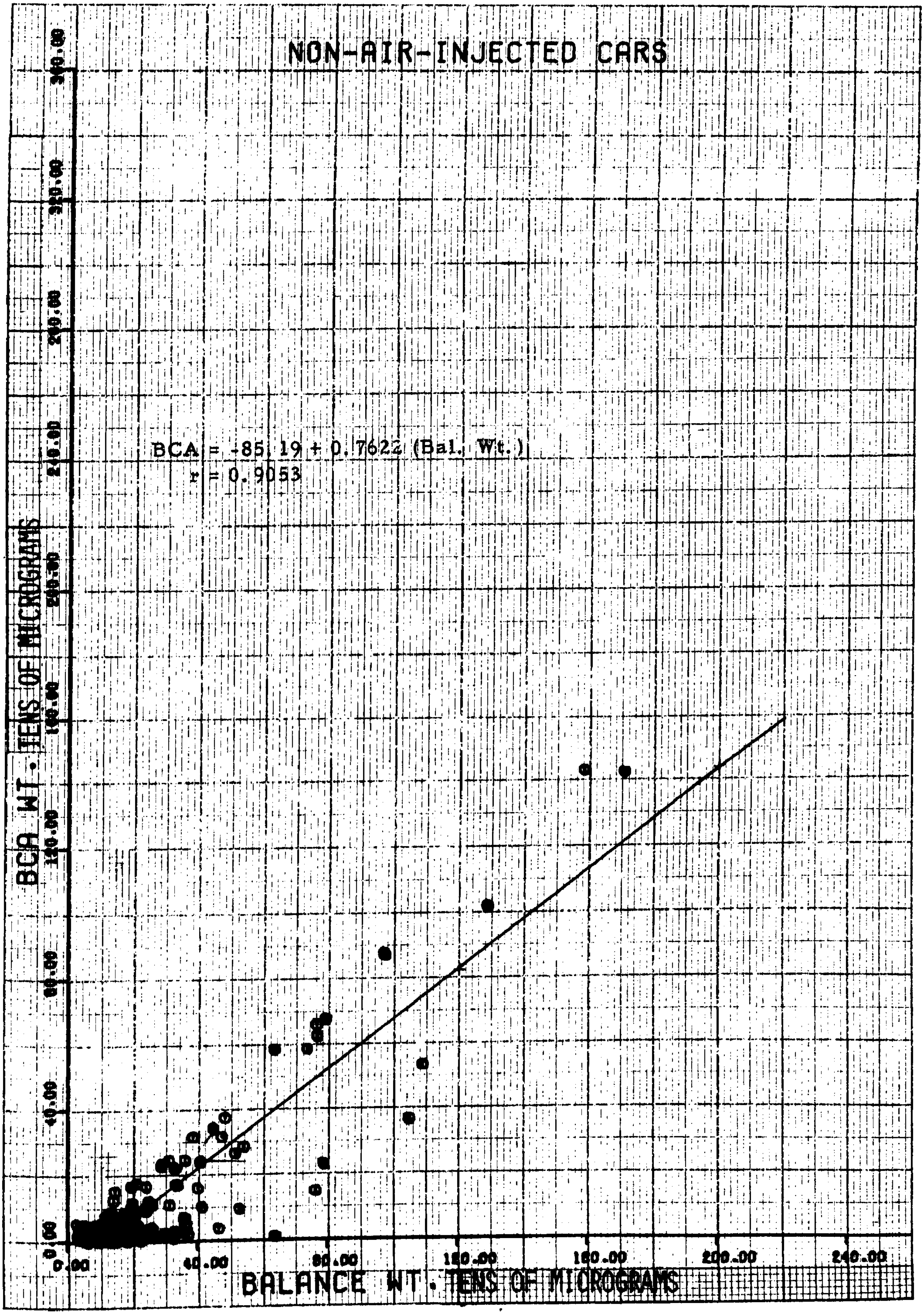



FIGURE 58. NET FILTER WEIGHT VERSUS BCA SULFATE WEIGHT AS AMMONIUM SULFATE FOR ALL NON-FTP TEST ON NON AIR-INJECTED CARS

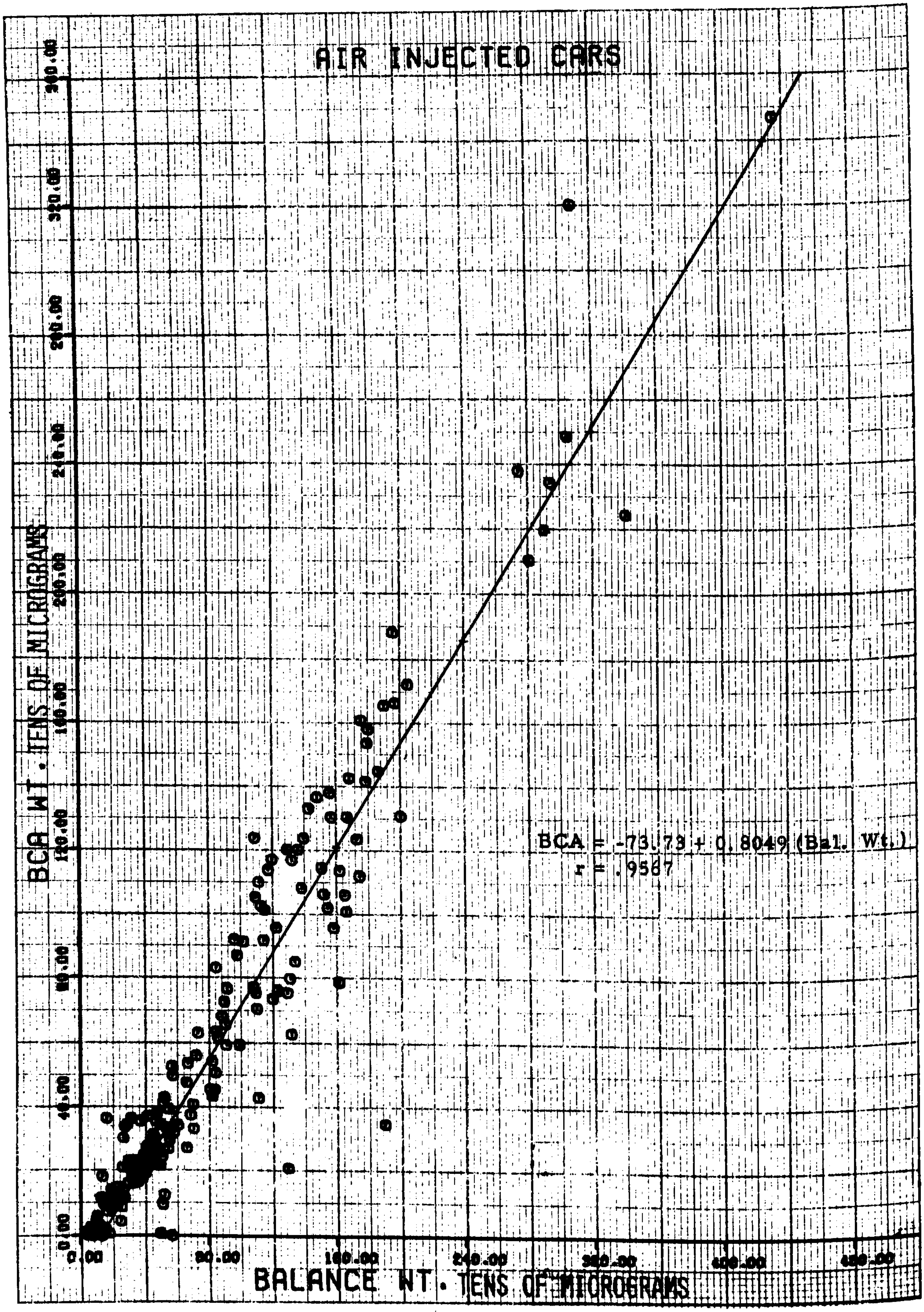



FIGURE 59. NET FILTER WEIGHT VERSUS BCA SULFATE WEIGHT AS AMMONIUM SULFATE FOR ALL NON FTP TESTS ON AIR-INJECTED CARS

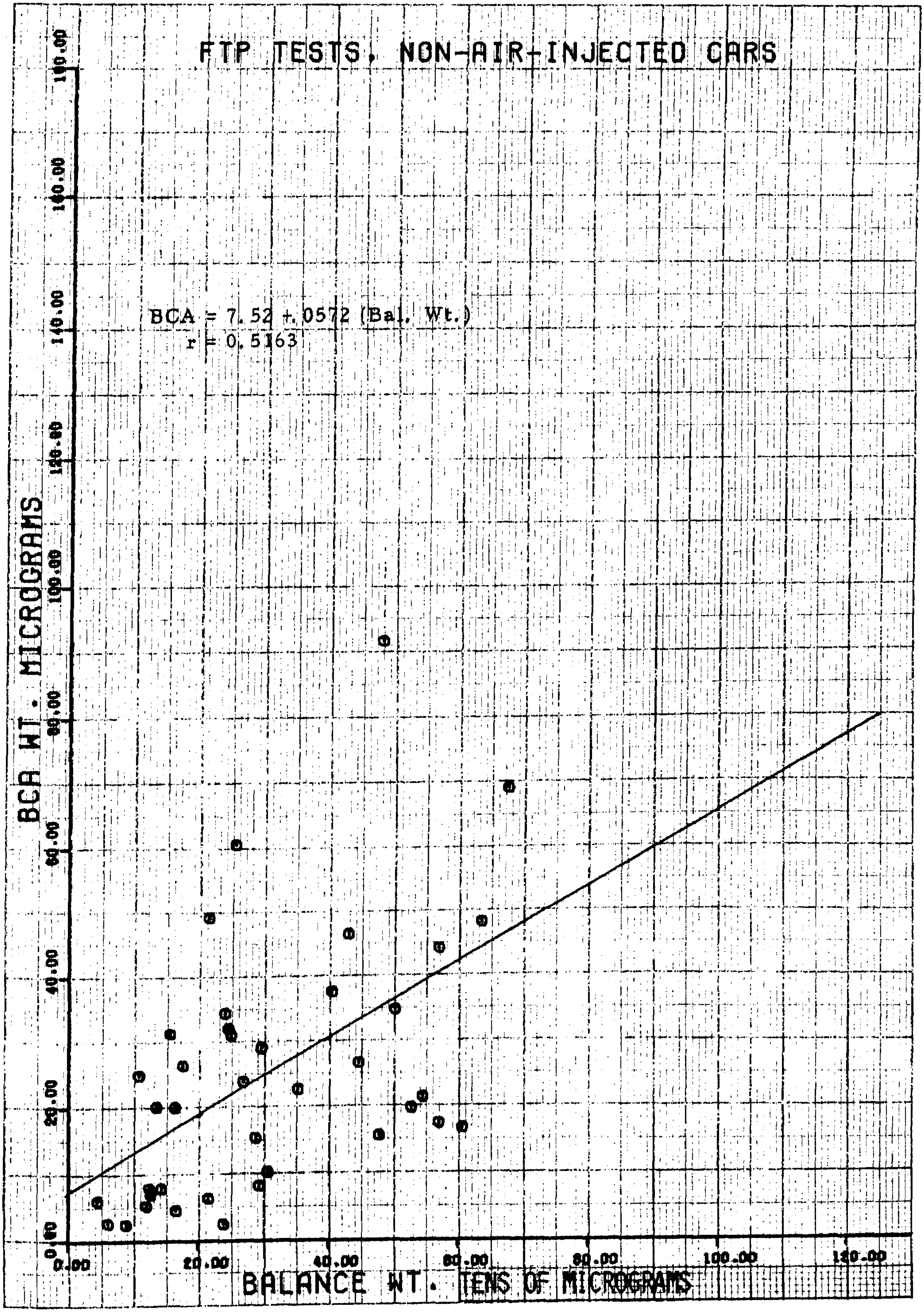



FIGURE 60. NET FILTER WEIGHT VERSUS BCA SULFATE WEIGHT AS AMMONIUM SULFATE FOR ALL FTP TESTS ON NON AIR-INJECTED CARS

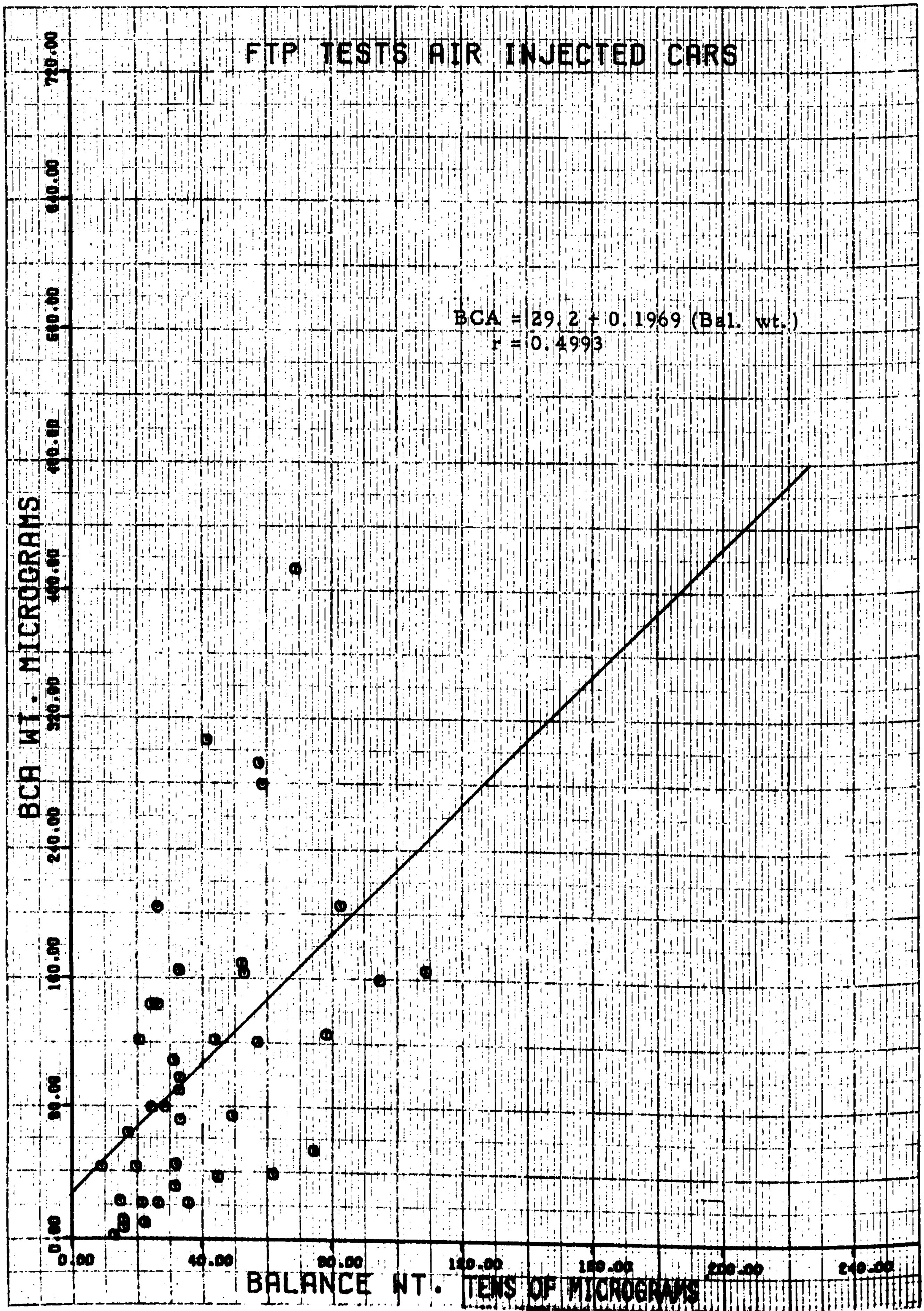



FIGURE 61. NET FILTER WEIGHT VERSUS BCA SULFATE WEIGHT AS AMMONIUM SULFATE FOR FTP TEST ON AIR-INJECTED CARS

that weighing the filters does, for some tests, give an indication, though not exact, as to the amount of sulfate on the filter. It is not recommended that weighing replace the BCA analysis. However, weighing the filter can provide a good quality control check. This check must be considered against the extra time required to weigh the filter after the test. This usually amounts to 8 to 12 hours since the filter must be conditioned in the same temperature and humidity environment in which it was weighed before the test.

4. Analysis of Tunnel Residue

At the conclusion of each distance test sequence on each car, the paraticulate residue in the sulfate tunnel was collected and qualitatively analyzed for various elements using X-ray fluorescence.

The resulting elemental analysis, as a percent of sample by weight, is shown in Table 26. The analysis was requested for platinum (Pt), palladium (Pd), aluminum (Al), nickel (Ni), iron (Fe), sulfur (S), lead (Pb), zinc (Zn), copper (Cu) and tin (Sn). Of these 10 elements, no platinum, palladium, nickel, copper, or tin was found in any of the samples. Chromium, silicon, and manganese were found in some of the samples and are included in Table 26.

As was the case when this same type of analysis was done on the sulfate characterization cars, the largest part of each sample was iron. This is not surprising, since from a visual inspection of the samples, it appears that rust, probably from the exhaust system, is the major constituent. The other elements were found in much smaller quantities and their origin is not certain. The X-ray detection limits for various elements are included in Table 7 in Section III.

TABLE 26. RESULTS OF X-RAY FLUORESCENT ANALYSIS OF SULFATE SAMPLING TUNNEL PARTICULATE RESIDUE FOR DISTANCE ACCUMULATION CARS

| Car | Total Weight Collected grams | Weight X-rayed mg | Elements, Percent by Weight | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Al | Fe | S | Pb | Zn | Cr | Si | Mn |
| EM-1 2000 mi | 0.053 | 1.36 | 0.4 | 29.3 | 0.2 | --- | --- | 0.2 | 0.4 | 0.2 |
| EM-2 2000 mi | 0.163 | 2.16 | 0.2 | 24.2 | 0.3 | --- | --- | 0.1 | 0.1 | 0.4 |
| EM-3 2000 mi | 0.051 | 1.31 | 0.4 | 28.1 | 0.5 | --- | --- | --- | 0.9 | --- |
| EM-4 2000 mi | 0.019 | 1.46 | 0.2 | 21.8 | 0.2 | --- | --- | --- | 0.1 | --- |
| EM-2 10000 mi | 0.123 | 1.65 | --- | 29.6 | 0.7 | --- | --- | --- | 0.2 | --- |
| EM-3 10000 mi | 1.265 | 1.78 | --- | 36.0 | 0.5 | --- | --- | --- | --- | --- |
| EM-4 10000 mi | 0.133 | 1.62 | 0.2 | 32.6 | 0.3 | --- | --- | --- | 0.2 | --- |
| EM-1 15000 mi | 0.190 | 1.66 | 1.0 | 31.0 | 0.5 | --- | --- | --- | 0.5 | --- |
| EM-2 15000 mi | 0.016 | 1.20 | 0.5 | 16.8 | 0.8 | --- | 1.3 | --- | 5.1 | --- |

# V. SULFATE REGULATION STUDIES

This section covers the testing done in support of the EPA activities to develop regulations for sulfate exhaust emissions during the period from April through August 1975.

## A. Background

On January 31, 1975, the EPA published an Issue Paper(15) which presented an evaluation of the potential public health impact of sulfate emissions from catalyst equipped cars. The risk-benefit analysis contained in that paper was the basis for the EPA decision to grant a one year delay in the statutory standards and to recommend to Congress a further five-year delay. Then on March 5, 1975, it was announced that the EPA had begun the activities necessary to develop a sulfate emission standard with the necessary driving cycle, test procedures and etc. The standard would be applicable beginning with the 1979 model year. The Department of Emissions Research at SwRI was selected as one of four laboratories to participate in the test procedure development. The other participating laboratories were Exxon Research; EPA, Research Triangle Park; and EPA, Ann Arbor.

## B. Purpose

This phase of the project had two principal purposes. One was to compare alternate preconditioning procedures and test sequences. The second purpose was to investigate the test-to-test variability of sulfates for the proposed driving cycle compared to other driving cycles on the cars provided. As testing progressed, two additional objectives were added. One was to investigate the effects of the evaporative emission canister, the second to investigate driver-to-driver differences.

## C. Cars Tested

For the SwRI portion of this procedural development study, two 1975 AMC Hornet Sportabouts were obtained by EPA from American Motors Corporation. These cars were designed to meet the Federal emissions standard and to be sold outside California. AMC catalyst cars with V-8 engines are one of the few car models for 49-state use equipped with air injection to the catalyst. The two cars were identical except for color and could be considered "matched cars" for emissions testing purposes. The AMC Engineering Department designation for the two cars was D50-34 and D50-36. At SwRI, these two cars were designated EM-5 and EM-6, respectively. Table 27 is a description of the cars. Figure 62 shows general views of the cars and test equipment.

Upon receipt of the cars, a 1975 FTP was run on each car for comparison with AMC tests conducted prior to shipment to SwRI. The comparison of these two sets of tests is shown in Table 28.

## D. Fuel Used

The base fuel used for all tests under this phase of the project except Sequence E of Part II was an unleaded gasoline obtained by EPA in a

TABLE 27. DESCRIPTION OF VEHICLES TESTED FOR PROCEDURAL DEVELOPMENT STUDIES

| | SwRI No. | |
|---|---|---|
| | EM-5 | EM-6 |
| Manufacturer | AMC | AMC |
| Model | Hornet Sportabout | Hornet Sportabout |
| Model Year | 1975 | 1975 |
| Inertia Weight Class | 3500 lbs | 3500 lbs |
| Engine Size | 304 CID V-8 | 304 CID V-8 |
| Catalyst | 160 in 3 pelletized | 160 in 3 pelletized |
| Air Injection | yes | yes |
| Vehicle Identification No. | A5A 087H209929 | A5A 087H214562 |
| Manufacturer Engine Design | D50-34 | D50-36 |
| Idle rpm | 700 | 700 |
| Timing | 5° BTDC | 5° BTDC |
| Curb Weight | 3401 (lbs) | 3406 (lbs) |
| Odometer Miles When Received | 2995 | 3152 |

TABLE 28. COMPARISON OF AMC AND SwRI LIGHT DUTY FTP EMISSIONS FROM TWO 1975 HORNET SPORTABOUTS

| | Emissions, grams/km | | | |
|---|---|---|---|---|
| | Car D60-34 | | Car D50-36 | |
| | SwRI | AMC | SwRI | AMC |
| HC | 0.27 | 0.28 | 0.24 | 0.26 |
| CO | 2.77 | 2.39 | 2.13 | 1.96 |
| $NO_x$ | 1.19 | 1.61 | 1.29 | 1.78 |

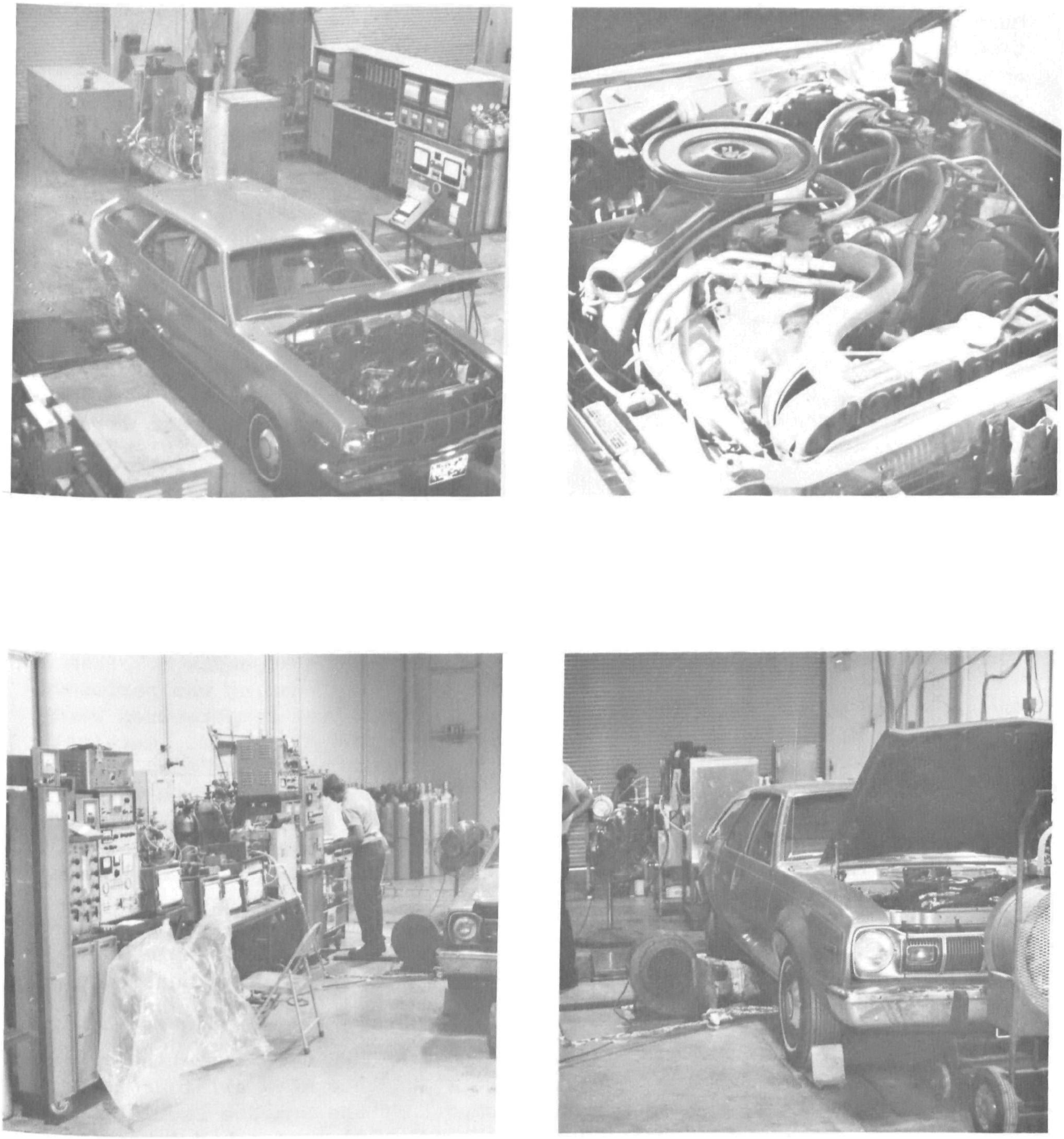


FIGURE 62. GENERAL VIEWS OF CARS AND TEST EQUIPMENT

large batch, by Dr. R. Bradow of EPA-ORD, Research Triangle Park, North Carolina. An analysis of that fuel is presented in Appendix F. By the time this phase of the project had begun, additional data had become available on national average gasoline sulfur content. This information showed the average fuel sulfur content to be approximately 0.03 percent rather than the 0.04 percent that had been used in previous phases of the project. Thiophene had been added to the base fuel to bring its sulfur level up to 0.03 percent. This fuel was identified within SwRI as EM-236-F.

The fuel used during the tests of car EM-3 under Sequence E of Part II of this phase was the same fuel the car was using for distance accumulaion. This fuel was an unleaded gasoline with a sulfur level of 0.04 percent. The fuel is described in Section IV of this report and in Appendix F.

E. Test Schedule and Procedures

The test schedule was divided into two parts. The first part was designed to investigate differences in sulfate emissions from the SET-7 due to test order and to investigate test-to-test variability of sulfate emissions. The test schedule for both cars for Part I is shown in Table 29. Note that two different types of road distance accumulations are specified, the AMA durability cycle and the Ann Arbor Road Route.

The route used by SwRI for the AMA durability cycle is described in Appendix H. The route used for the Ann Arbor Road Route, named the San Antonio Sulfate Preconditioning Route, is described in Appendix I. Item 1 of the Part I schedule, 3000 miles of AMA durability running was performed by AMC prior to shipment of the cars to SwRI. Catalyst temperatures were recorded on a multipoint temperature recorder during all tests. Catalyst temperature on each car was taken during one of the Ann Arbor Road Route preconditioning runs. The catalyst temperature and vehicle speed were manually recorded every 30 seconds over the road course. At the end of each test sequence (i.e., after the FET in Part 2A), the catalyst conversion efficiency was checked on the dynamometer at 30 mph and at 50 mph by sampling the exhaust before the catalyst for 2 minutes then after the catalyst for 2 minutes at each speed. It was realized that stable conditions were notreached during this time. The purpose of this sample was to ensure that the catalyst was performing consistently while putting a minimum amount of extra miles on the vehicle.

After completion of the Part I testing, the EPA held a meeting on July 15, 1975 in Ann Arbor, Michigan. In attendance were all four laboratories working on sulfate testing in support of the sulfate regulation studies. As a result of this meeting, the original test schedule for the Part II testing was changed. The testing requested of SwRI was outlined in an EPA memo from J. H. Somers to J. P. DeKany, dated July 18, 1975. This schedule was further modified by a telephone conversation on July 30, 1975 with Mr. Dick Lawrence, contract Project Officer. The resulting Part II test sequence is shown in Table 30.

In Part II of this phase, a third car, the 1975 California Plymouth Fury (car EM-3) used in the study of distance accumulation on sulfates,

TABLE 29. SULFATE TEST SCHEDULE, PART I

1. Run AMA to 3,000 miles
(regular AMA, 11 laps, 70 mph maximum speed)

2. Sequence A.
Ann Arbor Road Route - 1 hour
1 LA-4 (hot start)
- 4 hot start sulfate emission tests (SET)

Ann Arbor Road Route - 1 hour
1 LA-4 (hot start)
Overnight soak
- Federal Test Procedure (FTP)
- Fuel Economy Test (FET)

Repeat A
Repeat A again

3. Run 300 miles of <u>modified</u> AMA*

4. Sequence B.
Ann Arbor Road Route - 1 hour
1 LA-4 (hot start)
Overnight soak
- FTP
- SET - 2 times
- FET

Repeat B
Repeat B again

5. Run 300 miles of <u>modified</u> AMA

6. Sequence C.
Ann Arbor Road Route - 1 hour
1 LA-4 (hot start)
Overnight soak
- FTP
- FET
- SET - 2 times

Repeat C
Repeat C again

7. Sequence D.
- Run SET x times until stable sulfate emission value is obtained

8. Sequence E.
- Run a series of 12 SET-7 tests, 6 with fuel evaporative emissions canister connected, 6 with canister disconnected on car EM-5 only

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* 55 mph top speed, no WOT accels

• Sulfate and $SO_2$ emissions taken

TABLE 30. PART II TEST SCHEDULE

| | |
|---|---|
| Sequence A: | (Car EM-5, 1975 49 State Hornet)<br>12 Replicate SET-7 Tests with One Driver |
| Sequence B: | (Car EM-5, 1975 49 State Hornet)<br>5 Constant Speed 35 mph Tests (1 hour, each test)<br>2 SET-7 |
| Sequence C: | (Car EM-5, 1975 49 State Hornet)<br>5 Constant Speed 50 mph Tests (20 minutes, each test)<br>2 SET-7 |
| Sequence D: | (Car EM-5, 1975 49 State Hornet)<br>12 SET-9 Tests with One Driver |
| Sequence E: | (Car EM-3, 1975 California Plymouth Gran Fury)<br>30 SET-7 Tests With Three Drivers |

was included in the test series to investigate driver-to-driver differences. The car is described in Section IV of this project. Also in Part II, a "noise free" version of the SET-7 test, designated as SET-9, was evaluated.

## F. Test Results

### 1. Part I Results

As part of the test, catalyst temperatures on each of the two cars was measured on the San Antonio sulfate preconditioning route. The temperature and vehicle speed, as a function of time, is shown in Figures 63 and 64. These temperatures can be compared with the temperatures during the various dynamometer test cycles.

The purpose of this part of the test program was to investigate differences in sulfate emissions due to preconditioning and the order of testing in the test sequence. Tables 31 and 32 list the mean emission levels for each test sequence in Part I by test cycle. For Sequence D which was 20 repetitive SET-7 cycles and Sequence E on EM-5 which was also repetitive SET-7 test, the standard deviation and coefficient of variation are also listed. A complete listing of the results for each test is contained in Appendix I. As an aid to comparing the various tests, the sulfate emissions for each test are plotted in Figure 65.

It should also be noted that the FTP tests in Sequence A were performed in a slightly different manner than the FTP tests of Sequence B and C. For Sequence A, two 23 minute LA-4 cycles were run, one with a cold start and one with a hot start, one bag sample and one sulfate filter were taken during each 23 minute period. The results of the two cycle were then averaged, weighting the cold cycle 43 percent and the hot cycle 57 percent. For Sequence B and C, a regular "3 bag" FTP was run, taking only one sulfate filter and one $SO_2$ sample for the entire FTP. This means that while the emissions of HC, CO, and $NO_x$ are weighted for the cold and hot start portions of the test, the sulfate and $SO_2$ emissions are not weighted.

From the examination of the tables, it appears that the order of the SET-7 test in the test sequence has an effect on the sulfate emissions; but little, if any, effect on the HC, CO, and $NO_x$. When the two SET-7 tests followed an FTP test, the average sulfates from the first SET-7 were approximately 50 percent higher than those from the first SET-7 following an HFET. However, on the average, the second of the two SET-7 tests following an FTP had approximately 25 percent lower sulfate emissions than those from the second SET-7 following an HFET.

While the FTP was always first in the test order, there was a difference in the gaseous and sulfate emissions between Sequence A and Sequences B and C. At least part of this difference is probably due to the differences in test procedure explained earlier. The two procedures are mathematically equivalent for the gaseous emissions, but not for the sulfate emissions. The sulfate emissions from the HFET are also higher for Sequence A than for Sequences B and C.

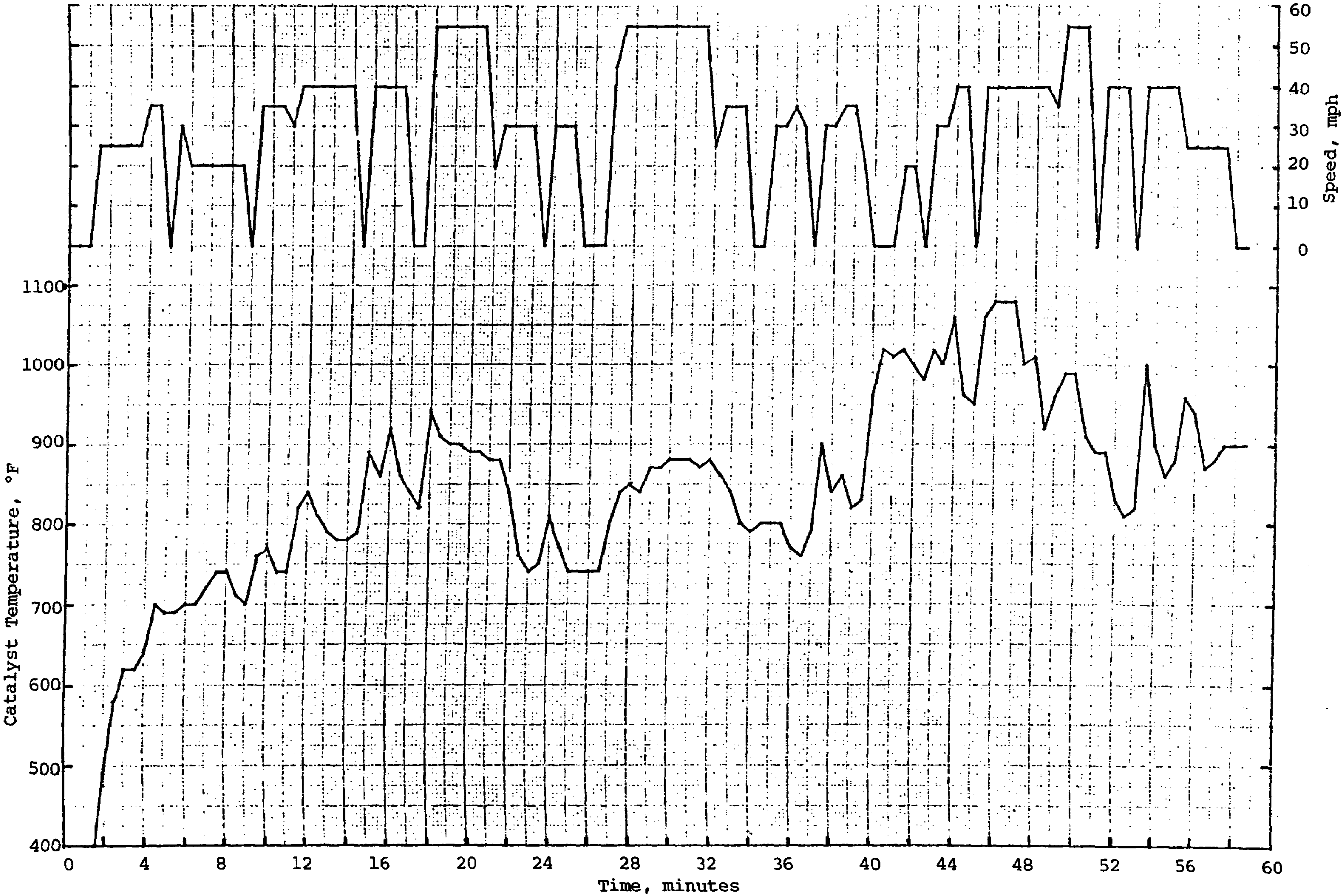



FIGURE 63. CATALYST TEMPERATURE OVER SAN ANTONIO VERSION OF ANN ARBOR ROAD COURSE FOR AMC HORNET NO. D50-34

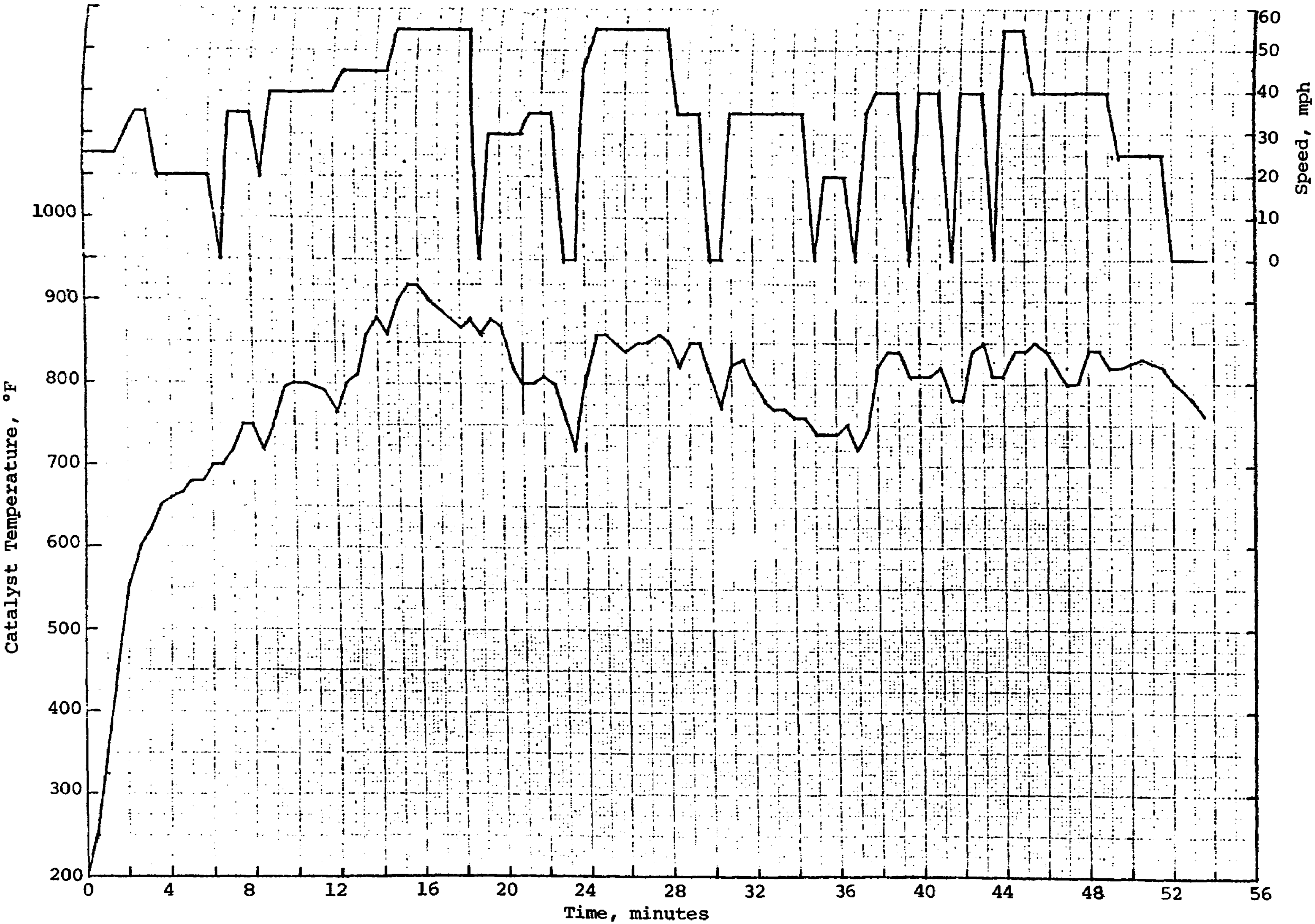



FIGURE 64. CATALYST TEMPERATURE OVER SAN ANTONIO VERSION OF ANN ARBOR ROAD COURSE FOR AMC HORNET NO. D50-36

TABLE 31. SUMMARY OF EMISSIONS FROM CAR EM-5 ON PART I TEST SEQUENCES

| | | | | | Average Emissions | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | g/km | | | mg/km | |
| Cycle | Sequence | Test No. | Replicates | Statistic | HC | CO | $NO_x$ | $SO_2$ | $H_2SO_4$ |
| SET-7 | A | 1 | 3 | Mean | 0.07 | 0.19 | 1.20 | 48 | 19.84 |
| SET-7 | | 2 | 3 | Mean | 0.07 | 0.11 | 1.30 | - | 25.36 |
| SET-7 | | 3 | 3 | Mean | 0.07 | 0.15 | 1.23 | - | 37.06 |
| SET-7 | | 4 | 3 | Mean | 0.07 | 0.10 | 1.28 | - | 47.21 |
| SET-7 | B | 2 | 3 | Mean | 0.08 | 0.08 | 1.65 | - | 20.50 |
| SET-7 | | 3 | 3 | Mean | 0.06 | 0.07 | 1.68 | - | 17.73 |
| SET-7 | C | 3 | 3 | Mean | 0.07 | 0.11 | 1.44 | 42 | 14.47 |
| SET-7 | | 4 | 3 | Mean | 0.05 | 0.09 | 1.44 | 41 | 23.81 |
| SET-7 | D | 1 to 20 | 20 | Mean | 0.06 | 0.10 | 1.50 | 36.25 | 35.70 |
| SET-7 | | 1 to 20 | 20 | Std. Dev. | 0.01 | 0.09 | 0.54 | 10.33 | 9.46 |
| SET-7 | | 1 to 20 | 20 | Coef. Var. | 8.3% | 88.9% | 36.4% | 28.5% | 26.6% |
| SET-7 | D | 4 to 20 | 17 | Mean | 0.06 | 0.10 | 1.36 | 38.35 | 37.86 |
| SET-7 | | 4 to 20 | 17 | Std. Dev. | $<$0.01 | 0.10 | 0.10 | 9.70 | 7.17 |
| SET-7 | | 4 to 20 | 17 | Coef. Var. | 8.2% | 100.0% | 7.3% | 25.30 | 18.9% |
| SET-7 | E | 2 to 5 | 4 | Mean | 0.06 | 0.06 | 1.80 | 45.50 | 40.2 |
| SET-7 | | 2 to 5 | 4 | Std. Dev. | 0.00 | 0.02 | 0.14 | 11.96 | 6.47 |
| SET-7 | | 2 to 5 | 4 | Coef. Var. | 0.00% | 43.3% | 7.6% | 26.3% | 16.1% |
| SET-7 | E | 7 to 12 | 6 | Mean | 0.06 | 0.06 | 1.66 | 33.43 | 42.37 |
| SET-7 | | 7 to 12 | 6 | Std. Dev. | 0.01 | 0.04 | 0.22 | 12.42 | 5.55 |
| SET-7 | | 7 to 12 | 6 | Coef. Var. | 8.32% | 55.3% | 13.5% | 37.2% | 13.1% |
| FTP | A* | 5 | 3 | Mean | 0.27 | 2.46 | 1.13 | 33 | 10.16 |
| FTP | B | 1 | 3 | Mean | 0.42 | 4.58 | 1.86 | - | 4.90 |
| FTP | C | 1 | 3 | Mean | 0.43 | 4.33 | 2.04 | 25 | 4.91 |
| HFET | A | 6 | 3 | Mean | 0.06 | 0.09 | 1.32 | 34 | 61.14 |
| HFET | B | 4 | 3 | Mean | 0.06 | 0.05 | 1.62 | - | 27.68 |
| HFET | C | 2 | 3 | Mean | 0.05 | 0.07 | 1.44 | 25 | 31.18 |

*$H_2SO_4$ and $SO_2$ emissions are weighted averages based on one sample for cold LA-4 and one sample for hot LA-4.

TABLE 32. SUMMARY OF EMISSIONS FROM CAR EM-6 ON PART I TEST SEQUENCES

| | | | | | Average Emissions | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | g/km | | | mg/km | |
| Cycle | Sequence | Test No. | Replicates | Statistic | HC | CO | $NO_x$ | $SO_2$ | $H_2SO_4$ |
| SET-7 | A | 1 | 3 | Mean | 0.07 | 0.025 | 1.35 | 38 | 26.48 |
| SET-7 | | 2 | 3 | Mean | 0.07 | 0.31 | 1.35 | - | 30.41 |
| SET-7 | | 3 | 3 | Mean | 0.07 | 0.11 | 1.40 | 32 | 36.07 |
| SET-7 | | 4 | 3 | Mean | 0.07 | 0.20 | 1.42 | 36 | 49.17 |
| SET-7 | B | 2 | 3 | Mean | 0.06 | 0.02 | 1.48 | - | 36.86 |
| SET-7 | | 3 | 3 | Mean | 0.06 | 0.08 | 1.42 | - | 29.41 |
| SET-7 | C | 3 | 3 | Mean | 0.05 | 0.03 | 1.41 | 34 | 22.17 |
| SET-7 | | 4 | 3 | Mean | 0.07 | 0.02 | 1.58 | 35 | 36.77 |
| SET-7 | D | 1 to 20 | 20 | Mean | 0.06 | 0.14 | 1.34 | 43 | 33.45 |
| SET-7 | | 1 to 20 | 20 | Std. Dev. | $<$0.01 | 0.13 | 0.07 | 14.54 | 10.28 |
| SET-7 | | 1 to 20 | 20 | Coef. Var. | 6.2% | 90.4% | 5.5% | 33.7% | 30.74 |
| SET-7 | D | 4 to 20 | 17 | Mean | 0.06 | 0.13 | 1.35 | 42 | 35.97 |
| SET-7 | | 4 to 20 | 17 | Std. Dev. | $<$0.01 | 0.13 | 0.07 | 14.54 | 7.56 |
| SET-7 | | 4 to 20 | 17 | Coef. Var. | 7.9% | 95.9% | 5.4% | 34.8% | 21.0% |
| FTP | A* | 5 | 3 | Mean | 0.26 | 1.99 | 1.27 | - | 13.03 |
| FTP | B | 1 | 3 | Mean | 0.41 | 3.51 | 2.11 | - | 13.10 |
| FTP | C | 1 | 3 | Mean | 0.44 | 3.34 | 2.09 | 28 | 9.66 |
| HFET | A | 6 | 3 | Mean | 0.06 | 0.02 | 1.48 | 19 | 72.00 |
| HFET | B | 4 | 3 | Mean | 0.05 | 0.02 | 1.37 | - | 40.02 |
| HFET | C | 2 | 3 | Mean | 0.04 | 0.02 | 1.86 | 36 | 42.98 |

*$H_2SO_4$ and $SO_2$ emissions are weighted averages based on one sample for cold LA-4 and one sample for hot LA-4.

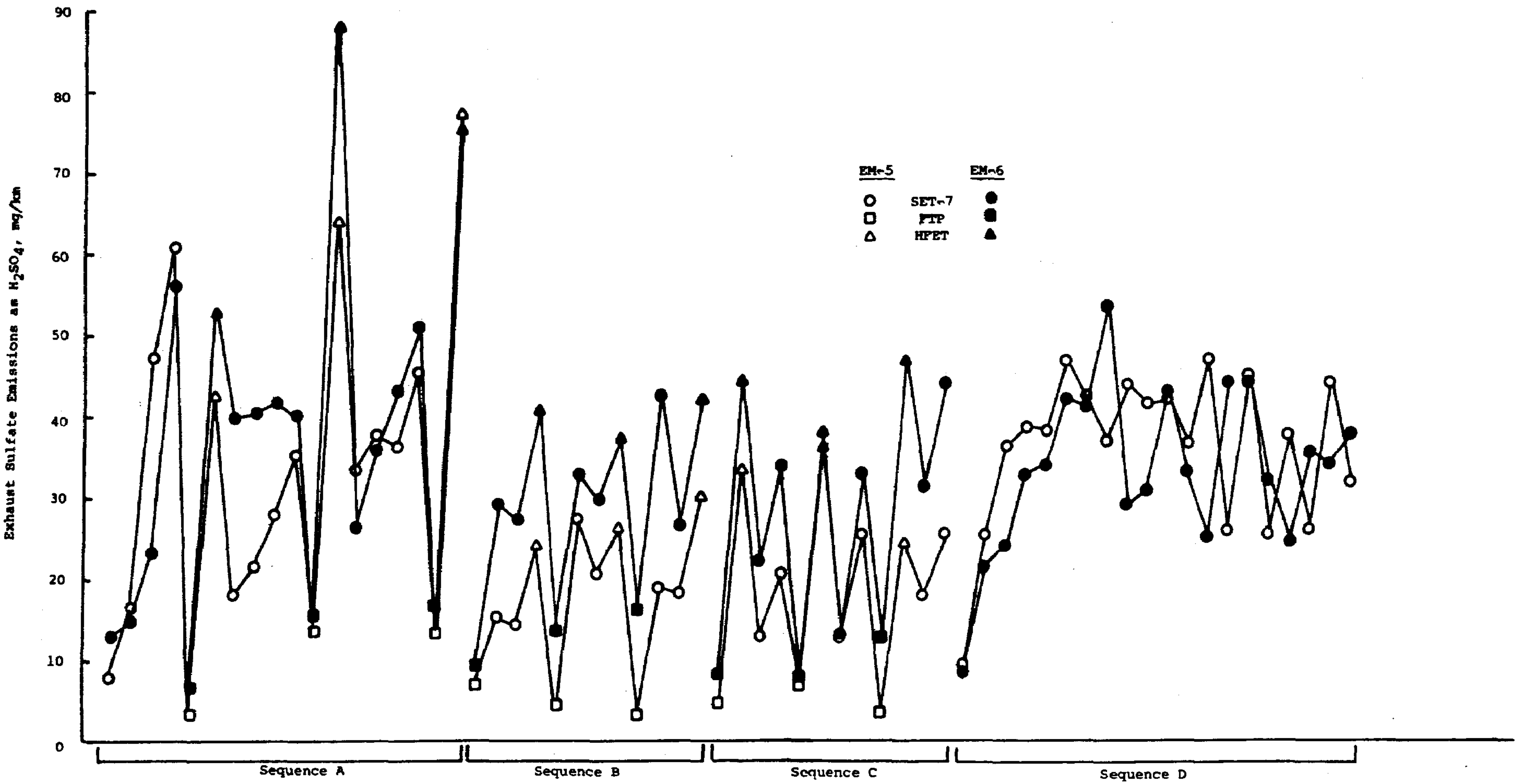



FIGURE 65. SULFATE EMISSIONS FROM PART I OF PROCEDURAL DEVELOPMENT STUDY

The sulfate emissions thus reach higher levels for all test cycles during Sequence A than any other sequence. Sequence A had a different long term preconditioning (regular AMA durability cycle instead of modified AMA durability cycle) than Sequences B and C. It is possible, therefore, that the differences are due to preconditioning. Yet, the regular AMA durability cycle has a section of wide open throttle (WOT) accelerations which the modified durability cycle does not. This would appear to indicate that the regular AMA durability would purge more stored sulfur from the catalyst, giving lower sulfate emissions on subsequent tests. However, the dynamics of sulfate production by the catalyst and the effects of sulfur storage are still not fully understood. At this time, all that can be said is that there is a possibility that preconditioning contributed to the differences in sulfate emissions seen between Sequence A and Sequences B and C. It should also be mentioned that the results from other laboratories did not always follow the same trends seen here.

An examination of Sequence D data indicates that from a cold start, about three SET-7 tests are required to reach relatively stable sulfate emission levels. Note that when the first three SET-7 tests in Sequence D are not used, the coefficient of variation is 18.9 percent compared with 26.6 percent for all tests in Sequence D.

Test Sequence E was run to determine the effect of the fuel evaporative emission canister on sulfate emissions. It was thought that perhaps in some modes the canister could release fuel vapors into the carburetor and possibly have an adverse effect on sulfate emissions. The average sulfate emissions from tests with the canister connected to the engine were compared with the average sulfate emissions with the canister disconnected. The average sulfate emissions are essentially the same for the two sets of tests being 40.2 and 42.37 for the connected and disconnected tests, respectively. The coefficients of variation are 16.1 for the tests with the canister connected and 13.1 for tests with the canister disconnected. Thus, it appears that the fuel evaporative emissions canister has no effect on repetitive SET-7 sulfate emissions.

### 2. Part II Results

The purpose of the testing under Part II of this phase was to investigate test-to-test repeatability. The repeatability of the SET-7 test was compared to that obtained at 35 mph cruise, 50 mph and an alternate sulfate test cycle SET-9. The sulfate emission differences of tests with different drivers were also investigated. It was requested that the test results from this part of the test program be expressed in grams (or milligrams) per mile so that the results could easily be compared with other laboratories working on this project. Therefore, the data in this section will be in those units rather than in all metric units as is done for the other sections of this report.

Table 33 lists the mean, standard deviation and coefficient of variation of the exhaust emissions for test Sequences A, B, C, and D. For the two SET-7 tests at the end of Sequences B and C, only the mean and the range are shown. Appendix I contains the results for each individual

TABLE 33. STATISTICAL SUMMARY OF EMISSIONS FROM TESTS ON PART II, TEST SEQUENCE A, B, C, AND D

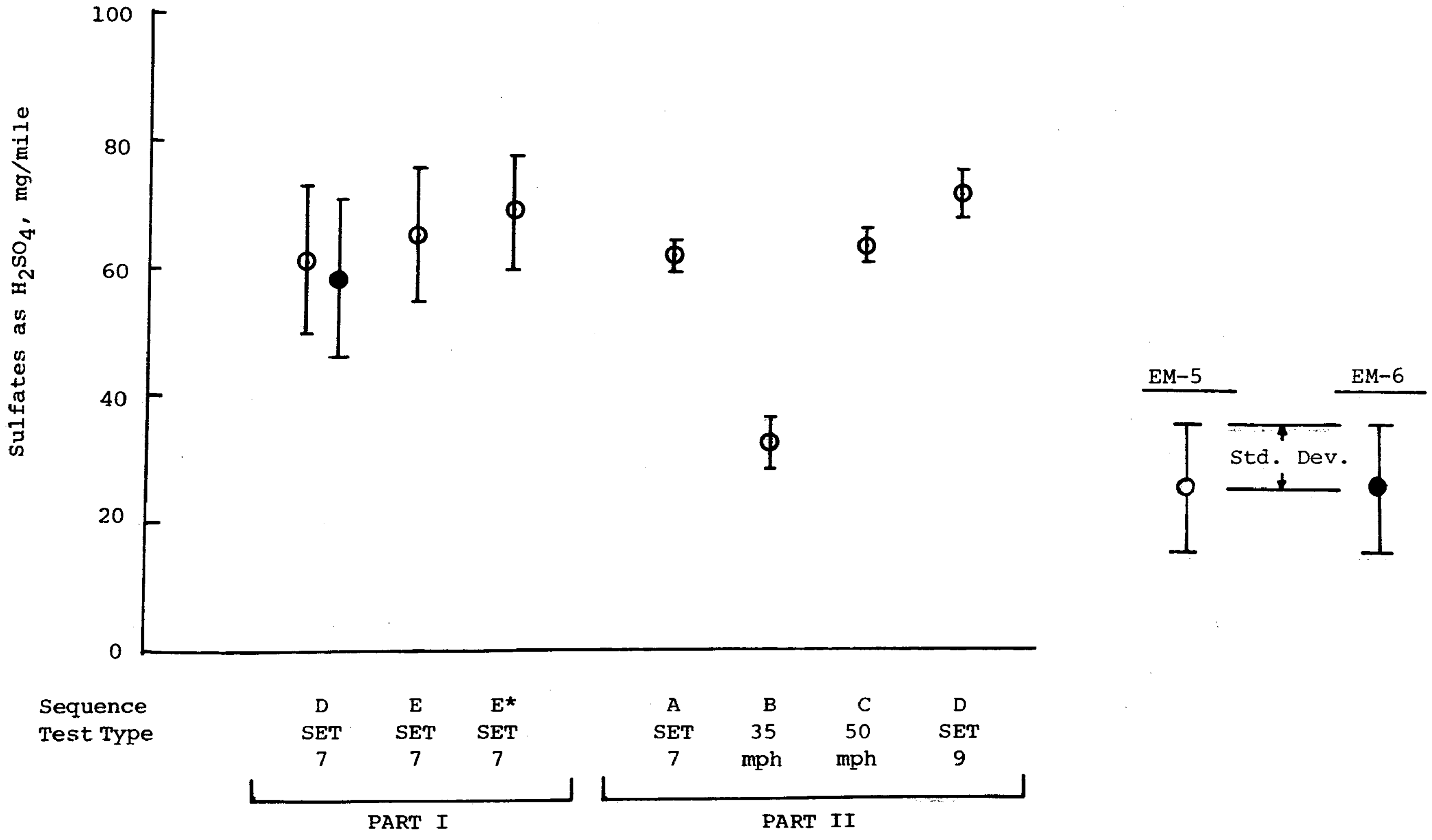
| Test Sequence | Test Cycle | Variable | HC, g/mile | CO, g/mile | $NO_x$, g/mile | $SO_2$, mg/mile | $H_2SO_4$, mg/mile | Avg. Cat. Temp., °F | No. of Tests |
|---|---|---|---|---|---|---|---|---|---|
| A | SET-7 | Mean | 0.10 | 0.06 | 2.18 | 60.12 | 56.73 | 912 | 12 |
| | | Std. Dev. | 0.02 | 0.03 | 0.11 | 10.28 | 9.29 | 3.0 | (tests 1-12) |
| | | Coef. Var, % | 15.7 | 53.9 | 5.1 | 17.1 | 16.4 | 0.3 | |
| A | SET-7 | Mean | 0.09 | 0.06 | 2.19 | 59.61 | 61.35 | 912 | 9 |
| | | Std. Dev. | 0.02 | 0.04 | 0.12 | 11.04 | 2.45 | 2.8 | (tests 4-12) |
| | | Coef. Var, % | 20.0 | 64.3 | 5.3 | 18.5 | 4.0 | 0.3 | |
| B | 35 mph | Mean | 0.06 | 0.04 | 2.37 | 40.44 | 28.48 | 751 | 5 |
| | | Std. Dev. | 0.03 | 0.03 | 0.08 | 13.24 | 8.65 | 8.4 | (tests 1-5) |
| | | Coef. Var, % | 58.2 | 82.2 | 3.2 | 32.8 | 30.4 | 1.1 | |
| | 35 mph | Mean | 0.07 | 0.03 | 2.36 | 44.30 | 32.02 | 749 | 4 |
| | | Std. Dev. | 0.02 | 0.03 | 0.08 | 11.6 | 4.01 | 8.8 | (tests 2-5) |
| | | Coef. Var, % | 28.6 | 100.0 | 3.5 | 26.2 | 12.5 | 1.2 | |
| | SET-7 | Mean | 0.08 | 0.04 | 2.78 | 146.31 | 122.93 | 922 | 2 |
| | | Range | 0.00 | 0.06 | 0.25 | 48.95 | 67.26 | 1 | |
| C | 50 mph | Mean | 0.06 | 0.02 | 1.97 | 33.42 | 62.06 | 966 | 5 |
| | | Std. Dev. | 0.01 | 0.03 | 0.15 | 4.46 | 2.98 | 5.4 | (tests 1-5) |
| | | Coef. Var, % | 16.7 | 104.6 | 7.6 | 13.3 | 4.8 | 0.6 | |
| | 50 mph | Mean | 0.06 | 0.02 | 1.99 | 33.39 | 62.91 | 965 | 4 |
| | | Std. Dev | 0.01 | 0.02 | 0.16 | 5.15 | 2.64 | 5.7 | (tests 2-5) |
| | | Coef. Var, % | 23.5 | 115.5 | 8.0 | 15.4 | 4.2 | 0.6 | |
| | SET-7 | Mean | 0.11 | 0.11 | 2.54 | 65.68 | 72.71 | 906 | 2 |
| | | Range | 0.20 | 0.09 | 0.09 | 11.51 | 1.49 | 3.0 | |
| D | SET-9 | Mean | 0.11 | 0.09 | 2.30 | 46.76 | 68.29 | 907 | 12 |
| | | Std. Dev. | 0.05 | 0.11 | 0.10 | 12.95 | 7.19 | 5.3 | (tests 1-12) |
| | | Coef. Var, % | 45.8 | 119.7 | 4.2 | 27.8 | 10.5 | 0.6 | |
| | SET-9 | Mean | 0.10 | 0.07 | 2.31 | 50.88 | 70.93 | 905 | 9 |
| | | Std. Dev. | 0.02 | 0.04 | 0.08 | 5.85 | 3.82 | 2.5 | (tests 4-12) |
| | | Coef. Var, % | 21.1 | 63.0 | 3.6 | 11.5 | 5.4 | 0.3 | |

test. The table contains the statistical summary for each sequence based on all tests in the sequence and also based only on the tests considered to represent a stabilized condition.

The sulfate results from Sequence A of Part II show better repeatability than seen in the Part I tests. The reasons for this are not known. However, two items may contribute to the improved repeatability. The first item is that only one driver was used for all 12 tests; the second is that the spectrophotometer areas indicating the sulfate concentrations were determined using an automatic computer integrating system starting with Sequence A of Part II instead of manual integration with a polar planimeter. It should be noted that the catalyst bed temperatures from Part II, Sequence A show better repeatability than in the Part I tests.

The sulfate emissions coefficient of variation from the stabilized SET-7 tests of Sequence A can be compared with the sulfate emission coefficient of variation for the other test types. When this is done, it appears that the SET-7 test cycle repeatability is as good as, or better than, the other test cycles. In fact, the sulfate coefficient of variation for all test cycles compares favorably with the coefficient of variation from the gaseous emissions of the same test cycle. When the SET-7 tests are compared to the SET-9 tests, the average sulfate emissions from the SET-9 tests are found to be approximately 16 percent higher than the sulfates from the SET-7 tests. The coefficient of variation for the two types of tests are not significantly different, being 4.0 for the SET-7 test and 5.4 for the SET-9 tests. From these test series it would appear that the SET-9 does not offer any real improvement in test-to-test repeatability over the SET-7.

The differences in sulfate emissions between the two SET-7 tests following the 35 mph sequence and the two SET-7 sets following the 50 mph tests are worthy of vote. If the 35 mph test sequence is examined on a test by test basis using Table I-11 in Appendix I, it can be seen that the 35 mph test started out in a storage mode and apparently finally reached equilibrium at the fifth test, after four hours of running. The first SET-7, which had the highest sulfate emissions seen during the entire project (157 mg/mi), apparently was releasing a portion of the sulfur stored during the previous five hours of running at 35 mph. This conclusion is supported by the fact that the second SET-7 test of this sequence has a considerably lower sulfate emission rate. The SET-7 tests following the 50 mph tests, which apparently were operating close to equilibrium for all tests, showed little difference in sulfate emissions between the two tests. In addition, the level of sulfates was lower than the SET-7 tests following the 35 mph sequence and more in line with the sulfate levels from the stabilized SET-7 tests of Sequence A. These tests again support the conclusion, reached in the discussion of the Part I results, that differences in SET-7 sulfate emissions can occur because of differences in prior operation of the car. To help in comparing the various repetitive tests, including those from Part I, the average sulfate emissions and standard deviation for each test sequence are shown in Figure 66.




* Fuel evap cannister disconnected

FIGURE 66. SULFATE EMISSIONS FROM REPETITIVE TESTS OF VARIOUS TEST CYCLES

In order to ascertain if part of the variation seen in SET-7 sulfate emissions in Part I were due to driver effects, test Sequence E was run using car EM-3. This test sequence consisted of 30 SET-7 tests using three different drivers. A statistical summary of these tests is shown in Table 34. The results of each individual test are given in Table I-14. The tests were run on two different days, 15 tests on each day. In keeping with the finding from Part I, the first three tests on each day were considered warm-up tests and not used in the analysis. Remember that car EM-3 with 0.04 percent sulfur fuel was used for this test sequence, while EM-5 with 0.03 percent sulfur fuel was used for Sequences A, B, C, and D of Part II. The tests of the 1975 California Plymouth give an average sulfate emission level of 26.7 mg/mile (exclusive of the first three tests on each day of testing) at the 0.0415 percent fuel sulfur level. If this average level is normalized to 0.03 percent fuel sulfur, the sulfate emission level would be 19.3 mg/mile.

Examining the table, it can be seen that there is a considerable difference in the average sulfate emissions between the two test days. The reason for this difference is not known. The coefficients of variation for the data groupings are in the 20 to 30 percent range. This is more like the coefficient of variation seen in Part I Sequence D for car EM-5. There is a difference in the average sulfate emissions for each driver, whether each day is considered separately or all the data is taken together. To determine if the differences were statistically significant, an analysis of variance (ANOVA) was run for each test day separately and both days together with driver as the independent variable. The results of the ANOVA are also shown in Table 34. When the test days are considered separately, the driver was a significant variable at the 0.10 level, but not at 0.025 for each day. When the two days are considered together, the driver was not a significant variable below the 0.10 level. Considering the difference in average sulfate emissions for the two days, perhaps more emphasis should be placed on the results from the individual days. In that case, it appears that driver difference may explain some, but not all, of the test-to-test variation seen in the sulfate emissions.

## TABLE 34. STATISTICAL SUMMARY OF SULFATE EMISSION FROM REPETITIVE SET-7 TESTS (CALIF. PLYMOUTH)

### Part II, Sequence E

| | | Average $H_2SO_4$ mg/mile | No. of Tests | Std. Dev. mg/mile | Coefficient of Variation, Percent |
|---|---|---|---|---|---|
| Tests 4 to 15 | 8/1/75 | 20.58 | 11 | 3.96 | 19.2 |
| Tests 4 to 15 | 8/5/75 | 32.24 | 12 | 8.65 | 26.8 |
| Tests 4 to 15 | 8/1 and 8/5 | 26.66 | 23 | 8.95 | 33.6 |
| Driver A Tests | 8/1/75 | 18.38 | 5 | 3.97 | 21.6 |
| Driver B* Tests | 8/1/75 | 18.59 | 2 | - | - |
| Driver C Tests | 8/1/75 | 24.32 | 4 | 1.31 | 5.4 |
| Driver A Tests | 8/5/75 | 31.16 | 5 | 6.78 | 21.7 |
| Driver B* Tests | 8/5/75 | 24.53 | 3 | 4.93 | 20.1 |
| Driver C* Tests | 8/5/75 | 39.37 | 4 | 8.25 | 21.0 |
| Driver A Tests | 8/1 and 8/5 | 24.77 | 10 | 8.53 | 34.4 |
| Driver B* Tests | 8/1 and 8/5 | 22.15 | 5 | 4.77 | 21.5 |
| Driver C* Tests | 8/1 and 8/5 | 31.80 | 8 | 9.77 | 30.7 |

### Results of ANOVA

| Groups * | F statistic | Significance |
|---|---|---|
| Drivers on 8/1/75 | 5.15 | $0.05 < p < 0.025$ |
| Drivers on 8/5/75 | 4.00 | $0.10 < p < 0.05$ |
| Drivers on 8/1 & 8/5/76 | 2.50 | $p < 0.10$ |

* Not including first three tests from each day

## VI. BASELINE TESTING

As part of the EPA sulfate baseline study, SwRI measured sulfate emissions on eight cars. While administratively this work was done under Task 2 of Task Order 68-03-2196, the test results are reported here, as specified in the task order.

### A. Background

To gain information on the sulfate emission levels on a broad spectrum of cars, the EPA initiated a sulfate baseline study in the late summer of 1975. This program involved the testing of 59 vehicles for sulfuric acid and gaseous emissions (HC, CO, $NO_x$). A variety of catalyst and noncatalyst cars were tested. These cars included both current production cars and cars designed to meet advanced emissions standards. Five different laboratories participated in this program.

### B. Purpose

There were two main purposes of this study. The first was to obtain sulfate emission factors on a wide group of different in-use and prototype vehicles. These emission factors can then be used to evaluate sulfate emissions from individual emission control systems and vehicles as well as being used for input to air quality models assessing the impact of automotive sulfate emissions. The second purpose of the study was to determine the effect on sulfate emission from vehicles meeting increasingly stringent emission standards for HC, CO and $NO_x$.

### C. Cars Tested

As its part of the baseline study, the Department of Emission Research at SwRI tested eight cars. Two of the cars were 1975 production models without catalysts. One was a 1975 production model with catalyst and air injection, designed to meet 1975 Federal emission standards. Two were 1975 California production models with catalysts and air injection. One was a 1975 production model diesel powered car. The remaining two were prototype fuel injected vehicles with three-way catalysts. A complete description of the cars is given in Table 35.

Cars I-3 and I-4 were obtained from local rental sources. Car IIA-1 was one of the cars used in the procedural development phase of this project and was supplied by the manufacturer. Cars IIB-1 and IIB-6 were two of the distance accumulation cars leased new for the distance accumulation study. Car III-7 was supplied by EPA. Car IV-4 and IV-17 were in reality one car with two different exhaust catalyst systems. The car was a prototype loaned to EPA by the manufacturer.

### D. Fuel Used

The fuel that had been planned for use on the baseline gasoline powered cars was part of the batch of Phillips Petroleum unleaded gasoline obtained in a large batch by Dr. R. Bradow of EPA-RTP. An analysis of this fuel is

TABLE 35. SULFATE BASELINE CARS
TESTED AT SOUTHWEST RESEARCH INSTITUTE

| EPA Number | Year | Make | Model | Engine CID | Distance Accumulated km[3] | Catalyst |
|---|---|---|---|---|---|---|
| I-3 | 1975 | Ford | Granada | 351W | 9,886 | No |
| I-4 | 1975 | Dodge | Coronet | 318 | 16,605 | No |
| IIA-1 | 1975 | Hornet | Sportabout | 304 | 8,473 | Yes w/air |
| IIB-1 | 1975 | Chevrolet | Impala[1] | 350 | 24,135 | Yes w/air |
| IIB-6 | 1975 | Plymouth | Gran Fury[1] | 360 | 16,090 | Yes w/air |
| III-7 | 1975 | Mercedes | 240D[2] | 147 | 2,824 | No |
| IV-4 | 197X | Ford | Pinto | 140 | 1,900 | 3-way Degussa + Oxidation w/air |
| IV-17 | 197X | Ford | Pinto | 140 | 1,900 | 3-way Engelhard TWC-9 |

(1) California model
(2) Diesel powered
(3) On catalyst cars, distance accumulated refers to distance accumulated on catalyst

contained in Appendix F. Thiophene was added to the fuel to raise the fuel sulfur level to 0.03 percent. This doped fuel was identified within SwRI as EM-236-F. This fuel was used for the tests of cars I-3, I-4, IIA-1, and IV-4.

Recall that cars IIB-1 and IIB-6 were part of the distance accumulation project. Since the cars were still in the process of accumulating distance, it was felt that the fuel used for the baseline tests should be the same as used in the distance accumulation project. This fuel, identified as EM-212-F had a nominal sulfur level of 0.04 percent.

The diesel fuel used for car III-7 was a commercially-available Gulf 2D diesel fuel. This fuel was chosen rather than a diesel fuel blended to meet the EPA specifications for emissions test fuel. The emission test fuels are higher in sulfur and aromatics than normal diesel fuels. The diesel fuel used was numbered EM-246-F.

Car IV-17 started its preconditioning on the Phillips fuel, EM-236-F, however, engine operation problems were encountered during the preconditioning of car IV-17. With the assistance of representatives from Ford Motor Company, the problem was traced to stuck fuel injectors.

The car ran approximately 750 miles on the Phillips fuel before encountering operational problems. New injectors were installed and after 60 miles of operation and an overnight soak, the new injectors were also stuck. It seems unlikely that a fuel that the car had run on for 800 miles would cause new injectors to stick after a single overnight soak. More likely, something in either one barrel of the fuel or in the vehicle fuel tank was the cause.

To eliminate either cause, the vehicle fuel tank was drained, removed from the vehicle and thoroughly cleaned. Water and some biological growth were found in the drained fuel and in the fuel drum from which the vehicle had been fueled. It was likely that this growth was what fouled the injectors. The vehicle was refueled with the Gulf Oil Company Gulf Crest unleaded fuel used throughout the mileage accumulation part of this project, except that the sulfur level was adjusted to 0.03 percent. This fuel was identified as EM-243-F.

E. Test Sequence and Procedure

The test sequence for all eight cars is shown in Table 36. As shown in the table, the noncatalyst cars received the normal FTP preconditioning. In this case, the preconditioning consisted of 1 LA-4 driving schedule, followed by step 1 of the test procedure, an overnight soak. The catalyst cars with air injection were all operated for 1609 km on the modified AMA durability route shown in Appendix H prior to an overnight soak. The prototype car with the three-way catalyst was operated for 805 km on this route prior to an overnight soak with each exhaust configuration. The test procedures were the same as those used in the other phases of this project and outlined in Section II of this report.

TABLE 36. SULFATE BASELINE TEST SEQUENCE

Preconditioning

| Car | Procedure |
|---|---|
| I-3, I-4, III-7 | Normal FTP preconditioning |
| II-AI, II-BI, II-B6 | 1000 Miles Modified AMA |
| IV-4, IV-17 | 500 Miles Modified AMA |

Test Procedure

| Step | Operation |
|---|---|
| 1 | 12-20 hour soak |
| 2 | 1975 FTP (1 sulfate filter, 1 $SO_2$ sample) |
| 3 | Idle (5 minutes) |
| 4 | SET-7 |
| 5 | Idle |
| 6 | SET-7 |
| 7 | Idle |
| 8 | HWFET |
| 9 | Idle |
| 10 | SET-7 |
| 11 | Idle |
| 12 | SET-7 |

Repeat Steps 1 to 12 without any other preconditioning.

Emissions of HC, CO, $NO_x$, $CO_2$, $H_2SO_4$ and $SO_2$ are to be taken during all test modes except idle.

F. Test Results

A summary of the sulfate and $SO_2$ test results is given in Table 37. A listing of the complete test results for each test is contained in Appendix J. To aid in the comparison of the $H_2SO_4$ emissions, Figure 67 contains histograms of the sulfate emissions for each car.

The sulfate emissions from the two noncatalyst cars agree with sulfate emissions seen on other noncatalyst cars tested at SwRI and at other laboratories. Cars IIA-1, IIB-1 and IIB-6 all had been tested rather extensively and their baseline test results are as expected from past tests Recall that cars IIB-1, IIB-6 were tested using a fuel with 0.04 percent sulfur. While it is not known if sulfate emissions vary directly with fuel sulfur content, if it is assumed that they do, the results from cars IIB-1 and IIB-6 can be adjusted to 0.03 percent sulfur fuel. When this is done, the average SET-7 test sulfate emissions are 6.82 mg/km for car IIB-1 and 23.43 mg/km for car IIB-6. The reasons for the differences in these two

TABLE 37. *SUMMARY OF SULFATE AND $SO_2$ EMISSIONS FROM BASELINE TESTS AT SwRI*

| EPA Car Number | I-3 | I-4 | IIA-1 | IIB-1 | IIB-6 | III-7 | IV-4 | IV-17 |
|---|---|---|---|---|---|---|---|---|
| Make | Ford | Dodge | Hornet | Chevrolet | Plymouth | Mercedes | Ford | Ford |
| Model | Granada | Coronet | Sportabout | Impala | Gran Fury | 240D | Pinto | Pinto |
| Model Year | 1975 | 1975 | 1975 | 1975 | 1975 | 1975 | 197X | 197X |
| Engine CID | 351W | 318 | 304 | 350 | 360 | 147 | 140 | 140 |
| Catalyst | None | None | Pelleted | Pelleted | Mono. | None | 3-way Degussa | 3-way TWC-9 |
| Test Dates | 10/23,11/6/75 | 10/28-29/75 | 10/7-8/75 | 11/6-7/75 | 10/2-3/75 | 11/18-19/75 | 10/6-7/75 | 10/28-29/75 |
| Percent S in Fuel | 0.030 | 0.030 | 0.030 | 0.0415 | 0.0415 | 0.23 | 0.0300 | 0.030 |
| **FTP** | | | | | | | | |
| mg/km | | | | | | | | |
| $H_2SO_4$ | 0.88 | 1.05 | 8.67 | 3.12 | 5.50 | 11.06 | 24.46 | 0.53 |
| $SO_2$ | 66 | 73 | 38 | 109 | 88 | 338 | 34 | 53 |
| Percent of Fuel S | | | | | | | | |
| $H_2SO_4$ | 0.70 | 0.73 | 8.38 | 1.41 | 2.40 | 2.05 | 27.99 | 0.58 |
| $SO_2$ | 81.53 | 76.10 | 57.81 | 74.07 | 58.33 | 96.32 | 61.26 | 90.82 |
| Total Recovery | 82.23 | 76.83 | 66.19 | 75.48 | 60.73 | 98.36 | 89.25 | 91.40 |
| SET-7 (8 tests per car) | | | | | | | | |
| mg/km | | | | | | | | |
| $H_2SO_4$ | 0.36 | 1.68 | 16.24 | 9.43 | 32.41 | 10.84 | 50.95 | 0.11 |
| $SO_2$ | 55.5 | 54.25 | 50 | 80 | 69 | 303 | 34 | 52 |
| Percent of fuel S | | | | | | | | |
| $H_2SO_4$ | 0.41 | 1.64 | 21.38 | 6.16 | 21.59 | 2.41 | 78.67 | 0.16 |
| $SO_2$ | 94.84 | 80.12 | 96.57 | 79.42 | 69.19 | 102.83 | 79.46 | 121.55 |
| Total Recovery | 95.25 | 81.75 | 115.60 | 85.57 | 93.57 | 105.24 | 156.26 | 121.71 |
| HWFET | | | | | | | | |
| mg/km | | | | | | | | |
| $H_2SO_4$ | 0.45 | 2.17 | 38.01 | 10.09 | 58.56 | 9.50 | 51.74 | 0.15 |
| $SO_2$ | 65 | 50 | 36 | 58 | 62 | 326 | 35 | 50 |
| Percent of fuel S | | | | | | | | |
| $H_2SO_4$ | 0.56 | 2.47 | 55.84 | 7.18 | 45.84 | 2.29 | 84.81 | 0.25 |
| $SO_2$ | 120.55 | 87.55 | 81.78 | 62.01 | 73.85 | 120.31 | 87.06 | 129.50 |
| Total Recovery | 121.11 | 90.02 | 137.62 | 69.19 | 119.68 | 122.60 | 171.87 | 129.75 |

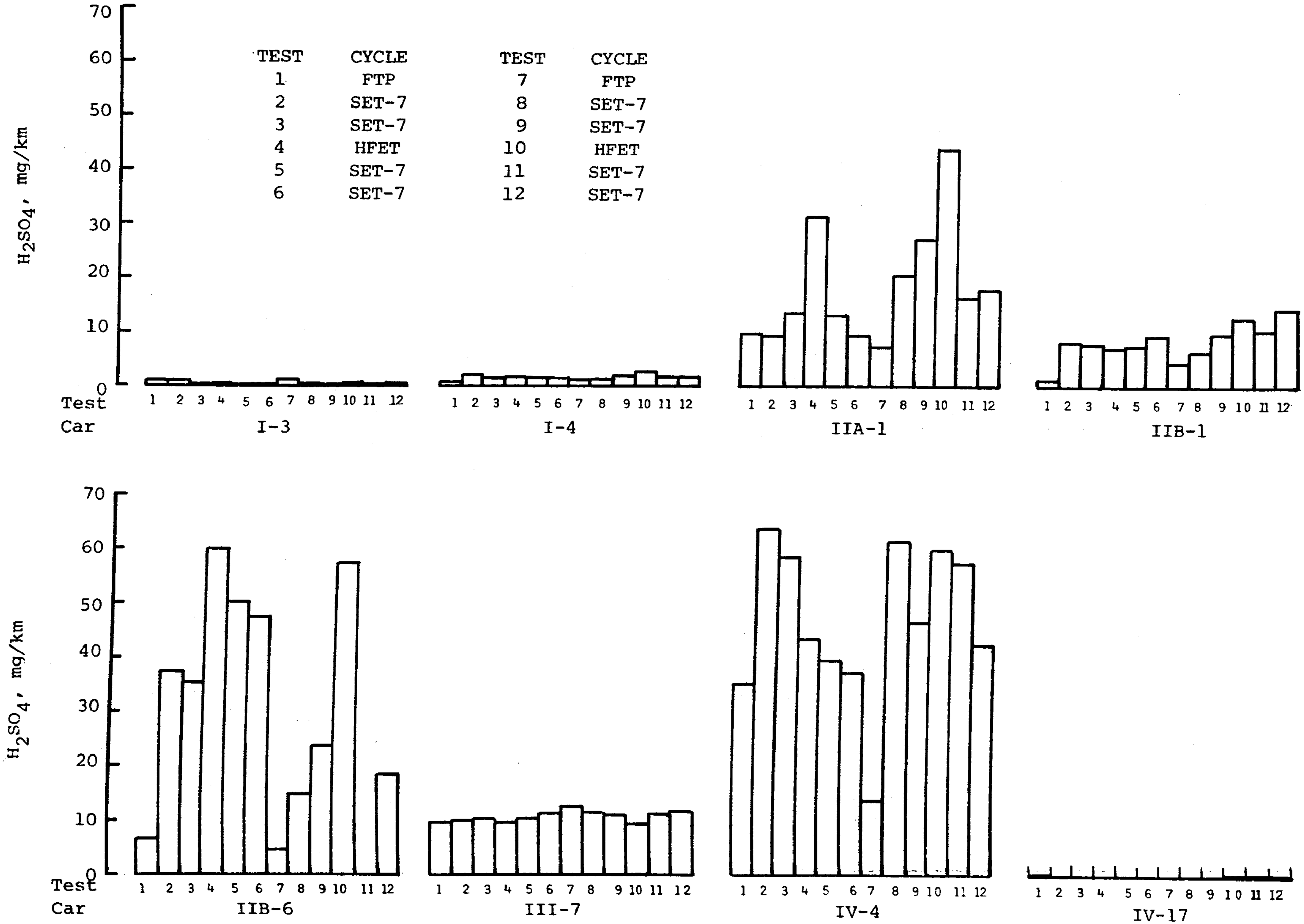



FIGURE 67. SULFATE EMISSIONS FOR BASELINE TEST SEQUENCE FROM EIGHT BASELINE CARS

cars with similar emissions systems are fully discussed in Section IV of this report.

The test results from car IV-4 are of interest since this car is a 197X Ford Pinto equipped with an experimental fuel injection system together with a Degussa three-way catalyst followed by an air injected oxidation catalyst. This system would appear to offer the possibility of high sulfate emissions. Examination of the data contained in Table J-6 shows this to be the case, with an average of 51 mg/km for the SET-7 tests. The total recovery indicates that a great deal of storage must take place at some operating conditions. The stored sulfur appears to have been given up during the SET-7 and FET tests, since the total recovery (which starts at almost 200 percent) decreased toward 100 percent with each successive SET-7 test.

It is interesting to compare the test results from car IV-4 and car IV-17 since these are both the same car but with different catalyst systems. Car IV-17 was equipped with an Engelhard TWC-9 three-way catalyst and no air injection. A comparison of both systems in Table 37 shows significantly lower sulfate emissions levels for the car with the TWC-9 catalyst; for example, 0.11 mg/km $H_2SO_4$ for the TWC-9 catalyst versus 50.95 mg/km $H_2SO_4$ for the Degussa catalyst car for an average SET-7. It has been shown in a tightly controlled fuel-air ratio near stocihometric produces almost no sulfates.[16] It is reasonable to conclude, therefore, that the high sulfate emissions from car IV-4 are probably due to the air injected-oxidation catalyst downstream of the three-way catalyst.

The diesel car was a special case. The diesel car tested converted approximately the same percentage of fuel sulfur to sulfates as did the non catalyst cars and non air-injected catalyst cars. However, because of the high level of sulfur in the diesel fuel (average of 0.23 versus 0.03 weight percent for gasoline used in most of the baseline) the sulfate emissions in mg/km were similar to the air-injected catalyst cars.

No attempt has been made to rank order the sulfate emissions of these cars or to otherwise statistically analyze the test results. Since this was only a small part of the total EPA baseline, it should be analyzed in the context of the results from all the baseline cars.

One general conclusion seems to be warranted however. It appears that noncatalyst cars produce the least sulfates and that air-injected catalyst cars, the most sulfates. The diesel seems to fall at the lower end of the air-injected catalyst range. The three-way catalyst alone appears to be capable to attaining sulfate emission levels as low as noncatalyst cars.

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# APPENDIX A

# SPEED VERSUS TIME LISTING OF SET-7

# DRIVING CYCLE

# EPA SULFATE 7 DRIVING CYCLE



CYCLE DIST = 13.51 MI
AVG SPEED = 34.78 MPH

| SEC | MPH | SEC | MPH | SEC | MPH | SEC | MPH |
|---|---|---|---|---|---|---|---|
| 0 | 0.0 | | | | | | |
| 1 | 0.0 | 51 | 23.10 | 101 | 29.10 | 151 | 20.00 |
| 2 | 0.0 | 52 | 24.50 | 102 | 28.70 | 152 | 19.80 |
| 3 | 0.0 | 53 | 26.00 | 103 | 29.60 | 153 | 20.00 |
| 4 | 0.0 | 54 | 27.60 | 104 | 30.30 | 154 | 19.60 |
| 5 | 0.0 | 55 | 28.80 | 105 | 30.70 | 155 | 18.10 |
| 6 | 0.0 | 56 | 29.60 | 106 | 30.00 | 156 | 15.70 |
| 7 | 0.0 | 57 | 31.50 | 107 | 29.40 | 157 | 12.60 |
| 8 | 0.0 | 58 | 32.50 | 108 | 27.80 | 158 | 10.30 |
| 9 | 0.0 | 59 | 32.50 | 109 | 25.60 | 159 | 10.00 |
| 10 | 0.0 | 60 | 31.20 | 110 | 25.00 | 160 | 9.50 |
| 11 | 1.60 | 61 | 29.50 | 111 | 25.00 | 161 | 9.70 |
| 12 | 4.50 | 62 | 29.10 | 112 | 24.80 | 162 | 10.00 |
| 13 | 7.20 | 63 | 29.40 | 113 | 23.50 | 163 | 10.00 |
| 14 | 9.70 | 64 | 30.80 | 114 | 23.00 | 164 | 10.00 |
| 15 | 11.70 | 65 | 30.80 | 115 | 23.00 | 165 | 10.00 |
| 16 | 13.30 | 66 | 30.80 | 116 | 23.60 | 166 | 10.50 |
| 17 | 14.30 | 67 | 30.70 | 117 | 24.00 | 167 | 11.80 |
| 18 | 14.90 | 68 | 30.70 | 118 | 25.00 | 168 | 13.60 |
| 19 | 15.00 | 69 | 30.70 | 119 | 26.30 | 169 | 15.20 |
| 20 | 15.70 | 70 | 29.70 | 120 | 27.30 | 170 | 16.80 |
| 21 | 16.20 | 71 | 28.80 | 121 | 28.30 | 171 | 18.40 |
| 22 | 15.40 | 72 | 27.20 | 122 | 29.30 | 172 | 19.60 |
| 23 | 14.70 | 73 | 25.00 | 123 | 29.90 | 173 | 20.00 |
| 24 | 14.70 | 74 | 22.50 | 124 | 30.40 | 174 | 20.20 |
| 25 | 15.00 | 75 | 20.50 | 125 | 31.90 | 175 | 20.00 |
| 26 | 15.00 | 76 | 19.30 | 126 | 32.40 | 176 | 19.80 |
| 27 | 14.90 | 77 | 19.30 | 127 | 32.40 | 177 | 20.00 |
| 28 | 13.90 | 78 | 19.50 | 128 | 32.00 | 178 | 19.50 |
| 29 | 11.60 | 79 | 20.70 | 129 | 31.60 | 179 | 18.20 |
| 30 | 10.00 | 80 | 21.30 | 130 | 31.00 | 180 | 16.20 |
| 31 | 10.00 | 81 | 20.60 | 131 | 29.60 | 181 | 13.50 |
| 32 | 10.00 | 82 | 20.10 | 132 | 28.90 | 182 | 10.90 |
| 33 | 10.00 | 83 | 20.00 | 133 | 27.80 | 183 | 10.00 |
| 34 | 10.70 | 84 | 20.30 | 134 | 26.30 | 184 | 10.00 |
| 35 | 12.20 | 85 | 20.10 | 135 | 24.40 | 185 | 9.70 |
| 36 | 13.50 | 86 | 20.00 | 136 | 22.10 | 186 | 10.00 |
| 37 | 14.50 | 87 | 20.40 | 137 | 19.70 | 187 | 10.30 |
| 38 | 14.80 | 88 | 21.10 | 138 | 17.40 | 188 | 10.30 |
| 39 | 15.00 | 89 | 22.20 | 139 | 15.80 | 189 | 10.00 |
| 40 | 15.20 | 90 | 23.40 | 140 | 15.00 | 190 | 10.10 |
| 41 | 15.50 | 91 | 24.50 | 141 | 15.00 | 191 | 10.60 |
| 42 | 15.00 | 92 | 25.50 | 142 | 15.00 | 192 | 11.60 |
| 43 | 15.00 | 93 | 26.60 | 143 | 15.10 | 193 | 12.90 |
| 44 | 15.20 | 94 | 27.70 | 144 | 16.10 | 194 | 14.00 |
| 45 | 15.10 | 95 | 28.70 | 145 | 17.40 | 195 | 15.10 |
| 46 | 15.80 | 96 | 29.50 | 146 | 18.60 | 196 | 16.20 |
| 47 | 17.00 | 97 | 30.80 | 147 | 19.70 | 197 | 17.30 |
| 48 | 18.60 | 98 | 30.60 | 148 | 20.00 | 198 | 18.40 |
| 49 | 20.20 | 99 | 30.40 | 149 | 20.50 | 199 | 19.30 |
| 50 | 21.60 | 100 | 29.90 | 150 | 20.00 | 200 | 19.90 |

| SEC | MPH | SEC | MPH | SEC | MPH | SEC | MPH |
|---|---|---|---|---|---|---|---|
| 201 | 20.00 | 251 | 56.00 | 301 | 46.00 | 351 | 51.10 |
| 202 | 20.00 | 252 | 56.50 | 302 | 46.90 | 352 | 50.20 |
| 203 | 20.00 | 253 | 56.50 | 303 | 48.00 | 353 | 49.80 |
| 204 | 20.40 | 254 | 56.30 | 304 | 49.00 | 354 | 49.50 |
| 205 | 21.40 | 255 | 56.00 | 305 | 49.90 | 355 | 49.50 |
| 206 | 22.70 | 256 | 55.50 | 306 | 50.90 | 356 | 49.40 |
| 207 | 24.60 | 257 | 55.20 | 307 | 51.90 | 357 | 49.60 |
| 208 | 26.50 | 258 | 55.00 | 308 | 52.90 | 358 | 49.80 |
| 209 | 28.20 | 259 | 54.80 | 309 | 53.80 | 359 | 50.00 |
| 210 | 29.80 | 260 | 54.50 | 310 | 54.50 | 360 | 50.00 |
| 211 | 31.50 | 261 | 54.20 | 311 | 54.90 | 361 | 50.20 |
| 212 | 33.20 | 262 | 53.90 | 312 | 55.20 | 362 | 50.40 |
| 213 | 34.90 | 263 | 54.00 | 313 | 55.00 | 363 | 50.30 |
| 214 | 36.70 | 264 | 54.50 | 314 | 54.70 | 364 | 50.00 |
| 215 | 38.20 | 265 | 54.50 | 315 | 54.30 | 365 | 49.70 |
| 216 | 39.30 | 266 | 52.80 | 316 | 53.50 | 366 | 49.00 |
| 217 | 40.00 | 267 | 50.40 | 317 | 53.00 | 367 | 47.80 |
| 218 | 40.70 | 268 | 50.00 | 318 | 52.70 | 368 | 46.20 |
| 219 | 41.00 | 269 | 49.60 | 319 | 53.30 | 369 | 44.00 |
| 220 | 41.00 | 270 | 49.70 | 320 | 53.70 | 370 | 41.00 |
| 221 | 41.00 | 271 | 50.00 | 321 | 53.70 | 371 | 38.00 |
| 222 | 41.00 | 272 | 50.50 | 322 | 53.70 | 372 | 34.70 |
| 223 | 40.00 | 273 | 50.30 | 323 | 54.50 | 373 | 31.40 |
| 224 | 39.50 | 274 | 50.00 | 324 | 55.00 | 374 | 28.10 |
| 225 | 39.30 | 275 | 49.30 | 325 | 55.00 | 375 | 24.80 |
| 226 | 39.60 | 276 | 47.80 | 326 | 55.20 | 376 | 21.80 |
| 227 | 39.90 | 277 | 45.30 | 327 | 55.40 | 377 | 20.50 |
| 228 | 40.00 | 278 | 42.30 | 328 | 55.50 | 378 | 20.00 |
| 229 | 40.40 | 279 | 40.20 | 329 | 55.60 | 379 | 20.00 |
| 230 | 41.20 | 280 | 40.00 | 330 | 55.60 | 380 | 20.00 |
| 231 | 42.20 | 281 | 39.80 | 331 | 55.50 | 381 | 19.70 |
| 232 | 43.60 | 282 | 39.70 | 332 | 55.40 | 382 | 18.50 |
| 233 | 44.90 | 283 | 40.00 | 333 | 55.30 | 383 | 16.30 |
| 234 | 46.20 | 284 | 40.20 | 334 | 55.30 | 384 | 13.20 |
| 235 | 47.40 | 285 | 40.50 | 335 | 55.30 | 385 | 10.60 |
| 236 | 48.60 | 286 | 42.40 | 336 | 55.60 | 386 | 10.00 |
| 237 | 49.80 | 287 | 44.20 | 337 | 55.90 | 387 | 10.00 |
| 238 | 51.00 | 288 | 45.00 | 338 | 56.10 | 388 | 9.90 |
| 239 | 52.30 | 289 | 45.50 | 339 | 56.10 | 389 | 9.60 |
| 240 | 53.40 | 290 | 45.20 | 340 | 56.10 | 390 | 8.90 |
| 241 | 54.30 | 291 | 45.40 | 341 | 56.10 | 391 | 7.90 |
| 242 | 54.90 | 292 | 45.00 | 342 | 55.90 | 392 | 6.70 |
| 243 | 55.30 | 293 | 45.00 | 343 | 55.60 | 393 | 5.60 |
| 244 | 55.50 | 294 | 44.80 | 344 | 55.30 | 394 | 5.00 |
| 245 | 55.50 | 295 | 44.00 | 345 | 55.10 | 395 | 4.80 |
| 246 | 55.00 | 296 | 43.80 | 346 | 54.90 | 396 | 4.30 |
| 247 | 55.00 | 297 | 43.50 | 347 | 54.70 | 397 | 4.00 |
| 248 | 55.00 | 298 | 44.10 | 348 | 54.10 | 398 | 4.50 |
| 249 | 55.00 | 299 | 44.60 | 349 | 53.30 | 399 | 5.00 |
| 250 | 55.00 | 300 | 45.30 | 350 | 52.20 | 400 | 5.00 |

| SEC | MPH | SEC | MPH | SEC | MPH | SEC | MPH |
|---|---|---|---|---|---|---|---|
| 401 | 5.00 | 451 | 7.80 | 501 | 9.40 | 551 | 32.30 |
| 402 | 5.00 | 452 | 10.20 | 502 | 9.00 | 552 | 29.80 |
| 403 | 5.40 | 453 | 12.10 | 503 | 7.10 | 553 | 26.80 |
| 404 | 7.20 | 454 | 13.50 | 504 | 5.20 | 554 | 23.50 |
| 405 | 9.00 | 455 | 14.50 | 505 | 5.00 | 555 | 20.20 |
| 406 | 9.80 | 456 | 15.20 | 506 | 5.00 | 556 | 17.00 |
| 407 | 9.70 | 457 | 15.00 | 507 | 5.00 | 557 | 14.00 |
| 408 | 9.50 | 458 | 14.80 | 508 | 5.00 | 558 | 11.00 |
| 409 | 9.20 | 459 | 14.80 | 509 | 5.00 | 559 | 9.80 |
| 410 | 9.30 | 460 | 14.80 | 510 | 5.00 | 560 | 9.60 |
| 411 | 9.50 | 461 | 14.80 | 511 | 5.00 | 561 | 9.50 |
| 412 | 9.90 | 462 | 15.00 | 512 | 5.00 | 562 | 9.50 |
| 413 | 10.20 | 463 | 15.10 | 513 | 5.00 | 563 | 9.50 |
| 414 | 10.40 | 464 | 15.20 | 514 | 4.40 | 564 | 9.50 |
| 415 | 10.70 | 465 | 15.30 | 515 | 3.00 | 565 | 9.60 |
| 416 | 12.10 | 466 | 15.30 | 516 | 1.00 | 566 | 9.90 |
| 417 | 13.50 | 467 | 16.70 | 517 | 0.0 | 567 | 10.40 |
| 418 | 14.70 | 468 | 18.80 | 518 | 0.0 | 568 | 11.40 |
| 419 | 15.00 | 469 | 20.70 | 519 | 0.0 | 569 | 12.50 |
| 420 | 15.00 | 470 | 22.60 | 520 | 0.0 | 570 | 13.50 |
| 421 | 15.20 | 471 | 24.30 | 521 | 0.0 | 571 | 14.50 |
| 422 | 15.00 | 472 | 24.50 | 522 | 0.0 | 572 | 15.20 |
| 423 | 14.70 | 473 | 24.80 | 523 | 0.0 | 573 | 15.60 |
| 424 | 15.00 | 474 | 25.00 | 524 | 0.0 | 574 | 15.80 |
| 425 | 15.00 | 475 | 25.40 | 525 | 0.0 | 575 | 15.50 |
| 426 | 15.10 | 476 | 26.00 | 526 | 0.0 | 576 | 15.50 |
| 427 | 16.20 | 477 | 26.20 | 527 | 0.0 | 577 | 15.30 |
| 428 | 17.60 | 478 | 26.10 | 528 | 0.50 | 578 | 15.50 |
| 429 | 18.90 | 479 | 25.50 | 529 | 3.30 | 579 | 15.00 |
| 430 | 19.90 | 480 | 25.20 | 530 | 6.30 | 580 | 14.30 |
| 431 | 20.00 | 481 | 25.00 | 531 | 9.40 | 581 | 11.30 |
| 432 | 20.00 | 482 | 24.30 | 532 | 12.70 | 582 | 8.00 |
| 433 | 20.00 | 483 | 22.60 | 533 | 16.00 | 583 | 5.00 |
| 434 | 20.00 | 484 | 19.60 | 534 | 19.30 | 584 | 5.00 |
| 435 | 19.80 | 485 | 16.40 | 535 | 22.60 | 585 | 5.00 |
| 436 | 18.80 | 486 | 13.10 | 536 | 25.90 | 586 | 5.00 |
| 437 | 16.80 | 487 | 10.20 | 537 | 29.00 | 587 | 5.00 |
| 438 | 13.80 | 488 | 9.70 | 538 | 32.00 | 588 | 5.10 |
| 439 | 10.50 | 489 | 9.40 | 539 | 34.50 | 589 | 6.10 |
| 440 | 7.20 | 490 | 9.00 | 540 | 35.50 | 590 | 7.40 |
| 441 | 4.50 | 491 | 8.80 | 541 | 35.30 | 591 | 8.60 |
| 442 | 1.80 | 492 | 8.50 | 542 | 35.30 | 592 | 9.70 |
| 443 | 0.0 | 493 | 8.10 | 543 | 35.30 | 593 | 10.00 |
| 444 | 0.0 | 494 | 8.40 | 544 | 35.30 | 594 | 10.20 |
| 445 | 0.0 | 495 | 8.80 | 545 | 35.20 | 595 | 10.10 |
| 446 | 0.0 | 496 | 9.10 | 546 | 35.10 | 596 | 9.90 |
| 447 | 0.0 | 497 | 9.00 | 547 | 35.00 | 597 | 9.80 |
| 448 | 0.20 | 498 | 8.90 | 548 | 35.00 | 598 | 9.80 |
| 449 | 2.20 | 499 | 8.90 | 549 | 34.80 | 599 | 9.90 |
| 450 | 5.00 | 500 | 9.50 | 550 | 33.90 | 600 | 9.90 |

EPA SULFATE 7 DRIVING CYCLE



| SEC | MPH | SEC | MPH | SEC | MPH | SEC | MPH |
|---|---|---|---|---|---|---|---|
| 601 | 9.30 | 651 | 20.00 | 701 | 41.00 | 751 | 56.00 |
| 602 | 8.00 | 652 | 19.80 | 702 | 42.40 | 752 | 56.00 |
| 603 | 6.30 | 653 | 19.70 | 703 | 43.80 | 753 | 56.00 |
| 604 | 5.00 | 654 | 19.70 | 704 | 44.90 | 754 | 55.50 |
| 605 | 5.00 | 655 | 19.90 | 705 | 45.10 | 755 | 55.00 |
| 606 | 5.20 | 656 | 19.90 | 706 | 45.40 | 756 | 55.00 |
| 607 | 5.40 | 657 | 20.00 | 707 | 46.10 | 757 | 55.00 |
| 608 | 5.10 | 658 | 20.20 | 708 | 46.70 | 758 | 55.00 |
| 609 | 5.00 | 659 | 20.00 | 709 | 47.10 | 759 | 54.70 |
| 610 | 5.90 | 660 | 20.80 | 710 | 47.10 | 760 | 54.80 |
| 611 | 8.10 | 661 | 22.10 | 711 | 47.00 | 761 | 55.00 |
| 612 | 10.20 | 662 | 24.00 | 712 | 46.30 | 762 | 55.00 |
| 613 | 12.30 | 663 | 26.40 | 713 | 45.60 | 763 | 54.90 |
| 614 | 14.30 | 664 | 28.70 | 714 | 45.20 | 764 | 54.50 |
| 615 | 15.30 | 665 | 30.80 | 715 | 44.90 | 765 | 53.70 |
| 616 | 16.00 | 666 | 32.90 | 716 | 45.00 | 766 | 52.60 |
| 617 | 16.60 | 667 | 35.00 | 717 | 45.10 | 767 | 51.30 |
| 618 | 16.50 | 668 | 37.10 | 718 | 45.40 | 768 | 50.30 |
| 619 | 16.00 | 669 | 39.30 | 719 | 45.80 | 769 | 49.70 |
| 620 | 16.10 | 670 | 41.50 | 720 | 46.80 | 770 | 49.50 |
| 621 | 15.80 | 671 | 43.20 | 721 | 48.10 | 771 | 49.20 |
| 622 | 15.20 | 672 | 44.40 | 722 | 49.20 | 772 | 48.90 |
| 623 | 14.90 | 673 | 45.00 | 723 | 50.30 | 773 | 48.70 |
| 624 | 15.10 | 674 | 45.30 | 724 | 51.50 | 774 | 48.50 |
| 625 | 15.10 | 675 | 45.60 | 725 | 52.60 | 775 | 48.70 |
| 626 | 14.90 | 676 | 45.80 | 726 | 53.70 | 776 | 48.80 |
| 627 | 14.50 | 677 | 45.70 | 727 | 54.60 | 777 | 48.90 |
| 628 | 13.60 | 678 | 45.10 | 728 | 55.00 | 778 | 50.00 |
| 629 | 12.30 | 679 | 44.50 | 729 | 55.40 | 779 | 50.10 |
| 630 | 10.80 | 680 | 44.00 | 730 | 55.80 | 780 | 50.30 |
| 631 | 10.00 | 681 | 43.90 | 731 | 55.90 | 781 | 50.30 |
| 632 | 10.10 | 682 | 44.10 | 732 | 56.50 | 782 | 50.00 |
| 633 | 10.60 | 683 | 44.60 | 733 | 57.00 | 783 | 50.00 |
| 634 | 10.90 | 684 | 45.00 | 734 | 57.00 | 784 | 50.20 |
| 635 | 10.80 | 685 | 45.10 | 735 | 57.00 | 785 | 50.10 |
| 636 | 9.90 | 686 | 45.00 | 736 | 56.70 | 786 | 50.20 |
| 637 | 9.20 | 687 | 44.90 | 737 | 55.80 | 787 | 50.60 |
| 638 | 9.70 | 688 | 44.30 | 738 | 54.90 | 788 | 51.20 |
| 639 | 10.00 | 689 | 43.30 | 739 | 54.20 | 789 | 51.90 |
| 640 | 10.40 | 690 | 41.90 | 740 | 53.80 | 790 | 52.50 |
| 641 | 11.30 | 691 | 40.50 | 741 | 53.30 | 791 | 53.10 |
| 642 | 12.70 | 692 | 39.80 | 742 | 52.80 | 792 | 53.80 |
| 643 | 14.00 | 693 | 39.70 | 743 | 52.70 | 793 | 54.40 |
| 644 | 15.20 | 694 | 40.00 | 744 | 53.00 | 794 | 54.80 |
| 645 | 16.50 | 695 | 40.00 | 745 | 54.00 | 795 | 55.00 |
| 646 | 17.80 | 696 | 40.00 | 746 | 55.00 | 796 | 55.50 |
| 647 | 19.00 | 697 | 40.00 | 747 | 55.80 | 797 | 55.70 |
| 648 | 19.80 | 698 | 40.00 | 748 | 55.90 | 798 | 56.00 |
| 649 | 20.20 | 699 | 40.10 | 749 | 55.90 | 799 | 56.30 |
| 650 | 20.10 | 700 | 40.30 | 750 | 56.00 | 800 | 56.50 |

# EPA SULFATE 7 DRIVING CYCLE



| SEC | MPH | SEC | MPH | SEC | MPH | SEC | MPH |
|---|---|---|---|---|---|---|---|
| 801 | 56.20 | 851 | 45.20 | 901 | 19.70 | 951 | 18.70 |
| 802 | 56.00 | 852 | 45.00 | 902 | 19.40 | 952 | 20.60 |
| 803 | 55.50 | 853 | 45.00 | 903 | 19.70 | 953 | 22.30 |
| 804 | 55.00 | 854 | 45.00 | 904 | 19.90 | 954 | 24.00 |
| 805 | 55.00 | 855 | 45.00 | 905 | 20.00 | 955 | 25.70 |
| 806 | 55.00 | 856 | 45.00 | 906 | 20.10 | 956 | 27.60 |
| 807 | 54.50 | 857 | 45.00 | 907 | 20.90 | 957 | 29.00 |
| 808 | 54.70 | 858 | 45.00 | 908 | 21.90 | 958 | 29.90 |
| 809 | 55.00 | 859 | 45.00 | 909 | 22.90 | 959 | 30.20 |
| 810 | 55.50 | 860 | 45.00 | 910 | 23.90 | 960 | 30.50 |
| 811 | 56.00 | 861 | 44.90 | 911 | 24.80 | 961 | 30.80 |
| 812 | 56.50 | 862 | 44.50 | 912 | 25.30 | 962 | 30.60 |
| 813 | 56.00 | 863 | 43.60 | 913 | 25.60 | 963 | 30.80 |
| 814 | 55.50 | 864 | 42.30 | 914 | 25.40 | 964 | 30.60 |
| 815 | 55.00 | 865 | 40.90 | 915 | 25.30 | 965 | 30.40 |
| 816 | 55.00 | 866 | 40.00 | 916 | 25.20 | 966 | 30.20 |
| 817 | 55.00 | 867 | 40.00 | 917 | 25.00 | 967 | 30.10 |
| 818 | 55.00 | 868 | 39.70 | 918 | 25.00 | 968 | 30.20 |
| 819 | 55.00 | 869 | 39.40 | 919 | 25.00 | 969 | 30.30 |
| 820 | 55.00 | 870 | 39.30 | 920 | 24.80 | 970 | 31.20 |
| 821 | 55.00 | 871 | 39.00 | 921 | 23.90 | 971 | 32.30 |
| 822 | 55.00 | 872 | 39.50 | 922 | 22.30 | 972 | 33.20 |
| 823 | 55.00 | 873 | 39.70 | 923 | 20.50 | 973 | 34.30 |
| 824 | 54.70 | 874 | 40.00 | 924 | 20.00 | 974 | 34.90 |
| 825 | 54.00 | 875 | 39.50 | 925 | 20.00 | 975 | 35.20 |
| 826 | 52.90 | 876 | 37.70 | 926 | 20.00 | 976 | 35.50 |
| 827 | 51.50 | 877 | 35.30 | 927 | 20.00 | 977 | 35.20 |
| 828 | 50.30 | 878 | 35.00 | 928 | 20.00 | 978 | 35.10 |
| 829 | 50.00 | 879 | 35.00 | 929 | 19.70 | 979 | 35.00 |
| 830 | 49.70 | 880 | 35.00 | 930 | 19.50 | 980 | 35.00 |
| 831 | 50.00 | 881 | 35.00 | 931 | 19.30 | 981 | 34.80 |
| 832 | 51.30 | 882 | 35.00 | 932 | 19.10 | 982 | 34.20 |
| 833 | 51.70 | 883 | 35.00 | 933 | 19.30 | 983 | 33.00 |
| 834 | 52.00 | 884 | 35.00 | 934 | 19.50 | 984 | 31.50 |
| 835 | 52.00 | 885 | 35.00 | 935 | 19.70 | 985 | 30.20 |
| 836 | 51.70 | 886 | 34.80 | 936 | 19.90 | 986 | 30.00 |
| 837 | 51.40 | 887 | 34.60 | 937 | 19.10 | 987 | 29.80 |
| 838 | 51.20 | 888 | 33.00 | 938 | 17.50 | 988 | 29.60 |
| 839 | 51.00 | 889 | 30.00 | 939 | 15.60 | 989 | 29.80 |
| 840 | 50.70 | 890 | 27.50 | 940 | 15.00 | 990 | 29.60 |
| 841 | 50.30 | 891 | 25.00 | 941 | 15.00 | 991 | 29.80 |
| 842 | 50.00 | 892 | 25.00 | 942 | 14.70 | 992 | 29.60 |
| 843 | 50.20 | 893 | 25.30 | 943 | 14.30 | 993 | 29.40 |
| 844 | 50.50 | 894 | 25.50 | 944 | 14.00 | 994 | 29.80 |
| 845 | 50.30 | 895 | 25.20 | 945 | 14.20 | 995 | 30.30 |
| 846 | 50.10 | 896 | 24.90 | 946 | 14.50 | 996 | 30.90 |
| 847 | 50.00 | 897 | 24.40 | 947 | 14.70 | 997 | 31.80 |
| 848 | 49.70 | 898 | 23.10 | 948 | 15.00 | 998 | 32.90 |
| 849 | 49.20 | 899 | 21.30 | 949 | 15.60 | 999 | 33.90 |
| 850 | 47.30 | 900 | 20.00 | 950 | 16.90 | 1000 | 34.90 |

| SEC | MPH | SEC | MPH | SEC | MPH | SEC | MPH |
|---|---|---|---|---|---|---|---|
| 1001 | 35.90 | 1051 | 40.70 | 1101 | 55.50 | 1151 | 52.90 |
| 1002 | 36.90 | 1052 | 40.80 | 1102 | 55.30 | 1152 | 53.60 |
| 1003 | 37.90 | 1053 | 40.90 | 1103 | 55.10 | 1153 | 54.30 |
| 1004 | 38.80 | 1054 | 40.70 | 1104 | 54.90 | 1154 | 54.80 |
| 1005 | 39.50 | 1055 | 40.50 | 1105 | 54.70 | 1155 | 55.20 |
| 1006 | 40.50 | 1056 | 40.70 | 1106 | 54.50 | 1156 | 55.50 |
| 1007 | 41.00 | 1057 | 40.80 | 1107 | 54.30 | 1157 | 55.70 |
| 1008 | 41.40 | 1058 | 40.60 | 1108 | 54.10 | 1158 | 55.90 |
| 1009 | 41.60 | 1059 | 40.80 | 1109 | 53.90 | 1159 | 56.00 |
| 1010 | 41.30 | 1060 | 40.80 | 1110 | 53.70 | 1160 | 56.10 |
| 1011 | 41.00 | 1061 | 40.90 | 1111 | 53.50 | 1161 | 55.90 |
| 1012 | 40.70 | 1062 | 42.50 | 1112 | 53.40 | 1162 | 55.80 |
| 1013 | 40.50 | 1063 | 44.00 | 1113 | 53.30 | 1163 | 55.60 |
| 1014 | 40.40 | 1064 | 45.00 | 1114 | 53.20 | 1164 | 55.40 |
| 1015 | 40.30 | 1065 | 45.00 | 1115 | 53.30 | 1165 | 55.20 |
| 1016 | 40.20 | 1066 | 45.50 | 1116 | 53.40 | 1166 | 55.10 |
| 1017 | 41.90 | 1067 | 46.00 | 1117 | 53.60 | 1167 | 55.20 |
| 1018 | 43.70 | 1068 | 46.30 | 1118 | 53.80 | 1168 | 55.30 |
| 1019 | 45.00 | 1069 | 46.60 | 1119 | 54.00 | 1169 | 55.20 |
| 1020 | 45.50 | 1070 | 46.30 | 1120 | 54.20 | 1170 | 55.10 |
| 1021 | 46.00 | 1071 | 46.00 | 1121 | 54.30 | 1171 | 55.10 |
| 1022 | 46.40 | 1072 | 45.70 | 1122 | 54.30 | 1172 | 55.00 |
| 1023 | 46.30 | 1073 | 45.40 | 1123 | 54.40 | 1173 | 55.00 |
| 1024 | 46.10 | 1074 | 45.10 | 1124 | 54.60 | 1174 | 55.00 |
| 1025 | 45.90 | 1075 | 44.90 | 1125 | 54.80 | 1175 | 54.90 |
| 1026 | 45.70 | 1076 | 44.70 | 1126 | 54.90 | 1176 | 54.70 |
| 1027 | 45.50 | 1077 | 44.50 | 1127 | 55.00 | 1177 | 54.50 |
| 1028 | 45.30 | 1078 | 44.30 | 1128 | 54.80 | 1178 | 54.60 |
| 1029 | 45.10 | 1079 | 44.50 | 1129 | 54.10 | 1179 | 54.60 |
| 1030 | 45.00 | 1080 | 44.60 | 1130 | 52.60 | 1180 | 54.70 |
| 1031 | 44.90 | 1081 | 44.80 | 1131 | 50.80 | 1181 | 54.80 |
| 1032 | 44.40 | 1082 | 45.00 | 1132 | 50.20 | 1182 | 54.90 |
| 1033 | 43.60 | 1083 | 45.00 | 1133 | 49.90 | 1183 | 54.80 |
| 1034 | 42.40 | 1084 | 45.10 | 1134 | 50.10 | 1184 | 54.70 |
| 1035 | 40.80 | 1085 | 45.80 | 1135 | 50.00 | 1185 | 54.60 |
| 1036 | 38.80 | 1086 | 47.00 | 1136 | 50.10 | 1186 | 54.70 |
| 1037 | 36.90 | 1087 | 48.40 | 1137 | 50.20 | 1187 | 54.70 |
| 1038 | 35.50 | 1088 | 49.60 | 1138 | 50.30 | 1188 | 54.80 |
| 1039 | 35.00 | 1089 | 50.90 | 1139 | 50.10 | 1189 | 54.70 |
| 1040 | 35.00 | 1090 | 52.10 | 1140 | 50.00 | 1190 | 54.60 |
| 1041 | 35.00 | 1091 | 53.40 | 1141 | 50.00 | 1191 | 54.70 |
| 1042 | 35.00 | 1092 | 54.40 | 1142 | 50.00 | 1192 | 55.00 |
| 1043 | 35.00 | 1093 | 55.00 | 1143 | 49.90 | 1193 | 55.00 |
| 1044 | 35.00 | 1094 | 55.50 | 1144 | 49.70 | 1194 | 55.00 |
| 1045 | 35.10 | 1095 | 56.00 | 1145 | 49.90 | 1195 | 55.00 |
| 1046 | 36.30 | 1096 | 56.30 | 1146 | 50.00 | 1196 | 54.90 |
| 1047 | 37.70 | 1097 | 56.50 | 1147 | 50.30 | 1197 | 54.50 |
| 1048 | 39.10 | 1098 | 56.30 | 1148 | 50.90 | 1198 | 53.80 |
| 1049 | 40.00 | 1099 | 56.00 | 1149 | 51.60 | 1199 | 52.70 |
| 1050 | 40.50 | 1100 | 55.30 | 1150 | 52.30 | 1200 | 51.40 |

# EPA SULFATE 7 DRIVING CYCLE



| SEC | MPH | SEC | MPH | SEC | MPH | SEC | MPH |
|---|---|---|---|---|---|---|---|
| 1201 | 50.40 | 1251 | 55.00 | 1301 | 49.20 | 1351 | 53.90 |
| 1202 | 49.80 | 1252 | 54.80 | 1302 | 49.00 | 1352 | 54.30 |
| 1203 | 49.00 | 1253 | 54.50 | 1303 | 49.20 | 1353 | 54.50 |
| 1204 | 48.30 | 1254 | 54.00 | 1304 | 49.10 | 1354 | 54.40 |
| 1205 | 48.00 | 1255 | 53.70 | 1305 | 49.10 | 1355 | 54.40 |
| 1206 | 47.90 | 1256 | 53.80 | 1306 | 49.10 | 1356 | 54.40 |
| 1207 | 48.00 | 1257 | 53.70 | 1307 | 49.60 | 1357 | 54.20 |
| 1208 | 48.30 | 1258 | 53.90 | 1308 | 49.90 | 1358 | 54.00 |
| 1209 | 48.30 | 1259 | 54.30 | 1309 | 50.30 | 1359 | 53.60 |
| 1210 | 48.30 | 1260 | 54.70 | 1310 | 51.10 | 1360 | 53.10 |
| 1211 | 48.30 | 1261 | 55.00 | 1311 | 51.90 | 1361 | 53.50 |
| 1212 | 48.70 | 1262 | 55.00 | 1312 | 52.70 | 1362 | 53.40 |
| 1213 | 50.10 | 1263 | 54.70 | 1313 | 53.60 | 1363 | 53.40 |
| 1214 | 50.30 | 1264 | 54.50 | 1314 | 54.40 | 1364 | 53.40 |
| 1215 | 50.40 | 1265 | 54.80 | 1315 | 54.90 | 1365 | 53.00 |
| 1216 | 50.40 | 1266 | 54.90 | 1316 | 55.10 | 1366 | 51.00 |
| 1217 | 50.10 | 1267 | 55.00 | 1317 | 55.30 | 1367 | 48.00 |
| 1218 | 49.90 | 1268 | 55.10 | 1318 | 55.70 | 1368 | 45.00 |
| 1219 | 50.00 | 1269 | 55.10 | 1319 | 56.00 | 1369 | 42.00 |
| 1220 | 50.00 | 1270 | 55.70 | 1320 | 56.20 | 1370 | 39.00 |
| 1221 | 50.00 | 1271 | 56.30 | 1321 | 56.00 | 1371 | 36.00 |
| 1222 | 50.20 | 1272 | 56.60 | 1322 | 55.50 | 1372 | 32.80 |
| 1223 | 50.50 | 1273 | 56.80 | 1323 | 55.70 | 1373 | 29.50 |
| 1224 | 50.90 | 1274 | 56.50 | 1324 | 55.70 | 1374 | 26.20 |
| 1225 | 51.00 | 1275 | 56.10 | 1325 | 55.70 | 1375 | 22.90 |
| 1226 | 50.70 | 1276 | 55.70 | 1326 | 55.70 | 1376 | 19.60 |
| 1227 | 50.90 | 1277 | 55.60 | 1327 | 55.50 | 1377 | 16.60 |
| 1228 | 50.80 | 1278 | 55.60 | 1328 | 55.70 | 1378 | 14.00 |
| 1229 | 51.60 | 1279 | 55.60 | 1329 | 55.90 | 1379 | 12.00 |
| 1230 | 52.30 | 1280 | 55.30 | 1330 | 56.20 | 1380 | 11.00 |
| 1231 | 53.00 | 1281 | 55.00 | 1331 | 56.60 | 1381 | 10.00 |
| 1232 | 53.70 | 1282 | 54.90 | 1332 | 56.70 | 1382 | 10.00 |
| 1233 | 54.40 | 1283 | 54.60 | 1333 | 56.30 | 1383 | 10.00 |
| 1234 | 54.90 | 1284 | 54.10 | 1334 | 56.00 | 1384 | 8.80 |
| 1235 | 55.10 | 1285 | 53.30 | 1335 | 56.00 | 1385 | 6.70 |
| 1236 | 55.40 | 1286 | 52.30 | 1336 | 55.80 | 1386 | 4.60 |
| 1237 | 56.10 | 1287 | 51.20 | 1337 | 55.70 | 1387 | 2.50 |
| 1238 | 56.30 | 1288 | 50.40 | 1338 | 55.50 | 1388 | 1.50 |
| 1239 | 56.30 | 1289 | 50.00 | 1339 | 55.30 | 1389 | 0.90 |
| 1240 | 56.10 | 1290 | 49.70 | 1340 | 55.00 | 1390 | 0.0 |
| 1241 | 56.20 | 1291 | 49.50 | 1341 | 55.20 | 1391 | 0.0 |
| 1242 | 56.30 | 1292 | 49.00 | 1342 | 55.30 | 1392 | 0.0 |
| 1243 | 56.00 | 1293 | 48.30 | 1343 | 55.20 | 1393 | 0.0 |
| 1244 | 56.00 | 1294 | 47.80 | 1344 | 55.20 | 1394 | 0.0 |
| 1245 | 55.70 | 1295 | 48.00 | 1345 | 55.00 | 1395 | 0.0 |
| 1246 | 55.20 | 1296 | 48.20 | 1346 | 54.80 | 1396 | 0.0 |
| 1247 | 55.00 | 1297 | 48.20 | 1347 | 54.70 | 1397 | 0.0 |
| 1248 | 55.00 | 1298 | 48.30 | 1348 | 54.50 | 1398 | 0.0 |
| 1249 | 55.10 | 1299 | 48.70 | 1349 | 54.00 | | |
| 1250 | 55.20 | 1300 | 49.40 | 1350 | 53.60 | | |

# APPENDIX B

# BCA-SULFATE PROCEDURE AND INTERFERENCE CHECKS

# DETERMINATION OF SOLUBLE SULFATES: BARIUM CHLORANILATE METHOD

(Adapted from a procedure supplied to SwRI by EPA, ORD developed by Dr. L. Teajeda, EPA, RTP, March, '74.)*

## 1. Principle and Applicability

1.1 This method is for the determination of watersoluble sulfates from diluted automobile exhausts collected on Fluoropore filters. This method is quite general and may be used for trace sulfate analysis of any sample from which sulfates can be leached out with water or aqueous alcoholic solutions. There are interferences from some anions and methods for minimizing or eliminating these are still being worked out. The method as written is applicable to sulfate analysis of exhaust emissions from cars run on non-leaded gasoline.

1.2 Auto exhaust is mixed with air in a dilution tunnel and sampled through isokinetic probes. $SO_3$ reacts with available moisture in the exhaust to form $H_2SO_4$ aerosols and is trapped on Fluoropore** filters with 0.50 micron pore size. The sulfate is extracted from the filter with 60/40 isopropyl alcohol/water solution (i.e. 60 ml isopropyl alcohol (IPA) + 40 ml water). The extract is fed by a high pressure liquid (chromatographic) pump through a column of cation exchange resin to remove cationic interferences and then through a column of solid barium chloranilate where $BaSO_4$ precipitates out. An equivalent amount of reddish colored acid chloranilate ion is released[1,2] and is measured colorimetrically at 310 nm[3,4]. To use this method for aqueous sulfate solutions, four parts by volume of the solution are mixed with six parts of IPA before feeding through the columns. Manual method or a dynamic sampling system can be used.

## 2. Range and Sensitivity

Working concentration range and sensitivity depend on sample size. A sensitivity better than 0.5 $\mu g$ $SO_4^=$ per ml in 60% IPA and working range of 0-25$\mu$g/ml were obtained using a 0.5 ml external sampling loop injection system in conjunction with a du Pont liquid chromatograph UV detector. Sensitivity may be further increased by increasing the alcohol content of the solvent, as this would further decrease the solubility of $BaSO_4$ and barium chloranilate. This, however, requires a much tighter control of the water/IPA ratio in the sample and in the mobile phase. To minimize spurious results arising from water imbalance, it is recommended that both the extracting solvent and the mobile phase for analytical runs be taken from the same stock solution. Sample size as large as 1.5 ml has been successfully used.

* The reader is advised to obtain the most recent version of the EPA BCA method from EPA, Ann Arbor, Michigan.

**Registered trade mark. Obtainable from Millipore Corp., Bedford, Mass.

3. Interferences

Cations interfere negatively by reacting with the acid chloranilate to form insoluble salts. These, however, are conveniently removed by passing the sample through a cation exchange resin in the hydrogen form. Some anions such as $Cl^-$, $Br^-$, $F^-$, $PO_4^{=}$ interfere positively by precipitating out as barium salts with subsequent release of acid chloranilate ions. Some buffer systems[2-5] are reported to minimize anion interference. These systems are being investigated for possible incorporation in the present procedure. Alternative clean-up methods are also under consideration. Fortunately, for non-leaded exhaust samples collected on filters, ionic interference is minimal. Interference from aromatic compounds is minimized by using a 300 nm cut-off filter in the optical path of the detector system or by using a spectrophotometer with narrow (i.e. 2.0nm) slit width.

4. Stability

4.1 Sulfuric acid standards containing 10 and 100 $\mu$g $SO_4^{=}$/ml in 60% IPA are stable for at least one month when stored in tightly capped volumetric flask which has been cleaned with 1:1 nitric acid and copiously rinsed with deionized water. Alternative storage containers are capped polyethylene reagent bottles.

4.2 For samples known to contain cations, it is advisable to remove these cations by external treatment with cation exchange resin prior to injection into the sampling loop.

4.3 As the barium chloranilate column is depleted each time sulfate samples are fed through, it is good practice to run sulfuric acid standards before and after the sample.

4.4 Exposure of alcoholic samples, standards, and solvents to the atmosphere should be minimized, since IPA solution picks up atmospheric water on standing.

5. Apparatus

A schematic of the principal components of the set-up is shown in Figure B-1.

5.1 Hardware

a. Reservoir (LR) for the solvent (60% IPA).
b. High pressure (HPS) capable for delivery liquid at flow rates of up to 3 ml/min at pressures as high as 1000 psi.

c. Flow or pressure controller (FC).

d. High pressure switching valve (SV) equipped with interchangeable external loop (L).

e. Ultraviolet detector (D) equipped with appropriate filters to isolate a narrow band of radiation centered at 310 nm.

f. Recorder to monitor detector response.

g. Cation exchange resin column (CX) - standard 1/4" O.D. x 10" stainless steel column packed with analytical grade Dowex 50W-X2 cation exchange resin in hydrogen form.

h. Barium chloranilate column (BC) - standard 1/4" O.D. x 5" stainless steel column packed with barium chloranilate.

5.2 Principle of Operation

Solvent (60% IPA) in reservoir (LR) is continuously fed through cation exchange (CX) and barium chloranilate columns at flow rates of about 3 ml/min. by a high pressure source (HPS). Background absorbance is continuously measured by a UV detector (D) at 310 nm and visually monitored on a strip chart recorder. A switching valve (SV) is used for filling the external sampling loop (L) with samples injecting the sample into the columns. Samples may be introduced into the sampling loop by syringe injection. At CX cations are removed and at BC, color reaction takes place. The $BaSO_4$ precipitate is retained in the column while the acid chloranilate is carried by the solvent through the detector system for colorimetric measurement.

For manual operation SV may be retained or replaced by a similar switching valve equipped with an extended handle for manual switching.

6. <u>Reagents</u>

6.1 Isopropyl alcohol (IPA) spectroquality grade or equivalent. Volatile solvent, safety class 1B.

6.2 60% IPA. Add four parts water to six parts IPA by volume. Store in tightly capped bottle. About three liters are needed for a 12 hour operation.

6.3 Barium chloranilate, suitable for sulfate analysis.

6.4 Dowex 50W-X2 cation exchange resin, hydrogen form, 100-200 mesh.

6.5 Hydrochloric acid (4N). Add 30 ml concentrated hydrochloric acid to 60 ml deionized water. (Danger, strong acid)

6.6 Standard sulfuric acid (1N). Dilute to the mark 2.8 ml of concentrated sulfuric acid with deionized distilled water in a liter volumetric flask which has been washed in 1:1 nitric acid and copiously rainsed with deionized distilled water. Standardized against accurately weighed sodium carbonate to get exact normality. 0.1N $H_2SO_4$ is equivalent to 4800 $\mu g/SO_4^=/ml$. (Danger, strong acid.)

6.7 Standard sulfate solution (1000 $\mu$g $SO_4^{=}$/ml). Dissolve 1.4787 gm sodium sulfate which has been heated up to 105°C for four hours and cooled in a dessicator and dilute to 1000 ml.

7. Procedure

7.1 Column preparation

7.1.1 Barium chloranilate column (BC). In order to prepare a full column with minimum dead volume connect two lengths of standard 1/4" O.D. stainless steel tubings as shown in Figure 2. b = 2", a = 5". Connect a small funnel to open end of B with a Tygon tubing sleeve. Fill the funnel half way with barium chloranilate and use a vibrator (i.e. electric pencil engraver) to pack the solid in column. Continue operation until B is about half filled. Remove funnel, plug empty space with glass wool, and cap the end with a 1/4" to 1/16" reducer. Plumb column B directly to SV in Figure B-1. Connect a Tygon tubing at A and direct tubing to waste reservoir. Activate liquid pump, set flow controller at pressure drop of about 600 psi. Let solvent flow for 20 minutes. Deactivate pump, disconnect column A from column B. Connect a glass wool plugged 1/4" to 1/16" reducer to uncapped end of column A.

7.1.2 Cation exchange resin column (CX). Add cation exchange resin, 100-200 mesh, Dowex 50W-X2 to 80 ml of 4N HCl in a 150 ml beaker until a wet volume equivalent to 20 ml has settled at the bottom. Let soak for at least three hours with occasional stirring using a glass rod. Decant the acid, add 100 ml deionized distilled water, stir and slowly decant the liquid as soon as most of the solid has settled down at the bottom. Repeat rinsing procedure several times until rinse liquid gives a neutral reaction to pH paper.

Connect two standard 1/4" O.D. stainless steel tubings as in 7.1.1 with b = 5" and a = 10". Connect a small funnel to open end of B with Teflon or Tygon tubing sleeve. Clamp composite tube vertically and connect open end of A to vacuum line equipped with liquid trap. Fill funnel with deionized distilled water and turn on vacuum slowly until composite tube is completely filled with water. Add water until funnel is half-filled, stop vacuum and add slurry of freshly washed resin. Let resin settle by gravity until resin top is seen above B. Turn on vacuum slowly, keep adding resin slurry until composite tube is completely filled. Proceed as in 7.1.1 beginning with sentence: "Remove funnel, plug empty space . . ."

7.2 Priming System for Analytical Run

Connect the cation exchange and barium chloranilate columns with 1/4" union packed with glass wool as shown in Figure 1. Fill solvent reservoir (LR) with 60% IPA, activate liquid pump, detector, recorder, switching valve, sampler, and peristalic pump. Allow to cycle normally to clean out all components. For this initial operation, dip the sampling probe in at least 100 ml of 60% IPA. Set liquid flow rate at about 3 ml/min. Let run for at least 30 minutes. Deactivate switching valve, sampler, and peristaltic pump. Leave other components in operating mode. When background is stable at attenuation of .01 absorbance units full scale, system is ready for analysis.

7.3 Preparation of Calibration Standards

Either sulfuric acid or sodium sulfate standards may be used. Add 200 ml of 0.1 N $H_2SO_4$ aqueous stock solution to 300 ml 100% IPA in 500 ml volumetric flask. (Note: There is a volume decrease of about 2.7% when these proportions of water and IPA are mixed.) Dilute to the mark with 60% IPA. This is equivalent to 1,920 g $SO_4^=$/ml in 60% IPA. Prepare from this alcoholic stock solution calibration standards in the range of 0.5-25 g $SO_4^=$/ml by dilution of appropriate aliquots with 60% IPA.

7.4 Extraction of Soluble Sulfates from Fluoropore Filters Place filter in one oz. polyethylene bottle, add 10 ml 60% IPA and cap tightly. Shake until filter collapses and is completely immersed in liquid. Let stand overnight.

7.5 Analysis

Set Instrument in operating mode, remove sampling probe from holder, and dip in 100 ml 60% IPA. Let it run at flow rate of 3 ml/min until stable background is obtained, then remount sampling probe to holder. In the meantime, fill sample cuvettes with sample extract and blank solutions (60% IPA) and place on turntable. Sampling pattern is blank, blank, samplg, blank, blank at the rate of about six minutes per sample or blank. Blanks are used to wash out system between samples and minimize sample overlap. One blank between samples is adequate for dilute samples. (See also 5.2.) A series of standards (see 7.3) is run, preferably before sample runs and calibration curve, area vs. concentration, is plotted. A control standard may also be placed after every ten samples as a quality check on the stability of the system.

8. <u>Calculations</u>

Calculate the concentration of sulfate as $\mu g\ SO_4^=$ /ml using the calibration curve. Total soluble sulfates $SO_4^={}_F$ in filter is then given by:

$$SO_4^={}_F = (\mu g\ SO_4^=/m) \times V_o \times d$$

where: $V_o$ = total volume of original sample extract

$d$ = dilution factor

Example: Suppose 10 ml 60% IPA was used to extract the soluble sulfates in the filter and that 2 ml of this was diluted further to 6 ml with 60% IPA to bring detector response within calibration range. Suppose that the concentration of the diluted sample was found to be 5 $\mu$g/ml. Then,

$$SO_4^{=}\ _F = (5\,\mu g/ml) \times 10\ ml \times \frac{6}{2} = 150\,\mu g.$$

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5. M. E. Gales, Jr., W. H. Kaylor and J. E. Longbotton, "Determination of Sulfate by Automatic Colorimetric Analysis, " Analyst 93, 97 (1968).

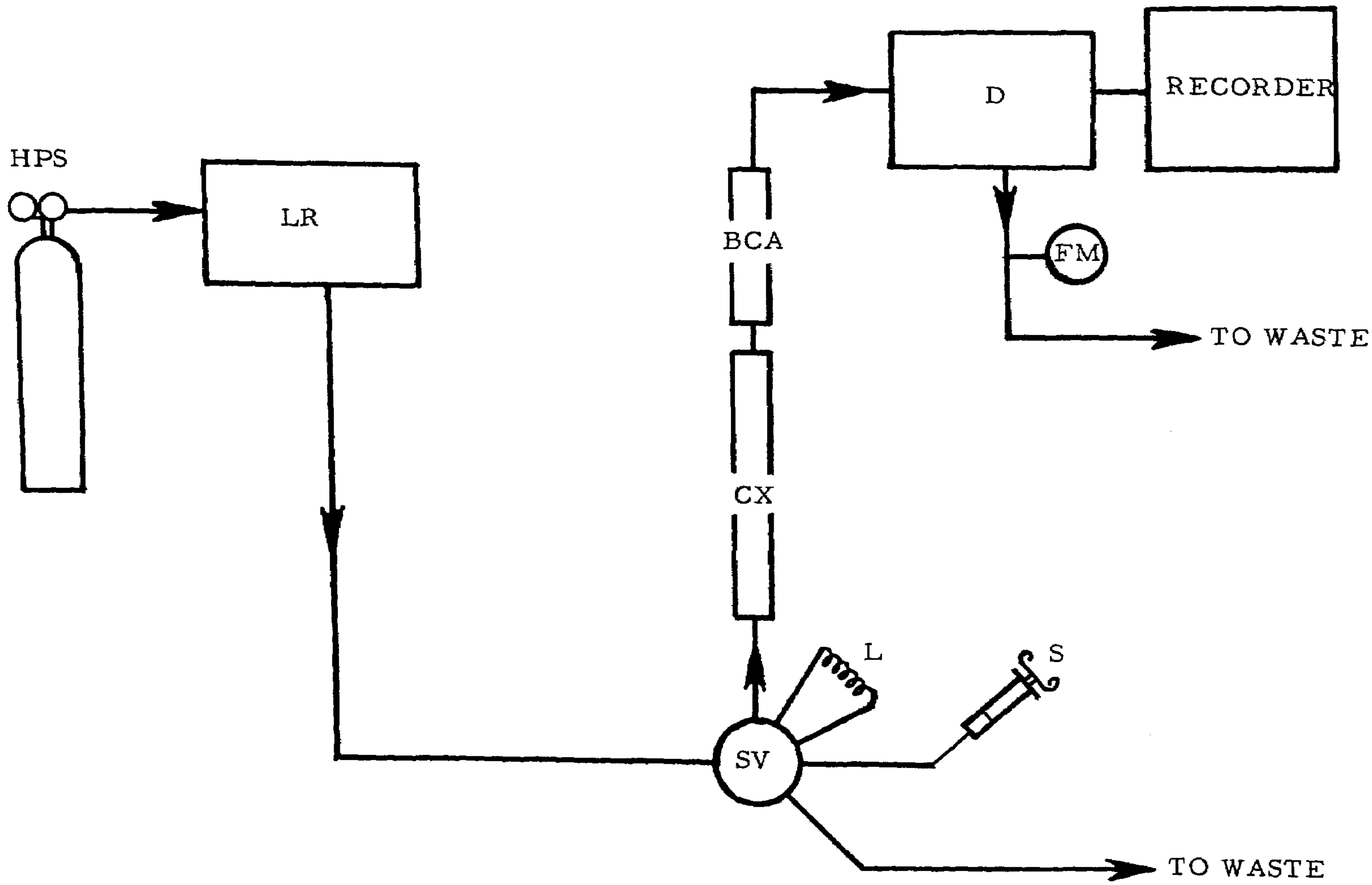



FIGURE B-1. FLOW SCHEMATIC FOR AUTOMATED SULFATE INSTRUMENT

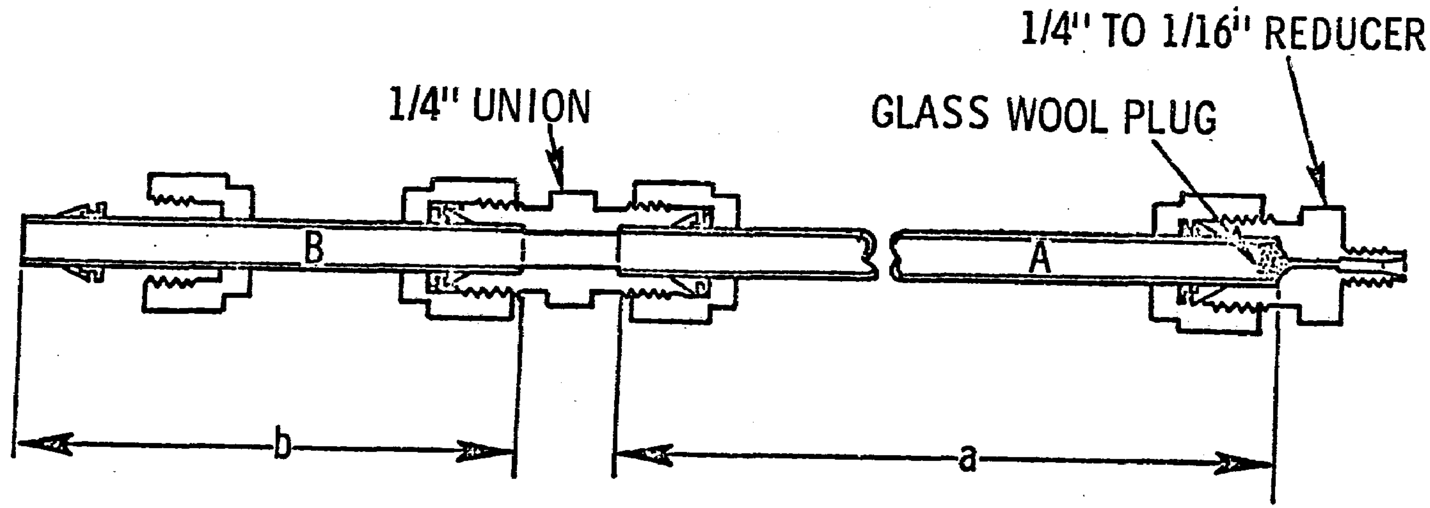



FIGURE B-2. CONFIGURATION FOR LOADING COLUMN

RESULTS OF STUDIES OF INTERFERENCES
IN BCA SULFATE PROCEDURE
PERFORMED AT SwRI DURING NOVEMBER, 1974

Although a cation exchange column is included as part of the sampling system, concern has been expressed for the analysis of sulfate on engines operating on leaded fuel. The Dowex 50W X-2 cation exchange column has been included to eliminate, or at least reduce, any lead that might be collected on the filters for sulfate analysis. Since the efficiency of the cation exchange column may not remove all of the lead ions it was decided to conduct a series of experiments to determine how much interference from lead might be expected. These experiments were conducted with an ion exchange column, which had been used for about one month on lead free samples.

A working sulfate standard of 23.93$\mu$g $SO_4^=$/ml was used to make comparisons with the various lead blends. Lead nitrate blends were prepared in 60 percent IPA in concentrations of 25.0, 12.5, and 5.0$\mu$g $Pb^{++}$/ml. These solutions were analyzed in the same manner as an extracted sample and the corresponding peak was calculated as response as $\mu$g $SO_4^=$/ml with $Pb^{++}$ concentrations ranging from 25 to 5$\mu$g $Pb^{++}$/ml. It was apparent that not all of the lead is being removed by the ion exchange column.

Since lead is generally added to the fuel in the form of a motor mix containing ethylene dichloride and ethylene dibromide as scavengers, it was decided to determine if these will produce erroneous results. The first experiment involved the preparation of three concentrations of chloride in 60 percent IPA. Sodium chloride was used in the preparation of the 24.3, 12.1 and 4.8$\mu$g $Cl^-$/ml. Again, these blends were analyzed just as a normal sulfate sample and the corresponding peak calculated as response as$\mu$g/$SO_4^=$/ml. These results are found in Table 1 and $\mu$g Cl/ml as a function of response as $\mu$g $SO_4^=$/ml is shown in Figure 1. The response as $\mu$g $SO_4^=$/ml varied from 7.1 to 2.1 with a range in $\mu$g $Cl^-$/ml of 24.3 to 5.0. In comparison with the experiment in lead interference, it was found that the chloride ions produced some 4 - 6 time greater interference than the lead ions alone.

A similar experiment involving the interference of bromide ions was conducted, Sodium bromide was added to 60 percent IPA in concentrations 31.1,15.5 and 6.2  g $Br^-$/ml. These blends were also analyzed according to the standard barium chloranilate procedure. The range of response as $\mu$g $SO_4^=$/ml was from 5.1 to 1.9 for the concentrations of $Br^-$tested.

Of the three interference species evaluated, it appears that with the normal barium chloranilate procedure, lead has the least interference and chloride the greatest. A nominal 15 $\mu$g $Pb^{++}$/ml concentration produced a response as one $\mu$g $SO_4^{=}$/ml. A bromide concentration of 3-6 $\mu$g $Br^{-}$/ml provide an equivalent response to one $\mu$g $SO_4^{=}$/ml. The chloride ion concentration required to give a response as $\mu$g $SO_4^{=}$/ml ranged from 2-3 g $Cl^{-}$/ml.

TABLE B-1. EFFECT OF LEAD CHLORIDE AND BROMIDE IONS ON SULFATE RESULTS USING THE BARIUM CHLORANILATE LIQUID CHROMATOGRAPH PROCEDURE

| | Sample Description | Response as $\mu g\ SO_4^{=}/ml$ | Response Ratio $\mu g\ Pb^{++}/ml$: $\mu g\ SO_4^{+}/ml$ |
|---|---|---|---|
| | 23.93 $\mu g\ SO_4^{=}/ml$ | 23.93 | |
| | 25.0 $\mu g\ Pb^{++}/ml$ | 1.71 | 14.6 |
| | 12.5 $\mu g\ Pb^{++}/ml$ | 0.66 | 18.9 |
| | 5.0 $\mu g\ Pb^{++}/ml$ | 0.33 | 15.1 |
| | 24.3 $\mu g\ Cl^{-}/ml$ | 7.06 | 3.4 |
| * | 12.1 $\mu g\ Cl^{-}/ml$ | 4.23 | 2.9 |
| | 4.8 $\mu g\ Cl^{-}/ml$ | 2.12 | 2.3 |
| | 31.1 $\mu g\ Br^{-}/ml$ | 5.07 | 6.1 |
| * | 15.5 $\mu g\ Br^{-}/ml$ | 4.04 | 3.8 |
| | 6.2 $\mu g\ Br^{-}/ml$ | 1.92 | 3.2 |

* These are reasonable levels of Cl and Br that might be expected from leaded fuel tests.

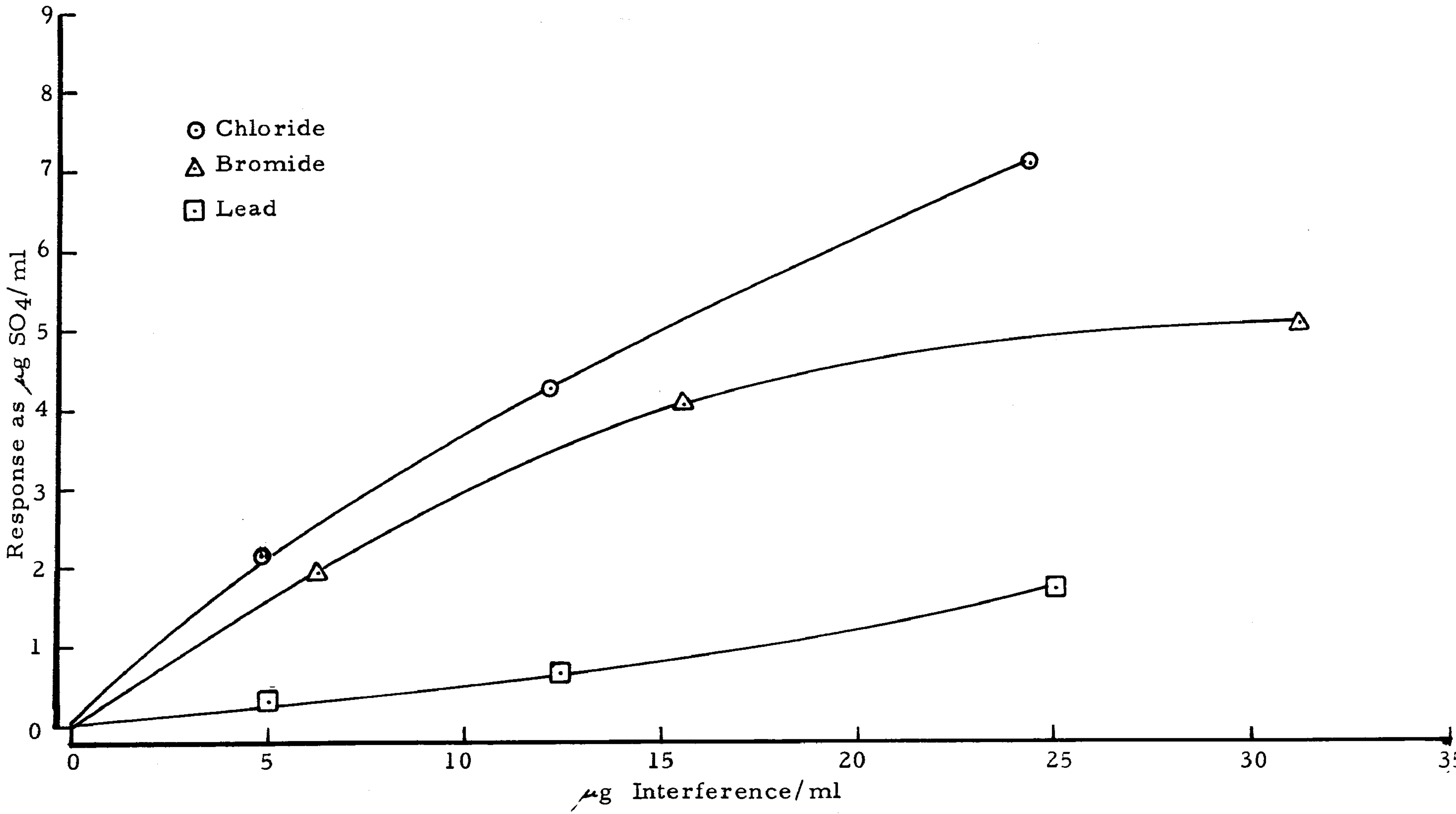



FIGURE B-3. THE EFFECT OF LEAD, CHLORIDE AND BROMIDE INTERFERENCES IN THE BARIUM CHLORANILATE PROCEDURE

# APPENDIX C

# SUMMARY OF PULSED FLUORESCENCE ANALYZER INTERFERENCE CHECKS AND EXHAUST RECOVERY TESTS

## MODEL 40 PULSED FLUORESCENT $SO_2$ ANALYZER INTERFERENCES

The use of the TECO-Model 40 pulsed fluorescent $SO_2$ analyzer in the presence of other exhaust gas components could cause potential interference problems. The intended use of this instrument will be in sampling CVS exhaust on a continuous basis. Since the exhaust will be essentially an air-based sample, the experiments described are orientated toward this particular application.

### CO and $CO_2$ Interferences

Initial CO and $CO_2$ interference checks were conducted using a single bottle cart containing eight golden standards named by EPA Ann Arbor. This group of bottles contained multi-component blends as well as single component mixtures. All eight bottles contained nitrogen as a balance gas. The first set of data was obtained using standard regulators with neophrene diaphragms and teflon tubing. The results of these tests are found in Table C-1. Response as $SO_2$ ranged

TABLE C-1. MULTICOMPONENT BLENDS OF CO AND $CO_2/N_2$ RESPONSE AS $SO_2$ IN MODEL 40 PULSED FLUORESCENT ANALYZER (NORMAL NEOPHRENE DIAPHRAGM REGULATOR)

| Test | Concentration, %* CO | $CO_2$ | Response as ppm $SO_2$ |
|---|---|---|---|
| 1 | 9.58 | 5.70 | 15.5 |
| 2 | - | 14.16 | 10.3 |
| 3 | - | 12.36 | 16.0 |
| 4 | - | 11.22 | 16.5 |
| 5 | 5.39 | 10.46 | 17.5 |
| 6 | 2.79 | 13.18 | 17.0 |
| 7 | 1.39 | - | 16.5 |
| 8 | 0.48 | 15.23 | 17.5 |

*balance gas $N_2$

from 10.3 to 17.5 ppm with no apparent correlation for response as ppm $SO_2$ and interference concentration. The CO concentrations varied from 0.48 to 9.58 percent, while the $CO_2$ values ranged from 5.7 to 15.23 percent.

Since it was obvious that something other than a straightforward single compound interference was involved, additional experiments to determine the extent of other variables that might lead to apparent interferences were conducted. The first such variable checked was the effect of regulator diaphragm type on the response as ppm $SO_2$. Since other data was previously run and substantial data available for neophrene regulator diaphragms, it was decided to investigate the response of several of the previously tested bottles using metal diaphragm regulators like those used for hydrocarbon span gases. The results of this experiment are found in Table C-2. Although it is difficult to make any definite conclusions, it was observed that the response as ppm $SO_2$ for these same three $CO/CO_2$ bottles was 2.5 to 3.0 ppm less for the metal diaphragm.

TABLE C-2. MULTICOMPONENT BLENDS OF CO AND $CO_2/N_2$ RESPONSE AS $SO_2$ IN MODEL 40 PULSED FLUORESCENT ANALYZER (METAL DIAPHRAGM REGULATOR)

| | Concentration, %* | | Response as |
|---|---|---|---|
| Test | CO | $CO_2$ | ppm $SO_2$ |
| 1 | 9.58 | 5.70 | 13.0 |
| 2 | 5.39 | 10.46 | 14.5 |
| 3 | 0.48 | 15.23 | 15.0 |

*balance gas $N_2$

The next item checked was $CO_2$ in balance zero air. A clean Tedlar bag was prepared with a double end shut off quick connect and filled with zero air. The bag sample was then analyzed in the Model 40 $SO_2$ instrument and no response was observed. The bag was then doped with some pure $CO_2$ to give a $CO_2$ concentration of about 13 percent. The bag was then run in the $SO_2$ instrument and still no response was observed. As a result of this experiment, it was obvious that $CO_2$ alone could not be considered to be an interference compound; however, in conjunction with other species could present interference problems. At this point, two facts were apparent; first, $CO_2/N$ blends gave 10-16 ppm $SO_2$ response and secondly, $CO_2$/Air blends gave no response.

To determine the extent of the $CO_2/N_2$ interference, additional experiments were conducted. The availability of a range of $O_2/N_2$ blends was used to narrow down this problem. The bottles were $N_2$ zero gas, 5 percent $O_2$/95 percent $N_2$, 10 percent $O_2$/90 percent $N_2$, 15 percent $O_2$/85 percent $N_2$, and 20 percent $O_2/N_2$. Several fresh bags were prepared and each blend was analyzed for response as ppm $SO_2$. Then each bag was doped with pure $CO_2$ to a level of about 10 percent. These bags were then run and the results of these tests are found in Table C-3.

It was apparent that by running the oxygen-nitrogen blends without any $CO_2$, certain effects could be observed. As the amount of oxygen in the sample decreased (and the nitrogen concentration increased), a positive response as ppm $SO_2$ was observed, even though no other compounds were known to be present. When the blends of about 12 percent $CO_2$ in various $O_2/N_2$ ratios were analyzed, it was found that the $CO_2$ and $O_2$ acted much the same in that the sum of the $CO_2$ and $O_2$ concentrations had the same quenching effect as the $O_2$ concentrations alone.

TABLE C-3. MULTICOMPONENT BLENDS OF $CO_2/O_2/N_2$ RESPONSE AS $SO_2$ IN MODEL 40 PULSED FLUORESCENT ANALYZER

| Test | Concentration, %* | | | Response as ppm $SO_2$ |
|---|---|---|---|---|
| | $CO_2$ | $O_2$ | $N_2$ | |
| 1 | - | 0 | 100 | 10+ |
| 2 | - | 5 | 95 | 0.5 |
| 3 | - | 10 | 90 | 0.2 |
| 4 | - | 15 | 85 | 0.1 |
| 5 | - | 20 | 80 | 0.0 |
| 6 | 10 % | 0 | 90 | 10+ |
| 7 | 10 % | 4.5 | 85.5 | 0.5 |
| 8 | 10 % | 9.0 | 80.0 | 0.2 |
| 9 | 10 % | 13.5 | 76.5 | 0.1 |
| 10 | 10 % | 18 | 72 | 0.0 |
| 11 | 100% | - | - | 2.0 |

Initial conclusions regarding CO and $CO_2$ interferences indicate that these two exhaust species do not interfere as positive $SO_2$ response provided there is a sufficient quenching effect provided by oxygen in the sample. Problems could be present if direct exhaust samples are obtained and oxygen levels are low. Preliminary experiments indicate that oxygen levels above 5 percent have less than 0.5 ppm response as $SO_2$. In cases where a CVS air diluted sample is obtained, no interferences due to CO or $CO_2$ were observed.

## $NO_x$ Interferences

Five bottles of $NO_x/N_2$ were used to conduct initial $NO_x$ interference experiments. These were also golden standards named by EPA Ann Arbor. Although these bottles were named as $NO_x$, they were actually NO in $N_2$ cylinders as verified by chemiluminescent analysis. The concentrations were selected to be typical ranges that might be expected in 1975 FTP testing. The results of this test are found in Table C-4. $NO_x$ concentrations ranged from 42 to 220 ppm and the apparent interferences as ppm $SO_2$ varied from 17.0-36.0. This was the only gas tested which appeared to produce an increased response with increasing component concentration. It should be noted that $N_2$ zero gas produced some 10+ ppm response as $SO_2$.

TABLE C-4. MULTICOMPONENT BLENDS OF $NO_x/O_2/N_2$ RESPONSE AS $SO_2$ IN MODEL 40 PULSED FLUORESCENT ANALYZER

| Test | Concentration | | | Response as |
|---|---|---|---|---|
| | $NO_x$, ppm | $O_2$, % | $N_2$, % | ppm $SO_2$ |
| 1 | 42 | - | 100 | 17.0 |
| 2 | 78 | - | 100 | 24.3 |
| 3 | 95.5 | - | 100 | 27.0 |
| 4 | 133.5 | - | 100 | 32.0 |
| 5 | 220 | - | 100 | 36.0 |
| 6 | 140 | 21 | 79 | 0.1 |
| 7 | 400 | 21 | 79 | 0 |
| 8 | 550 | 20 | 80 | 0.25 |
| 9 | 710 | 22 | 78 | 0. |
| 10 | 1125 | 20 | 80 | negative |
| 11 | 1400 | 19 | 81 | negative |
| 12 | 1750 | 20 | 80 | negative |

There was a definite trend observed regarding $NO_x$ concentration as a function of response as ppm $SO_2$, as shown in Figure C-1. Previous experiments involving CO and $CO_2$ interference checks indicated that the presence of nitrogen and the lack of oxygen could lead to apparent interferences. With this in mind, several blends of $NO/N_2$ were diluted with oxygen to obtain a nominal 20% $O_2$. The conversion of NO to $NO_2$ was immediately apparent due to the color change of the $NO \rightarrow NO_2$ reaction. Although the previous $NO_x$ check involved $NO/N_2$ blends, this experiment actually was $NO_2$/Air and comparison is somewhat difficult. The concentration of $NO_x$ ranged from 140-1400 in the bag samples analyzed. The $O_2$ and $N_2$ concentrations were relatively the same for purposes of this experiment. At any rate, the low concentrations (140-700) of $NO_2$/Air produced only slight response as ppm $SO_2$. At higher concentrations of $NO_2$, a negative response was observed for several gases.

It is difficult to make any absolute conclusions based on the data presented in Table C-4. Although $NO/N_2$ blends do give a positive response as ppm $SO_2$, it is impossible to determine the extent of NO/Air interferences due to the $NO \rightarrow NO_2$ oxidation in air. Bag samples obtained from a CVS are significantly air rich and have $O_2$ concentrations above 15 percent under most conditions. Since the CVS bag samples contain relatively low concentrations of $NO_x$ diluted in air, it is not felt that any significant $NO_x$ interferences will be experienced.

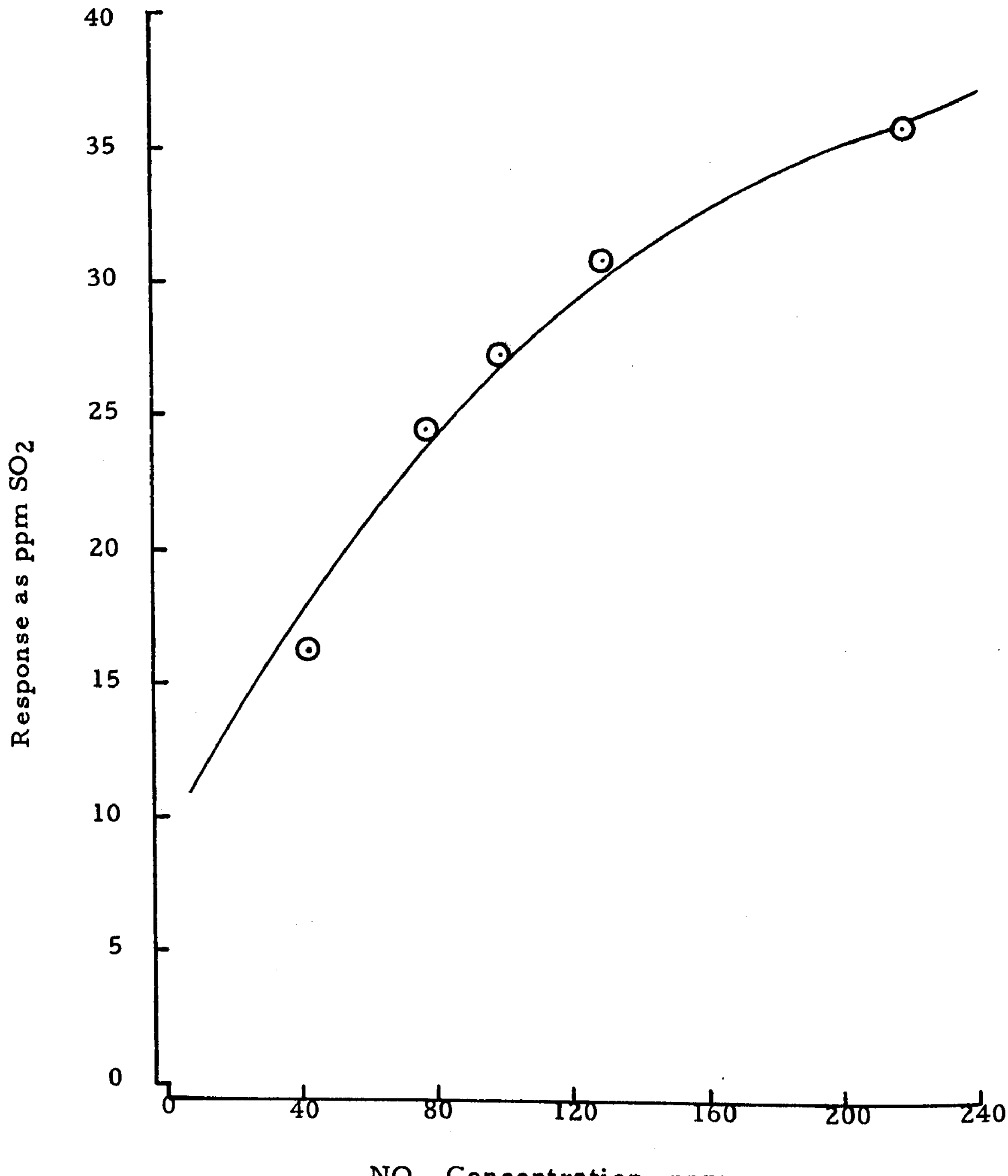



Figure C-1. The Effect of $NO_x$ Concentration (balance N2) on Response as ppm $SO_2$

## HC Interferences to Model 40 Pulsed Fluorescent $SO_2$ Analyzer

Several experiments were conducted using typical hydrocarbon blends in $N_2$ and air. The initial tests were conducted using propane in $N_2$ and propane in air. The results of these tests are found in Table C-5. The golden standard span gases were originally thought to be air

TABLE C-5. PROPANE SPAN GAS RESPONSE AS $SO_2$ IN TECO MODEL 40 PULSED FLUORESCENT ANALYZER

| Test | Concentration, ppmC | Balance Gas | Response as ppm $SO_2$ |
|---|---|---|---|
| 1 | 25 | Air | 0.0 |
| 2 | 34 | $N_2$ | 14.0 |
| 3 | 168 | Air | 0.0 |
| 4 | 301 | Air | 0.0 |
| 5 | 1024 | Air | 0.0 |

based gases, but during the tests it was found that the 34 ppm C bottle was actually a balance $N_2$ gas. This accounted for the fact that all of the other propane in air gases gave no response, whereas the 34 ppmC /$N_2$ gas gave an apparent response of 14 ppm $SO_2$. Hydrocarbon concentrations, varying from 25 to 1024 ppm C balance air, were found to produce no response as ppm $SO_2$.

It is suspected that the balance $N_2$ was responsible for the apparent interference in the 34 ppm C bottle. Once it was verified that typical air based HC span gases produced no interferences, it was decided to check the Model 40 pulsed fluorescent $SO_2$ instrument response to aromatic hydrocarbons. Two aromatic hydrocarbons typically found in automotive exhaust were selected for this experiment. These were benzene and toluene. The availability of several gases containing various ratios of $O_2$ and $N_2$ were selected for these tests. Baseline readings were obtained on each of these gases and these results are presented in Table C-6. A bag sample of each of these gases was obtained and a predetermined amount of benzene and toluene were added to each bag. Nominal benzene concentration was 120 ppm C and toluene concentration was about 140 ppm C.

The results of these experiments are illustrated in Figure C-2. In comparing the response as ppm $SO_2$ to the base $O_2/N_2$ blends to those same blends with added benzene and toluene it is apparent that some sort of interference due to aromatic compounds is present. It almost appears that the interference found in this test is an exponential function. Initial conclusions from this interference check indicate that samples containing less than 5 percent $O_2$ can have significant interference. These evaluations were conducted on the 0-10 ppm scale and the maximum interference that might be expected during CVS operation would be 0.2 ppm or 2 percent of full scale.

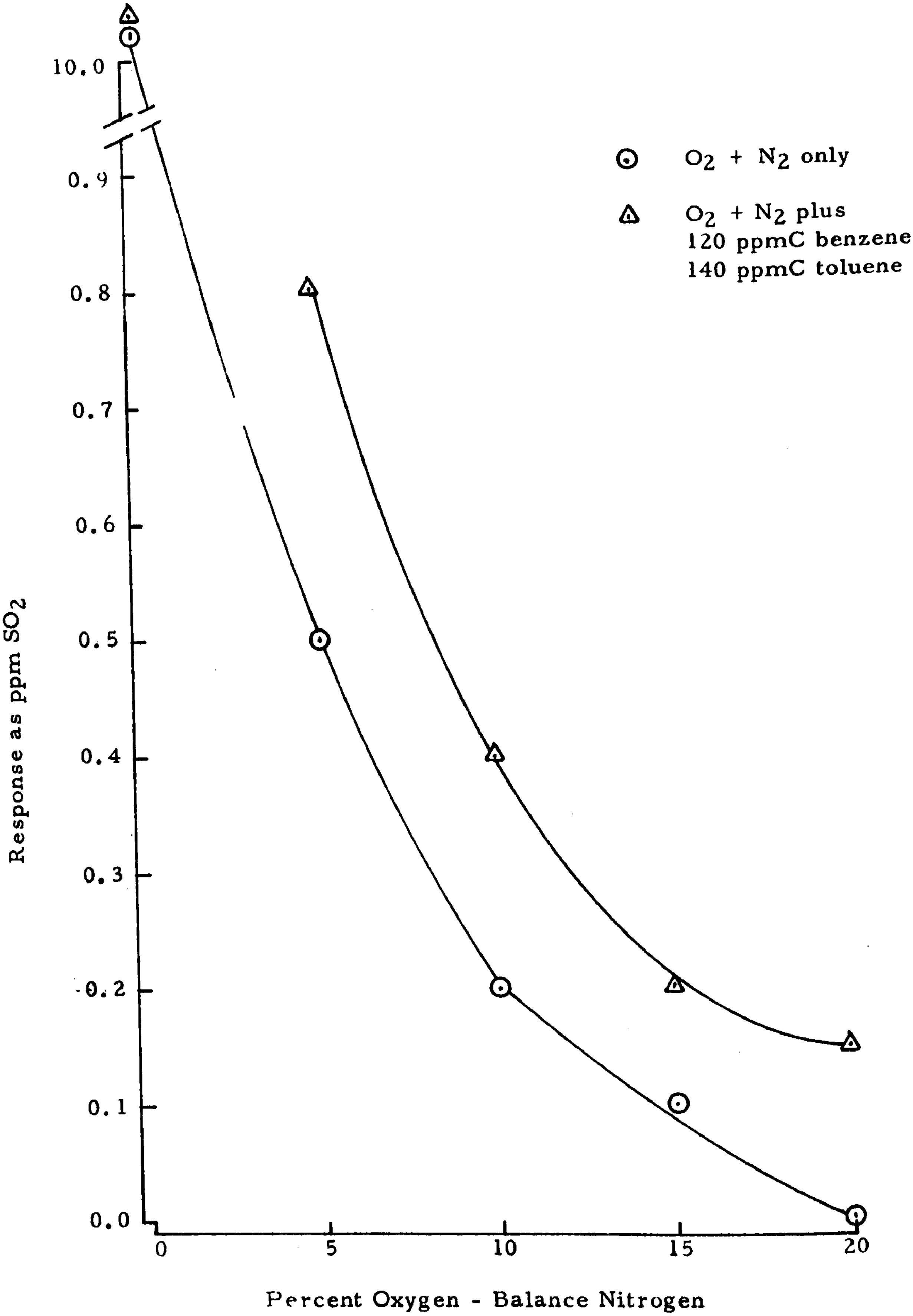



Figure C-2. The Effect of Benzene and Toluene in Various $O_2/N_2$ Blends as ppm $SO_2$ in Model 40 Pulsed Fluorescent Analyzer

TABLE C-6. MULTICOMPONENT BLENDS OF BENZENE, TOLUENE/$O_2$, $N_2$ RESPONSE AS $SO_2$ IN MODEL 40 PULSED FLUORESCENT ANALYZER

| Test | Concentration, ppm C | | Concentration, % | | Response as ppm $SO_2$ |
|---|---|---|---|---|---|
| | Benzene | Toluene | $O_2$ | $N_2$ | |
| 1 | - | - | 0 | 100 | 10+ |
| 2 | - | - | 5 | 95 | 0.5 |
| 3 | - | - | 10 | 90 | 0.2 |
| 4 | - | - | 15 | 85 | 0.1 |
| 5 | - | - | 20 | 80 | 0.0 |
| 6 | 140 | 160 | 0 | 100 | 10+ |
| 7 | 140 | 160 | 5 | 95 | 0.8 |
| 8 | 140 | 160 | 10 | 90 | 0.4 |
| 9 | 140 | 160 | 15 | 85 | 0.2 |
| 10 | 140 | 160 | 20 | 80 | 0.15 |

General Comments of Model 40 Pulsed Fluorescent $SO_2$ Analyzer

Upon completion of the aforementioned experiments, several contacts were made with other individuals who had working experience with the instrument or was involved with Thermo Electron Corporation. The first contact was Glenn Reschke at General Motors. He had conducted numerous experiments with this model instrument, many of the same nature of the SwRI evaluations. Although his particular application was for use in undiluted automotive exhaust sampling, his conclusions regarding the various component interferences were essentially identical to those presented herein.

Further verification of individual component interferences conclusions was obtained from Dennis Helms of Teco. He re-iterated the items presented in this report and those indicated by Glenn Reschke. Recommendations for specific application to CVS type exhaust sampling have been previously incorporated into the exhaust sampling system.

It may be considered a concensus of opinion that sampling from any air-rich CVS system and using air balance $SO_2$ span gases and air zero gases minimize on potential interferences. Should direct exhaust sampling with relatively low oxygen concentrations (less than 5 percent), additional interference checks might be warranted.

## SUMMARY OF PULSED FLUORESCENCE ANALYZER EXPERIMENTS

The $SO_2$ levels from the tests using the PF analyzer are shown in Tables C-7, C-8 and C-9 for 30 mph; 60 mph, and the '75 CVS test respectively. As can be seen from these tables, the PF analyzer greatly overstates the amount of $SO_2$ in the exhaust. It was felt that some effort had to be expended to try and determine the cause of this problem. Since tests run with the PF analyzer on another project using the same fuel, but with a 0.1 percent sulfur level (twice as high as the sulfur level on this project) had shown sulfur recovery of approximately 115 percent, it was reasoned that perhaps sulfur level had an effect on recovery. Stated in a different manner, there may be a constant positive interference, which of course becomes less significant as the $SO_2$ concentration in the exhaust increases. To check this hypothesis, a series of 30 mph steady state tests were run with 4 different sulfur levels in the same base fuel. The results of these tests are shown in Table C-10 and graphically in Figure C-3. It appears that there is indeed a constant interference that causes the recovery to increase far above 100 percent as the sulfur level in the fuel decreases. As a further check, one test was conducted with straight iso-octane as the fuel with thiophene added to give 0.051 percent sulfur. The results of the test run with this fuel at the 30 mph steady state condition are shown below.

| Fuel | Pct. S in fuel | Test Date | Exhaust $SO_2$ by PF, grams | Exhaust S grams | Fuel S grams | Recovery |
|---|---|---|---|---|---|---|
| Iso-octane | .051 | 11/21/74 | 1.23 | 0.616 | 0.752 | 82% |

It appears that recovery is a function of fuel composition also.

During the first week of December, 1974, the PF analyzer manufacturer, Thermo Electron Corporation (TECO), was contacted to solicit any comments and ideas they might have concerning the $SO_2$ recovery problem. Mr. Arvin Smith of TECO was in San Antonio on December 4, 1974 and visited the Emissions Research Department at SwRI to discuss the problem. It was his feeling that the high $SO_2$ readings from the analyzer were caused by light scattering from small particulates or aerosols not removed in the filtering system or even from glass fiber particles from the Gelman Spectro-Glass Fiber filters used as the primary filter in the sampling system.

To test this theory, a series of tests were run on December 5 and 6 with various sample filtering schemes. The results of these tests are shown in Table C-11. Two different fuels (iso-octane and regular grade gasoline) were used, each with two sulfur levels (0.02 percent and 0.1 percent). From the table it can be seen that while the 0.5 micron and 10 millimicron filters give an acceptable sulfur recovery with 0.1 percent sulfur in the regular grade gasoline used as the base fuel so far in this project, these filters do not give an acceptable sulfur recovery with 0.02 percent sulfur in the base fuel. Interpolating to the 0.04 percent sulfur level used in this project, it appears that the recovery would not be acceptable. Thus it was concluded that finer filters would not solve the sulfur recovery problem experienced with the PF analyzer at the fuel sulfur levels used in this project.

It was felt that enough time had been spent attempting to obtain an acceptable sulfur balance with the PF analyzer and that an alternate method would have to be used to determine $SO_2$ levels in the exhaust gases for this project.

TABLE C-7. EXHAUST $SO_2$ EMISSIONS FROM A 1972 PLYMOUTH AT 30 MILES PER HOUR USING A PULSED FLUORESCENT ANALYZER (.051 Percent Sulfur in Fuel)

| | | Pulsed Fluorescent Analyzer | | | | |
|---|---|---|---|---|---|---|
| Test Date | Run Duration | $SO_2$ Emissions grams | $SO_2$ grams/km | Sulfur in Exhaust, grams | Fuel Sulfur, grams | P. F. Analyzer, Recovery |
| 10/22/74 | 90 min | 12.59 | 0.174 | 6.12 | 3.33 | 183% |
| 11/7/74 | 90 min | 14.80 | 0.204 | 7.41 | 2.89 | 256% |
| 11/18/74 | 90 min | 13.74 | 0.190 | 7.16 | 3.29 | 218% |

TABLE C-8. EXHAUST $SO_2$ EMISSIONS FROM A 1972 PLYMOUTH AT 60 MILES PER HOUR USING A PULSED FLUORESCENT ANALYZER (.051 Percent Sulfur in Fuel)

| | | Pulsed Fluorescent Analyzer | | | | |
|---|---|---|---|---|---|---|
| Test Date | Run Duration | $SO_2$ Emissions grams | $SO_2$ grams/km | Sulfur in Exhaust, grams | Fuel Sulfur, grams | P. F. Analyzer Recovery |
| 11/8/74 | 70 min | 26.84 | 0.238 | 13.43 | 5.69 | 236% |
| 11/8/74 | 60 min | 17.81 | 0.184 | 8.91 | 4.59 | 194% |
| 11/18/74 | 60 min | 22.75 | 0.236 | 11.39 | 5.10 | 223% |
| 11/21/74 | 60 min | 16.72 | 0.173 | 8.37 | 5.12 | 163% |

TABLE C-9. EXHAUST $SO_2$ EMISSIONS FROM A 1972 PLYMOUTH RUN ON THE 1975 CVS PROCEDURE USING A PULSED FLUORESCENT ANALYZER (.051 Percent Sulfur in Fuel)

| | Pulsed Fluorescent Analyzer | | | | |
|---|---|---|---|---|---|
| Test Date | $SO_2$ Emissions grams | $SO_2$ grams/km | Sulfur in Exhaust, grams | Fuel Sulfur, grams | P.F. Analyzer Recovery |
| 10/22/74 | 4.34 | 0.25 | 2.17 | 1.66 | 131% |
| 11/7/74 | 5.59 | 0.34 | 2.79 | 1.59 | 177% |
| 11/19/74 | 6.05 | 0.37 | 3.03 | 1.63 | 186% |
| 11/20/74 | 4.94 | 0.30 | 2.47 | 1.53 | 161% |

TABLE C-10. SULFUR RECOVERY IN EXHAUST BY PULSED FLUORESCENT ANALYZER FROM 30 MILE PER HOUR STEADY STATE TESTS

| Test Date | Percent Sulfur in Fuel | Percent Sulfur Recovery Using PF Analyzer | Fuel Type |
|---|---|---|---|
| 11/25/74 | 0.019 | 483% | Unleaded |
| 11/25/74 | 0.019 | 614% | Unleaded |
| 10/22/74 | 0.051 | 183% | Leaded |
| 11/7/74 | 0.051 | 256% | Leaded |
| 11/18/74 | 0.051 | 218% | Leaded |
| 11/26/74 | 0.051 | 259% | Unleaded |
| 11/26/74 | 0.051 | 287% | Leaded |
| 11/25/74 | 0.10 | 134% | Unleaded |
| 11/26/74 | 0.10 | 186% | Unleaded |
| 11/27/74 | 0.20 | 143% | Unleaded |

TABLE C-11. SULFUR DIOXIDE EMISSIONS FROM 1972 PLYMOUTH USING VARIOUS SAMPLE FILTERS AT 30 mph STEADY STATE CONDITIONS

| Fuel | Fuel sulfur level, % | Filter* | P.F.** $SO_2$, g/km | Exhaust sulfur, g | Fuel sulfur, g | Percent recovery |
|---|---|---|---|---|---|---|
| Iso-octane | 0.02 | A | 0.20 | 0.16 | 0.19 | 84 |
| Iso-octane | 0.02 | B | 0.18 | 0.14 | 0.19 | 74 |
| Iso-octane | 0.10 | A | 0.84 | 0.68 | 0.92 | 74 |
| Iso-octane | 0.10 | B | 0.77 | 0.62 | 0.92 | 67 |
| Iso-octane | 0.10 | C | 1.14 | 0.92 | 0.92 | 100 |
| Base | 0.02 | A | 0.62 | 0.50 | 0.17 | 294 |
| Base | 0.02 | B | 0.59 | 0.48 | 0.17 | 282 |
| Base | 0.02 | C | 0.90 | 0.72 | 0.17 | 424 |
| Base | 0.10 | A | 1.08 | 0.87 | 0.89 | 98 |
| Base | 0.10 | B | 1.10 | 0.89 | 0.89 | 100 |
| Base | 0.10 | C | 1.91 | 1.54 | 0.89 | 173 |

* Filter code: A - 0.5 micron Fluoropore
B - 10 millimicron Millipore
C - Gellman Spectro Glass Fiber

**P. F. $SO_2$ is from dilute continuous sample.

Note: Base fuel is an unleaded regular grade gasoline.

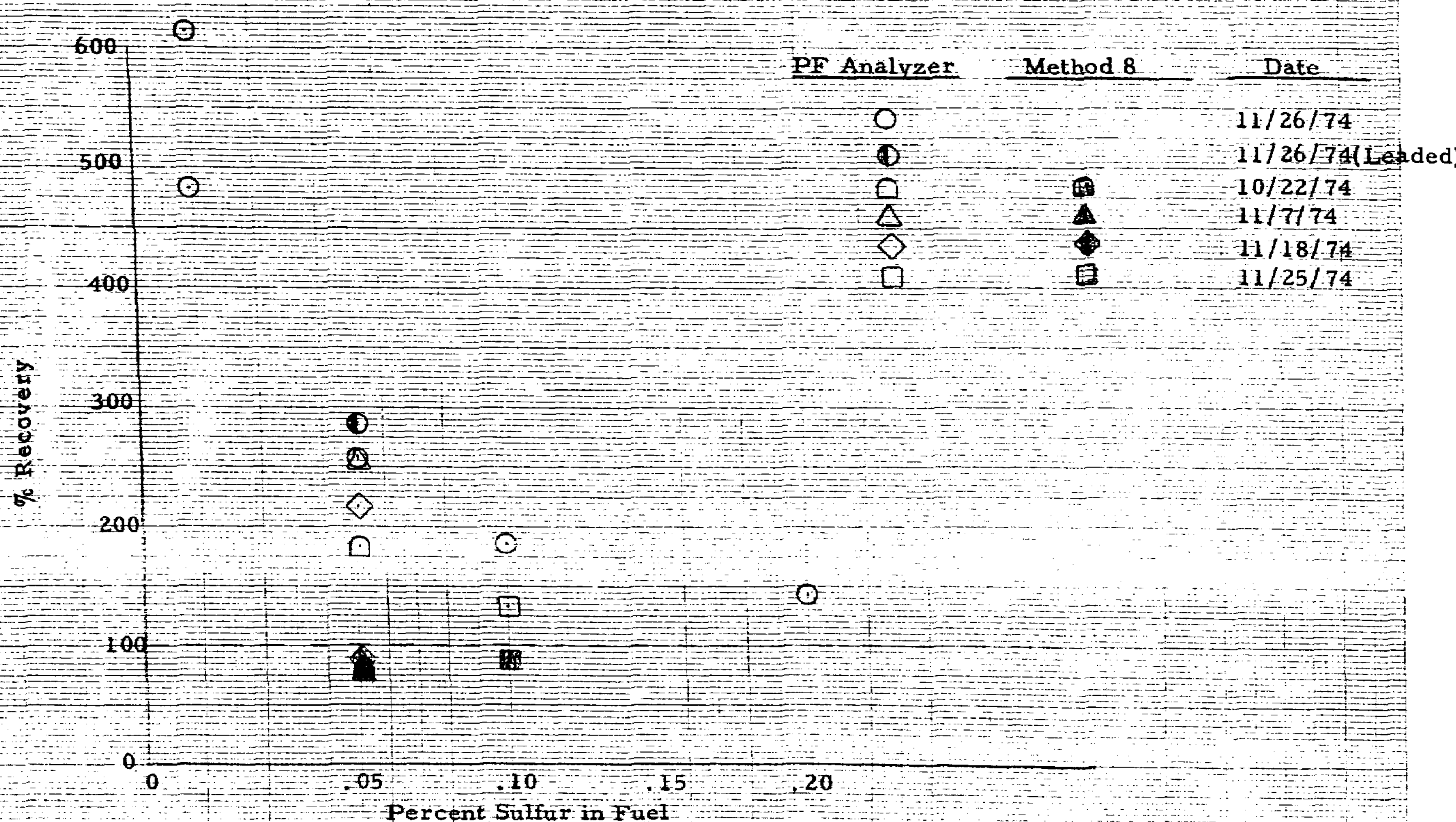



FIGURE C1. PERCENT SULFUR RECOVERY IN EXHAUST OF A 1972 PLYMOUTH AT 30 MILES PER HOUR USING PULSED FLOURESCENT ANALYZER AND EPA METHOD 8

# APPENDIX D

## SwRI $SO_2$-BCA PROCEDURE AND VALIDATION TESTS

# THE MEASUREMENT OF SULFUR DIOXIDE USING THE BARIUM CHLORANILATE METHOD ($SO_2$-BCA)

February 1975

Harry E. Dietzmann
Southwest Research Institute
San Antonio, Texas

## I. BACKGROUND

The measurement of sulfur dioxide ($SO_2$) in dilute automotive exhaust has been a difficult task. Although there are several continuous recording $SO_2$ instruments commercially available, they have not demonstrated the degree of accuracy necessary at the $SO_2$ levels observed in dilute automotive exhaust. A number of other wet chemical procedures are also available but are considered either excessively time consuming or lacking in sensitivity. With this in mind, an idea was conceived by EPA Research Triangle Park to use some basic concepts in the Federal Register and to adapt these concepts for measuring $SO_2$ in dilute automotive exhaust.

This procedure uses midget impingers with 3 percent hydrogen peroxide to oxidize the $SO_2$ to sulfate. The samples are then evaporated, treated, extracted and analyzed according to the barium chloranilate method for sulfate analysis. The main advantages of this procedure are the sensitivity and the simplicity of analysis.

## II. APPARATUS

This procedure incorporates two midget impingers in series with a 0.5μ filter in the sample line. Other items in the sample train include drierite tube, wet test meter, sample pump and flowmeter. A flow schematic is presented in Figure 1 to illustrate the relative positions of the various individual components. The sample probe is glass and the filter is a 0.5μ SS filter press-fit into the teflon union connecting the glass sample probe and the first bubbler. By use of appropriate valving, a dual system could be assembled if consecutive samples were desired such as in the cold start 505 and the stabilized portion of the 1975 FTP.

A. Midget impingers - capable of handling 25 ml of absorbing reagent.

B. Sample pump - must have sample flow capacity of at least 2 l/m.

C. Drierite column - filled with mixture of indicating and non-indicating drierite.

D. Wet test meter - capable of accurately measuring sample flow rates at least in the range of 2 l/min.

E. Flow meter - capable of monitoring flow rates in the range of 2 l/min.

F. Sample probe - glass should be of minimum length.

G. Filter - 0.5μ stainless steel filter disc press-fit into teflon union.

H. Barium Chloranilate Sulfate Analysis System[1].

## III. REAGENTS

A. 30 percent stabilized hydrogen peroxide ($H_2O_2$) ACS reagent grade. Store in refrigerator.

B. 3 percent hydrogen peroxide solution, dilute 30 percent 10:1 to obtain the required 3 percent $H_2O_2$. Use only distilled water as the dilutent. Prepare the day of use.

C. Ammonium hydroxide, 1M. Use ACS reagent grade diluted to obtain the desired 1M solution.

D. Red litmus paper.

E. Isopropyl alcohol, spectroquality identical to that used in the sulfate analysis.

F. 60 percent IPA - 40 percent $H_2O$, same solvent that is used in the barium chloranilate method for sulfate analysis.

G. Distilled water, used in preparation of absorbing reagent (3 percent $H_2O_2$) and extraction solvent (60 percent IPA).

H. Ammonium sulfate, ACS grade, used in the perparation of ammonium sulfate standards.

I. Miscellaneous analytical and chemical support items, routinely used in the Barium Chloranilate Procedure.

## IV. PREPARATION OF SULFATE STANDARDS (USING $(NH_4)_2SO_4$)

A. Comments

Weigh out exactly 2.750 g of ACS reagent grade $(NH_4)_2SO_4$ into a pre-weighed clean dry beaker. Dissolve the $(NH_4)_2SO_4$ in 60 percent IPA and dilute to a total of 1000 ml in a Class A volumetric flask. The resulting

(1) Designates that which is attached.

sulfate concentration is then 2000$\mu$g $SO_4^=$/ml. This solution is called the dilute primary standard and is to be used to prepare working calibration standards.

B. Calculations

$$2.750 \text{ g } (NH_4)_2SO_4 = 2.750 \text{ g } (NH_4)_2SO_4 \times \frac{96 \text{ awu } SO_4^=}{132 \text{ awu } (NH_4)_2SO_4}$$

$$2.750 \text{ g } (NH_4)_2SO_4 = 2.000 \text{ g } SO_4 =$$

$$2.000 \text{ g } SO_4^=/1 = 2.000 \text{ g } SO_4^=/1 \times \frac{1\ 1}{1000 \text{ ml}} \times \frac{10^6 \mu g}{1 \text{ g}}$$

$$2.000 \text{ g } SO_4^=/1 = \frac{2.000 \times 10^6 \mu g}{10^3 \text{ ml}} = 2000 \mu g/ml$$

C. Preparation of Working Standards

| Sample | Volume of Dilute Primary Standard* | Volumetric Flask, ml** | Sulfate Concentration $\mu$g $SO_4^=$/ml |
|---|---|---|---|
| 1 | 10 | 1000 | 20.0 |
| 2 | 15 | 2000 | 15.0 |
| 3 | 5 | 1000 | 10.0 |
| 4 | 5 | 2000 | 5.0 |
| 5 | 1 | 1000 | 2.0 |

* Measured using Class A volumetric pipet.
** Measured using Class A volumetric flask.

After each set of standards are prepared, run to establish the validity and linearity of the new working standards.

All glassware should be thoroughly cleaned and no visible glassware spots should be tolerated. Once the working standards are prepared, they should be transferred to clearly marked glass reagent bottles for storage.

## V. PROCEDURE

A. Sample Acquisition

The exhaust sample to be analyzed is bubbled through the two midget impingers in series. Prior to sampling, it is important to leak check the sampling system to insure no leaks are present. Once the absence of leaks is verified, pipet 25 ml of freshly prepared 3 percent hydrogen peroxide into each of the bubblers. All ground glass fittings should have stopcock grease to insure leak tight connections. Prior to testing, the drierite column is freshly prepared and the wet test meter is read. Once the test has started, the flow is adjusted to 1.5 l/min. Sampling times will vary depending on the concentration of the $SO_2$ in the exhaust sample; however, the extracted sample can be diluted if necessary.

Tests have shown that sufficient sample can be obtained from 10 minutes at 2 to 3 ppm $SO_2$ levels, bubbling at a rate of 1.5 l/min. It might be possible to use somewhat higher sample flow rates if necessary, but high recoveries have been observed at 1.5 l/min. Generally, sampling for periods of more than 20 minutes will require dilution at the 2 to 3 ppm $SO_2$ level. It should be pointed out that this will vary somewhat depending on the range capability of the individual BCA system.

B. Extraction Procedure

1. After the bubbling is complete, quantitatively transfer the absorbing reagent to a 100 ml beaker. Rinse the impinger tip and bubbler thoroughly several times with 3 percent $H_2O$. Add these rinsings to the original absorbing reagent in the 100 ml beaker. This will bring the total volume to about 30 ml. The final volume at this point is not critical since the absorbing reagent will be evaporated to dryness.

2. Place the 100 ml beaker on a steam bath and begin evaporating. Once the volume has evaporated to about 10 ml, make the solution slightly basic to litmus with 1M ammonium hydroxide. Use a stirring rod tip to touch the sample to a strip of red litmus paper. Usually 2 to 4 drops will be sufficient. Complete the evaporation to dryness to insure that no ammonium hydroxide remains in the beaker. Several experiments in determining recovery rates have indicated that any ammonium hydroxide remaining will create an interference.

3. Once the beaker is thoroughly dry, remove from the steam bath and allow to cool. The entire evaporation procedure requires about 4 to 5 hours per beaker. The ammonium sulfate appears as a white deposit on the bottom and sides of the beaker. Use a rubber policeman on a glass stirring rod with about 2 ml of 60 percent IPA to gently break loose the deposit and put into solution. This step is repeated several times using about 2 ml of 60 percent IPA each time. After each time, add the rinsing to a 10 ml volumetric flask. After a minimum of three extraction-rinsings, dilute to the mark with additional 60 percent IPA. After the sample has been properly prepared, it is then considered ready for analysis in the barium chloranilate system.

C. Analysis

After the sample has been bubbled, evaporated, treated and extracted, it is analyzed using the barium chloranilate procedure. Since these samples are essentially ammonium sulfate in 60 percent IPA, the working standards are also ammonium sulfate in 60 percent IPA. A copy of the barium chloranilate procedure is found in Appendix B. Standards are run before and after each sample and blanks are run between all samples and standards. A typical trace of a standard, blank, sample sequence is shown in Figure 2.

D. Calculations

The equation used to calculate the ppm $SO_2$ in an exhaust sample using the $SO_2$-BCA procedure is listed below:

$$\text{ppm } SO_2 \text{ sample} = \frac{(6.67 \times \text{conc } SO_4^{=} \text{ std}, \mu g) \times (\text{area } SO_4^{=} \text{ sample, in}^2) \times DF}{(\text{area } SO_4^{=} \text{ std, in}^2) \times (\text{density}, \mu g/l) \times \text{sample volume, l}}$$

The derivation of this equation is presented as an attachment and is applicable to this specific procedure.

Although calculations use peak areas, it would be possible to use peak heights under certain conditions:

(Example 1) - Assume an exhaust sample was bubbled through two bubblers in series and a total of 12.75 liters was sampled. The gas entering the dry gas meter was 0°C at a barometric pressure of 29.92" Hg. A $SO_4^{=}$ standard of 19.2µg/ml gave a response of 1.56 $in^2$. When diluted 5:1 for the first bubbler and left at full strength for the second, the unknown sample gave a response of 2.05 $in^2$ for the first bubbler and 0.42 $in^2$ for the second bubbler.

$$\text{ppm } SO_2 \text{ (bubbler 1)} = \frac{6.67 \times 19.2 \times 2.05 \times 5}{1.56 \times 2.927 \times 12.75} = 22.5 \text{ ppm}$$

$$\text{ppm } SO_2 \text{ (bubbler 2)} = \frac{6.67 \times 19.2 \times 0.42 \times 1}{1.56 \times 2.927 \times 12.75} = 0.9 \text{ ppm}$$

Total Sample ppm $SO_2$ = 22.5 ppm + 0.9 ppm = 23.4 ppm

(Example 2) - Assume an exhaust sample was bubbled through two bubblers in series and a total of 1.436 $ft^3$ was sampled. The gas entering the dry gas meter was 30°C at a barometric pressure of 29.31" Hg. An $SO_4^{=}$ standard of 9.6µg $SO_4^{=}$/ml gave a response of 0.78 $in^2$. When diluted 10:1 for the first bubbler and leaving the second at full strength, the unknown sample gave a response of 3.25 $in^2$ for the first bubbler and 0.21 $in^2$

for the second bubbler. (Note that there are two differences in the examples, this example has the sample volume in $ft^3$ rather than liters and the sampling conditions are not at STP.) The first calculation will be to obtain the density of $SO_2$ at 30°C and 29.31" Hg.

$$\text{density } SO_2 \text{ at } 0°C \text{ and } 29.92'' \text{ Hg} = \frac{2.927 \text{ g}}{1 \text{ l}}$$

1 liter at 0°C and 29.92" Hg = 1.133 liters at 30°C and 29.31" Hg

$$1 \text{ l} = 1 \text{ l} \times \frac{273 + 30°K}{273°K} \times \frac{29.92'' \text{ Hg}}{29.31'' \text{ Hg}} = 1.133 \text{ l}$$

$$\text{density } SO_2 \text{ at } 30°C \text{ and } 29.31'' \text{ Hg} = \frac{2.927 \text{ g}}{1.133 \text{ l}} = 2.583 \text{ g/l}$$

$$\underset{\text{(bubbler 1)}}{\text{ppm } SO_2} = \frac{0.2356 \times 9.6 \times 3.25 \times 10}{0.78 \times 2.583 \times 1.436} = 25.4 \text{ ppm}$$

$$\underset{\text{(bubbler 2)}}{\text{ppm } SO_2} = \frac{0.2356 \times 9.6 \times 1.95 \times 1}{0.78 \times 2.583 \times 1.436} = 1.5 \text{ ppm}$$

Total Sample ppm $SO_2$ = 25.4 + 1.5 = 26.9 ppm

SHEET NO. 1 OF 2 SHEETS

PROJECT 11-4015-001

SUBJECT DERIVATION OF SIMPLIFIED $SO_2$-BCA EQUATION

DATE 2-13-75

BY HARRY E. DIETZMANN

STEP I: (FROM DENSITY = WEIGHT/VOLUME)

$$\text{VOL } SO_2 \text{ SAMPLE}, \mu l = \frac{\text{WEIGHT OF } SO_2 \text{ SAMPLE}, \mu g}{\text{DENSITY } SO_2, g/l}$$

STEP II: (FROM DEFINITION OF PPM)

$$\text{PPM } SO_2 \text{ SAMPLE} = \frac{\text{VOL } SO_2 \text{ SAMPLE}, \mu l}{\text{SAMPLE VOL}, l}$$

STEP III: (FROM BCA PROCEDURE)

$$\text{CONC } SO_4^= \text{ SAMPLE}, \mu g/ml = \frac{\text{CONC } SO_4^= \text{ STD}, \mu g/ml \times \text{AREA } SO_4^= \text{ SAMPLE}, IN^2}{\text{AREA } SO_4^= \text{ STD}, IN^2}$$

$$\text{WEIGHT } SO_4^= \text{ SAMPLE}, \mu g = \text{CONC } SO_4^=, \mu g/ml \times 10\ ml \times D.F.$$

$$\text{WEIGHT } SO_4^= \text{ SAMPLE}, \mu g = \frac{\text{CONC } SO_4^= \text{ STD}, \mu g/ml \times \text{AREA } SO_4^= \text{ sample}, in^2 \times 10\ ml \times DF}{\text{AREA } SO_4^= \text{ STD}, IN^2}$$

STEP IV: (66.7% OF $SO_4^=$ IS $SO_2$)

$$\text{WEIGHT } SO_2 \text{ SAMPLE}, \mu g = 0.667 \times \text{WEIGHT } SO_4^= \text{ SAMPLE}, \mu g$$

$$\text{WEIGHT } SO_2 \text{ SAMPLE}, \mu g = \frac{0.667 \times \text{CONC } SO_4^= \text{ STD}, \mu g/ml \times \text{AREA } SO_4^= \text{ sample}, in^2 \times 10\ ml \times DF}{\text{AREA } SO_4^= \text{ STD}, IN^2}$$

STEP V: (COMBINING STEPS I + IV)

$$\text{VOL } SO_2 \text{ sample}, \mu l = \frac{0.667 \times \text{CONC } SO_4^= \text{ STD}, \mu g/ml \times \text{AREA } SO_4^= \text{ SAMPLE}, IN^2 \times 10\ ml \times DF}{\text{AREA } SO_4^= \text{ STD}, IN^2 \times \text{DENSITY } SO_2, g/l}$$

SUBJECT DERIVATION OF SIMPLIFIED $SO_2$ - BCA EQUATION


PROJECT 11-4015-001
DATE 2-13-75
BY HARRY E. DIETZMANN

STEP VI: (COMBINING STEPS II + V)

$$\text{PPM } SO_2 \text{ SAMPLE} = \frac{0.667 \times \text{Conc } SO_4^{=} \text{ STD}, \mu g/ml \times \text{Area } SO_4^{=} \text{ sample}, in^2 \times 10\,ml \times DF}{\text{Area } SO_4^{=} \text{ STD}, IN^2 \times \text{Density } SO_2, g/l \times \text{Sample Volume}, l}$$

STEP VII: (COMBINING CONSTANTS)

$$\text{PPM } SO_2 \text{ SAMPLE} = \frac{6.67 \times \text{Conc } SO_4^{=} \text{ STD}, \mu g/ml \times \text{Area } SO_4^{=} \text{ sample}, in^2 \times DF}{\text{Area } SO_4^{=} \text{ STD}, IN^2 \times \text{Density } SO_2, g/l \times \text{Sample Volume}, l}$$

(FOR VOLUMES MEASURED IN LITERS)

$$\text{PPM } SO_2 \text{ SAMPLE} = \frac{0.2356 \times \text{Conc } SO_4^{=} \text{ STD}, \mu g \times \text{Area } SO_4^{=} \text{ sample}, in^2 \times DF}{\text{Area } SO_4^{=} \text{ STD}, in^2 \times \text{Density } SO_2, g/l \times \text{Sample Volume}, FT^3}$$

(FOR SAMPLE VOLUMES MEASURED IN $FT^3$)

NOTES:

1. Use $SO_2$ density of 2.927 g/l @ 0°C and 29.92" Hg
2. Sample volume and $SO_2$ densities should be corrected to the same reference point, i.e. if the temperature of the sample gas at the dry gas meter was 30°C and the barometer read 28.95, then the density of $SO_2$ at those conditions should be used in the calculations.



PC-

Note: All tubing in sample train up to the impingers is glass or teflon.

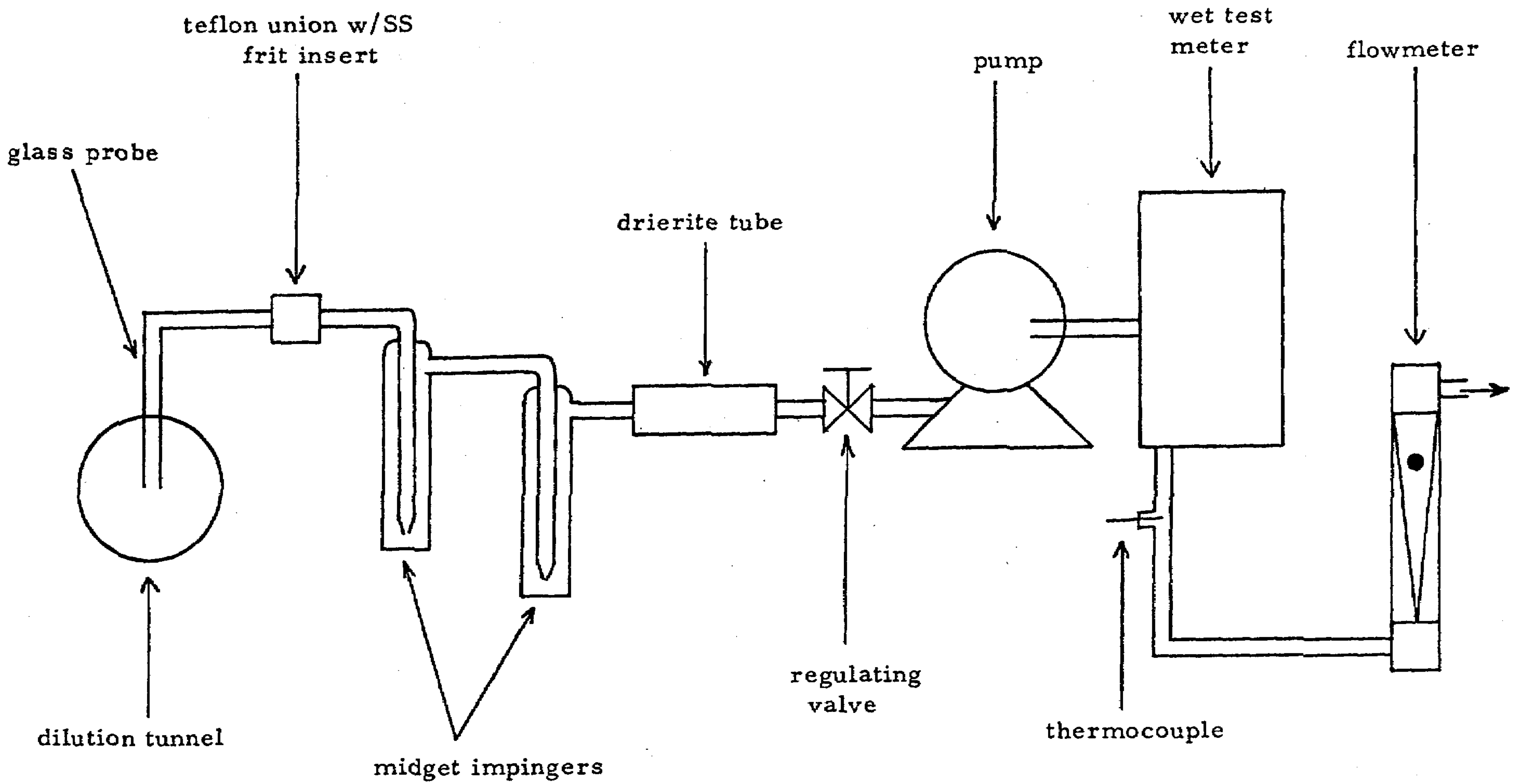
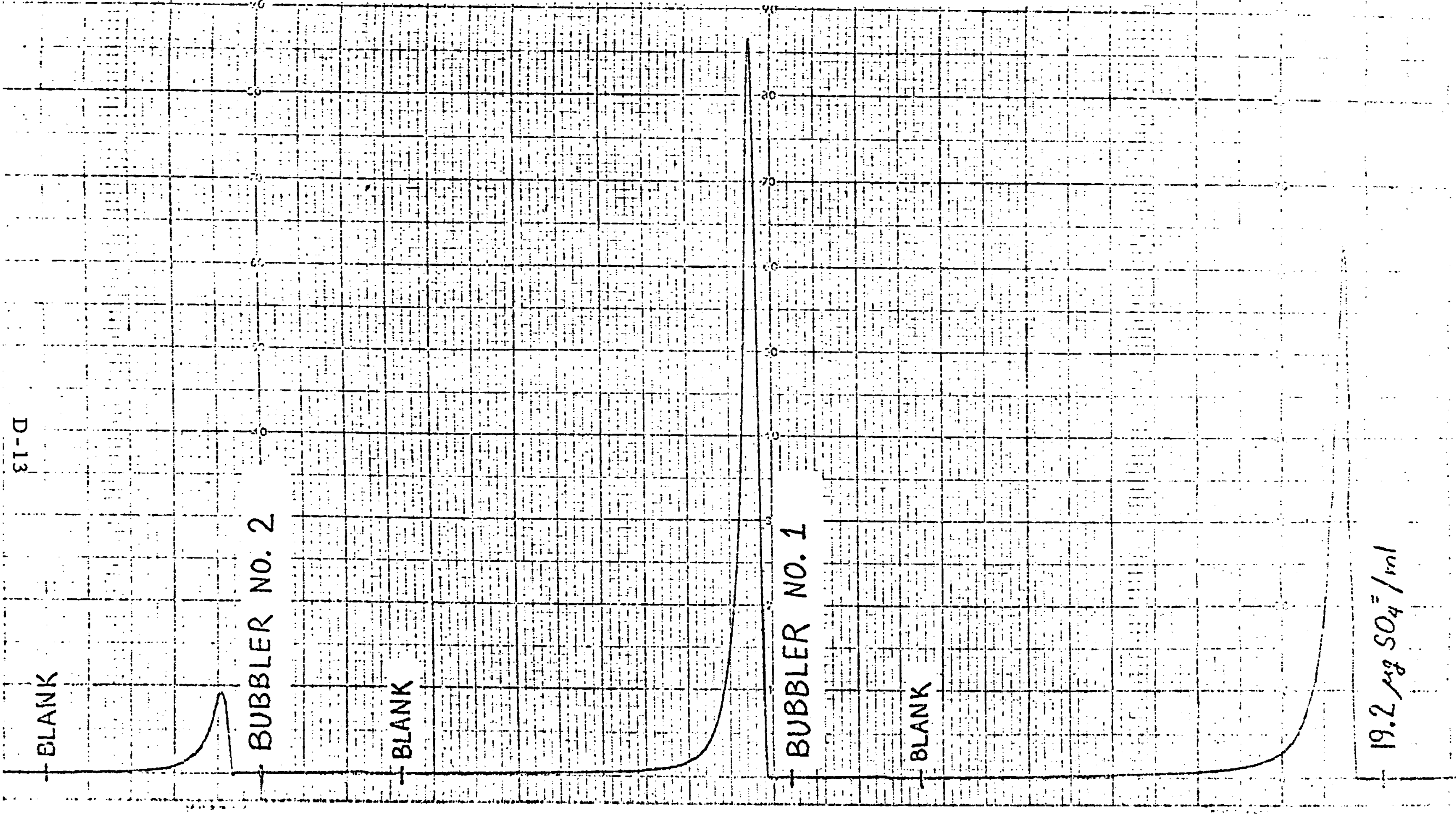



FIGURE D-1. $SO_2$-BCA FLOW SCHEMATIC

FIGURE D-2. TYPICAL BCA STANDARD AND SAMPLE TRACE



## RESULTS OF VALIDATION TESTS OF THE $SO_2$-BCA METHOD RUN AT SwRI

Extensive experiments were conducted to validate the sampling and extraction procedures. The experiments were conducted in both areas of the procedure, the sample acquisition and the sample analysis.

Experiments involving the sample acquisition phase of the procedure proved to be the most troublesome. Items investigated during this phase of experiments involved sampling flow rates, bubbler efficiencies, sample system positioning, reagent selection, and absorbing reagent temperature. The tests were conducted basically with 3g Pb/gal and 0.051 percent sulfur fuel. Through a series of experiments involving the sampling parameters, the recommended sampling procedure in this Appendix was formulated.

Several tests involving sample extraction and analysis were also conducted. Calibration standards were prepared in absorbing reagent, and the extraction procedure parameters were investigated. Between 97 and 100 percent recovery was obtained on known sulfate levels once the extraction procedure variables were determined. Variables investigated included the degree of evaporation (dryness or semi-dry), amount of ammonium hydroxide added, and the removal of the $(NH_4)_2SO_4$ deposit from the extraction beaker.

Most tests involving sulfur balances on the 1972 Plymouth were conducted using steady state conditions. Comparisons were made between on-line continuous sampling and bag samples analyzed once the test were complete. Several LA-4 tests were also performed (single bag 23-minute sample) where bag samples were also analyzed. A satisfactory recovery level could not be obtained from the bag samples. Several tests on a low level sulfur fuel were conducted and recoveries averaged 96 percent for three 30 mph and two 60 mph steady states.

The development testing resulted in a procedure that gives a satisfactory sulfur balance. Tables D-1, D-2 and D-3 summarize the testing done on 30 and 60 mph steady state and '75 light duty FTP testing respectively.

The average sulfur recovery for the steady state tests is approximately 106 percent with a range of approximately ±20, with most tests within ±10 percentage points of the average. The 1975 LD FTP has a somewhat lower average sulfur recovery of 92 percent, but a range of only 22 percentage points. These sulfur recovery levels are orders of magnitude better than the TECO PF analyzer and an improvement over what others have seen using titration or gravimetric analysis of hydrogen peroxide $SO_2$ collection systems.

TABLE D-1. SUMMARY OF $SO_2$ EMISSIONS FROM 30 MPH STEADY STATE TESTS OF A 1972 PLYMOUTH USING THE SwRI $SO_2$-BCA METHOD
Continuous Dilute Sampling With Glass Probe, 30 Min. Sample)

| Date | Speed | Run Time, Min | Fuel Type | Fuel Used, grams* | Grams S in Fuel | Exhaust $SO_2$, grams | Exhaust S, grams | Recovery, % |
|---|---|---|---|---|---|---|---|---|
| 1/9/75 | 30 | 102 | EM-225-F | 6641 | 3.39 | 7.00 | 3.50 | 103 |
| 1/9/75 | 30 | 102 | EM-225-F | 6641 | 3.39 | 6.71 | 3.36 | 99 |
| 1/9/75 | 30 | 102 | EM-225-F | 6641 | 3.39 | 7.48 | 3.74 | 111 |
| 1/10/75 | 30 | 94 | EM-225-F | 6056 | 3.08 | 7.46 | 3.73 | 121 |
| 1/10/75 | 30 | 94 | EM-225-F | 6056 | 3.08 | 7.46 | 3.73 | 121 |
| 1/10/75 | 30 | 94 | EM-225-F | 6056 | 3.08 | 7.46 | 3.73 | 121 |
| 1/24/75 | 30 | 90 | EM-225-F | 5922 | 3.02 | 6.21 | 3.11 | 103 |
| 1/24/75 | 30 | 90 | EM-225-F | 5922 | 3.02 | 5.16 | 2.58 | 85 |
| 1/24/75 | 30 | 90 | EM-225-F | 5922 | 3.02 | 5.40 | 2.70 | 89 |
| | | | | | | | Avg. | 106 |
| | | | | | | | Max | 121 |
| | | | | | | | Min | 85 |
| | | | | | | | Std. Dev. | 14 |
| | | | | | | | CV = 13% | |

* EM-225-F is unleaded regular grade gasoline with .051 percent sulfur
208-FC is leaded regular grade gasoline with .051 percent sulfur

TABLE D-2. SUMMARY OF $SO_2$ EMISSIONS FROM 60 MPH STEADY STATE TESTS OF A 1972 PLYMOUTH USING THE SwRI $SO_2$-BCA METHOD
Continuous Dilute Sampling With Glass Probe, 30 Min. Sample)

| Date | Speed | Run Time, Min | Fuel Type | Fuel Used, grams* | Grams S in Fuel | Exhaust $SO_2$, grams | Exhaust S, grams | Recovery, % |
|---|---|---|---|---|---|---|---|---|
| 1/13/75 | 60 | 84 | 208-FC | 10215 | 5.21 | 11.94 | 5.97 | 115 |
| 1/13/75 | 60 | 84 | 208-FC | 10215 | 5.21 | 13.08 | 6.54 | 126 |
| 1/13/75 | 60 | 84 | 208-FC | 10215 | 5.21 | 10.79 | 5.40 | 104 |
| 1/13/75 | 60 | 84 | 208-FC | 10215 | 5.21 | 11.50 | 5.75 | 110 |
| 1/21/75 | 60 | 60 | EM-225-F | 7507 | 3.82 | 6.80 | 3.40 | 89 |
| 1/21/75 | 60 | 60 | EM-225-F | 7507 | 3.82 | 8.51 | 4.26 | 112 |
| 1/21/75 | 60 | 60 | EM-225-F | 7507 | 3.82 | 8.74 | 4.37 | 114 |
| 1/23/75 | 60 | 60 | EM-225-F | 7203 | 3.67 | 6.86 | 3.43 | 93 |
| 1/23/75 | 60 | 60 | EM-225-F | 7203 | 3.67 | 7.20 | 3.60 | 98 |
| 1/23/75 | 60 | 60 | EM-225-F | 7203 | 3.67 | 8.26 | 4.13 | 113 |

Avg. 107
Max. 126
Min. 89
Std. Dev 11
CV = 11%

* EM-225-F is unleaded regular grade gasoline with .051 percent sulfur
208-FC is leaded regular grade gasoline with .051 percent sulfur

TABLE D-3. SUMMARY OF 1975 LD FTP TESTS OF A 1972 PLYMOUTH USING THE SwRI $SO_2$-BCA METHOD

Continuous Dilute Sampling With Glass Probe

| Date | Type Fuel | Fuel Used, grams* | Fuel S, grams | Exhaust $SO_2$, grams | Exhaust S, grams | Recovery, % |
|---|---|---|---|---|---|---|
| 1/14/75 | 208-FD | 2703 | 1.38 | 2.77 | 1.39 | 101 |
| 1/21/75 | 225-F | 2717 | 1.39 | 2.71 | 1.36 | 98 |
| 1/23/75 | 225-F | 2853 | 1.46 | 2.31 | 1.16 | 79 |
| 1/24/75 | 225-F | 2694 | 1.37 | 2.45 | 1.23 | 90 |
| | | | | | Avg. | 92 |
| | | | | | Max | 101 |
| | | | | | Min | 79 |
| | | | | | Std Dev. | 10 |

* EM-225-F is unleaded regular grade gasoline with .051 percent sulfur
208-FD is leaded regular grade gasoline with .051 percent sulfur

# APPENDIX E

## METHOD-8 DETERMINATION OF SULFURIC ACID MIST AND SULFUR DIOXIDE EMISSIONS FROM STATIONARY SOURCES

METHOD 8—DETERMINATION OF SULFURIC ACID MIST AND SULFUR DIOXIDE EMISSIONS FROM STATIONARY SOURCES

1. *Principle and applicability.*

1.1 Principle. A gas sample is extracted from a sampling point in the stack and the acid mist including sulfur trioxide is separated from sulfur dioxide. Both fractions are measured separately by the barium-thorin titration method.

1.2 Applicability. This method is applicable to determination of sulfuric acid mist (including sulfur trioxide) and sulfur dioxide from stationary sources only when specified by the test procedures for determining compliance with the New Source Performance Standards.

2. *Apparatus.*

2.1 Sampling. See Figure 8-1. Many of the design specifications of this sampling train are described in APTD-0581.

2.1.1 Nozzle—Stainless steel (316) with sharp, tapered leading edge.

2.1.2 Probe—Pyrex[1] glass with a heating system to prevent visible condensation during sampling.

2.1.3 Pitot tube—Type S, or equivalent, attached to probe to monitor stack gas velocity.

2.1.4 Filter holder—Pyrex[1] glass.

2.1.5 Impingers—Four as shown in Figure 8-1. The first and third are of the Greenburg-Smith design with standard tip. The second and fourth are of the Greenburg-Smith design, modified by replacing the standard tip with a ½-inch ID glass tube extending to one-half inch from the bottom of the impinger flask. Similar collection systems, which have been approved by the Administrator, may be used.

2.1.6 Metering system—Vacuum gauge, leak-free pump, thermometers capable of measuring temperature to within 5° F., dry gas meter with 2% accuracy, and related equipment, or equivalent, as required to maintain an isokinetic sampling rate and to determine sample volume.

2.1.7 Barometer—To measure atmospheric pressure to ±0.1 inch Hg.

[1] Trade name.

2.2 Sample recovery.

2.2.1 Wash bottles—Two.

2.2.2 Graduated cylinders—250 ml., 500 ml.

2.2.3 Glass sample storage containers.

2.2.4 Graduated cylinder—250 ml.

2.3 Analysis.

2.3.1 Pipette—25 ml., 100 ml.

2.3.2 Burette—50 ml.

2.3.3 Erlenmeyer flask—250 ml.

2.3.4 Graduated cylinder—100 ml.

2.3.5 Trip balance—300 g. capacity, to measure to ±0.05 g.

2.3.6 Dropping bottle—to add indicator solution.

3. *Reagents.*

3.1 Sampling.

3.1.1 Filters—Glass fiber, MSA type 1106 BH, or equivalent, of a suitable size to fit in the filter holder.

3.1.2 Silica gel—Indicating type, 6-16 mesh, dried at 175° C. (350° F.) for 2 hours.

3.1.3 Water—Deionized, distilled.

3.1.4 Isopropanol, 80%—Mix 800 ml. of isopropanol with 200 ml. of deionized, distilled water.

3.1.5 Hydrogen peroxide, 3%—Dilute 100 ml. of 30% hydrogen peroxide to 1 liter with deionized, distilled water.

3.1.6 Crushed ice.

3.2 Sample recovery.

3.2.1 Water—Deionized, distilled.

3.2.2 Isopropanol, 80%.

3.3 Analysis.

3.3.1 Water—Deionized, distilled.

3.3.2 Isopropanol.

3.3.3 Thorin indicator—1-(*o*-arsonophenylazo)-2-naphthol-3, 6-disulfonic acid, disodium salt (or equivalent). Dissolve 0.20 g. in 100 ml. distilled water.

3.3.4 Barium perchlorate (0.01*N*)—Dissolve 1.95 g. of barium perchlorate [$Ba(CO_4)_2 \cdot 3H_2O$] in 200 ml. distilled water and dilute to 1 liter with isopropanol. Standardize with sulfuric acid.

3.3.5 Sulfuric acid standard (0.01*N*)—Purchase or standardize to ± 0.0002 *N* against 0.01 *N* NaOH which has previously been standardized against primary standard potassium acid phthalate.

4. *Procedure.*

4.1 Sampling.

4.1.1 After selecting the sampling site and the minimum number of sampling points, determine the stack pressure, temperature, moisture, and range of velocity head.

4.1.2 Preparation of collection train. Place 100 ml. of 80% isopropanol in the first impinger, 100 ml. of 3% hydrogen peroxide in both the second and third impingers, and about 200 g. of silica gel in the fourth impinger. Retain a portion of the reagents for use as blank solutions. Assemble the train without the probe as shown in Figure 8-1 with the filter between the first and second impingers. Leak check the sampling train at the sampling site by plugging the inlet to the first impinger and pulling a 15-inch Hg vacuum. A leakage rate not in excess of 0.02 c.f.m. at a vacuum of 15 inches Hg is acceptable. Attach the probe and turn on the probe heating system. Adjust the probe heater setting during sampling to prevent any visible condensation. Place crushed ice around the impingers. Add more ice during the run to keep the temperature of the gases leaving the last impinger at 70° F. or less.

4.1.3 Train operation. For each run, record the data required on the example sheet shown in Figure 8-2. Take readings at each sampling point at least every 5 minutes and when significant changes in stack conditions necessitate additional adjustments in flow rate. To begin sampling, position the nozzle at the first traverse point with the tip pointing directly into the gas stream. Start the pump and immediately adjust the flow to isokinetic conditions. Maintain isokinetic sampling throughout the sampling period. Nomographs are available which aid in the

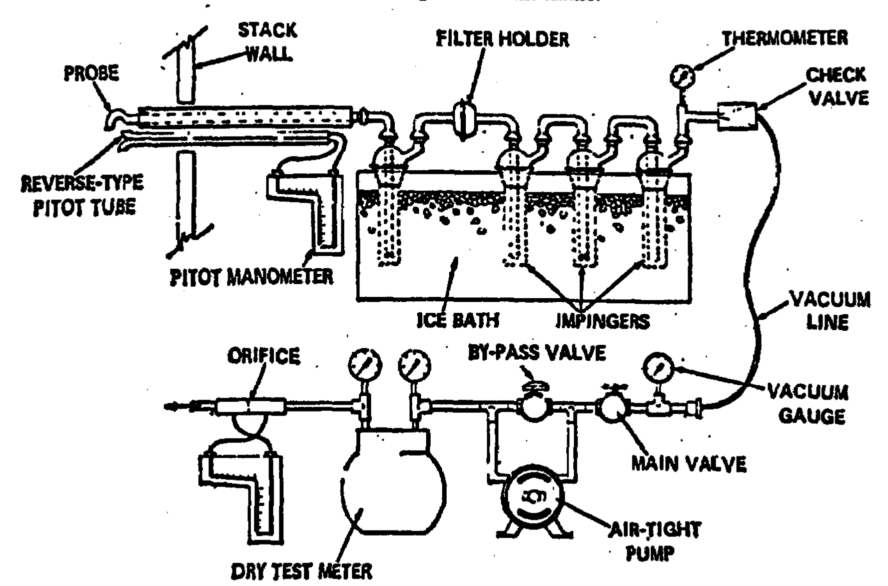



Figure 8-1. Sulfuric acid mist sampling train.

rapid adjustment of the sampling rate without other computations. *APTD-0576 details* the procedure for using these nomographs. At the conclusion of each run, turn off the pump and record the final readings. Remove the probe from the stack and disconnect it from the train. *Drain the ice bath and purge* the remaining part of the train by drawing clean ambient air through the system for 15 minutes.

PLANT ____________
LOCATION ____________
OPERATOR ____________
DATE ____________
RUN NO. ____________
SAMPLE BOX NO. ____________
METER BOX NO. ____________
METER ΔH@ ____________
C FACTOR ____________

SCHEMATIC OF STACK CROSS SECTION

AMBIENT TEMPERATURE ____________
BAROMETRIC PRESSURE ____________
ASSUMED MOISTURE, % ____________
HEATER BOX SETTING ____________
PROBE LENGTH, m. ____________
NOZZLE DIAMETER, in. ____________
PROBE HEATER SETTING ____________

| TRAVERSE POINT NUMBER | SAMPLING TIME (θ), min. | STATIC PRESSURE ($P_s$), in. Hg. | STACK TEMPERATURE ($T_s$), °F | VELOCITY HEAD ($\Delta P_s$) | PRESSURE DIFFERENTIAL ACROSS ORIFICE METER ($\Delta H$), in. $H_2O$ | GAS SAMPLE VOLUME ($V_m$), ft³ | GAS SAMPLE TEMPERATURE AT DRY GAS METER: INLET ($T_{m_{in}}$), °F | GAS SAMPLE TEMPERATURE AT DRY GAS METER: OUTLET ($T_{m_{out}}$), °F | SAMPLE BOX TEMPERATURE, °F | IMPINGER TEMPERATURE, °F |
|---|---|---|---|---|---|---|---|---|---|---|
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| | | | | | | | | | | |
| TOTAL | | | | | | | Avg. | Avg. | | |
| AVERAGE | | | | | | | Avg. | | | |

Figure 8-2. Field data.

4.2 Sample recovery.

4.2.1 Transfer the isopropanol from the first impinger to a 250 ml. graduated cylinder. Rinse the probe, first impinger, and all connecting glassware before the filter with 80% isopropanol. Add the rinse solution to the cylinder. Dilute to 250 ml. with 80% isopropanol. Add the filter to the solution, mix, and transfer to a suitable storage container. Transfer the solution from the second and third impingers to a 500 ml. graduated cylinder. Rinse all glassware between the filter and silica gel impinger with deionized, distilled water and add this rinse water to the cylinder. Dilute to a volume of 500 ml. with deionized, distilled water. Transfer the solution to a suitable storage container.

4.3 Analysis.

4.3.1 Shake the container holding isopropanol and the filter. If the filter breaks up, allow the fragments to settle for a few minutes before removing a sample. Pipette a 100 ml. aliquot of sample into a 250 ml. Erlenmeyer flask and add 2 to 4 drops of thorin indicator. Titrate the sample with barium perchlorate to a pink end point. Make sure to record volumes. Repeat the titration with a second aliquot of sample. Shake the container holding the contents of the second and third impingers. Pipette a 25 ml. aliquot of sample into a 250 ml. Erlenmeyer flask. Add 100 ml. of isopropanol and 2 to 4 drops of thorin indicator. Titrate the sample with barium perchlorate to a pink end point. Repeat the titration with a second aliquot of sample. Titrate the blanks in the same manner as the samples.

5. *Calibration.*

5.1 Use standard methods and equipment which have been approved by the Administrator to calibrate the orifice meter, pitot tube, dry gas meter, and probe heater.

5.2 Standardize the barium perchlorate with 25 ml. of standard sulfuric acid containing 100 ml. of isopropanol.

6. *Calculations.*

6.1 Dry gas volume. Correct the sample volume measured by the dry gas meter to standard conditions (70° F., 29.92 inches Hg) by using Equation 8-1.

$$V_{m_{std}}=V_m\left(\frac{T_{std}}{T_m}\right)\left(\frac{P_{bar}+\frac{\Delta H}{13.6}}{P_{std}}\right)=\left(17.71\frac{°R}{\text{in. Hg}}\right)V_m\left(\frac{P_{bar}+\frac{\Delta H}{13.6}}{T_m}\right)$$

equation 8-1

where:

$V_{m_{std}}$ = Volume of gas sample through the dry gas meter (standard conditions), cu. ft.

$V_m$ = Volume of gas sample through the dry gas meter (meter conditions), cu. ft.

$T_{std}$ = Absolute temperature at standard conditions, 530° R.

$T_m$ = Average dry gas meter temperature, °R.

$P_{bar}$ = Barometric pressure at the orifice meter, inches Hg.

$\Delta H$ = Pressure drop across the orifice meter, inches $H_2O$.

13.6 = Specific gravity of mercury.

$P_{std}$ = Absolute pressure at standard conditions, 29.92 inches Hg.

6.2 Sulfuric acid concentration.

$$C_{H_2SO_4}=\left(1.08\times10^{-4}\frac{\text{lb.-l.}}{\text{g.-ml.}}\right)\frac{(V_t-V_{tb})(N)\left(\frac{V_{soln}}{V_a}\right)}{V_{m_{std}}}$$

equation 8-2

$C_{H_2SO_4}$ = Concentration of sulfuric acid at standard conditions, dry basis, lb./cu. ft.

$1.08\times10^{-4}$ = Conversion factor including the number of grams per gram equivalent of sulfuric acid (49 g./g.-eq.), 453.6 g./lb., and 1,000 ml./l., lb.-l./g.-ml.

$V_t$ = Volume of barium perchlorate titrant used for the sample, ml.

$V_{tb}$ = Volume of barium perchlorate titrant used for the blank, ml.

$N$ = Normality of barium perchlorate titrant, g.-eq./l.

$V_{soln}$ = Total solution volume of sulfuric acid (first impinger and filter), ml.

$V_a$ = Volume of sample aliquot titrated, ml.

$V_{m_{std}}$ = Volume of gas sample through the dry gas meter (standard conditions), cu. ft., see Equation 8-1.

6.3 Sulfur dioxide concentration.

$$C_{SO_2}=\left(7.05\times10^{-5}\frac{\text{lb.-l.}}{\text{g.-ml.}}\right)\frac{(V_t-V_{tb})(N)\left(\frac{V_{soln}}{V_a}\right)}{V_{m_{std}}}$$

equation 8-3

where:

$C_{SO_2}$ = Concentration of sulfur dioxide at standard conditions, dry basis, lb./cu. ft.

$7.05\times10^{-5}$ = Conversion factor including the number of grams per gram equivalent of sulfur dioxide (32 g./g.-eq.) 453.6 g./lb., and 1,000 ml./l., lb.-l./g.-ml.

$V_t$ = Volume of barium perchlorate titrant used for the sample, ml.

$V_{tb}$ = Volume of barium perchlorate titrant used for the blank, ml.

$N$ = Normality of barium perchlorate titrant, g.-eq./l.

$V_{soln}$ = Total solution volume of sulfur dioxide (second and third impingers), ml.

$V_a$ = Volume of sample aliquot titrated, ml.

$V_{m_{std}}$ = Volume of gas sample through the dry gas meter (standard conditions), cu. ft., see Equation 8-1.

7. *References.*


Atmospheric Emissions from Sulfuric Acid Manufacturing Processes, U.S. DHEW, PHS, Division of Air Pollution, Public Health Service Publication No. 999-AP-13, Cincinnati, Ohio, 1965.

Corbett, D. F., The Determination of $SO_2$ and $SO_3$ in Flue Gases, Journal of the Institute of Fuel, 24:237-243, 1961.

Martin, Robert M., Construction Details of Isokinetic Source Sampling Equipment, Environmental Protection Agency, Air Pollution Control Office Publication No. APTD-0581.

Patton, W. F., and J. A. Brink, Jr., New Equipment and Techniques for Sampling Chemical Process Gases, J. Air Pollution Control Assoc. *13*, 162 (1963).

# APPENDIX F

# ANALYSIS OF FUELS USED

TABLE F-1. LIST OF FUELS USED

| Date in Service* | SwRI Designation | Type Fuel | Base Stock | % Sulfur | SwRI Additives to Base Stock | Project Phase Using Fuel |
|---|---|---|---|---|---|---|
| | EM-205F | unleaded gas | - | 0.013 | None | base stock |
| | EM-208FD | leaded gas | EM-205F | 0.051 | motor mix, thiophene | characterization |
| | EM-225F | unleaded gas | EM-205F | 0.051 | thiophene | |
| | EM-212F | unleaded gas | Gulf Crest | 0.042 | thiophene | distance accumulation<br>characterization<br>procedure development<br>baseline |
| | EM-233F | unleaded gas | Gulf Crest | 0.033 | thiophene | baseline (IV-17) |
| | EM-236F | unleaded gas | EM-205F | 0.031 | thiophene | procedure development<br>baseline<br>distance accumulation |
| 9/15/75 | EM-243F | unleaded gas | Gulf Crest | 0.042 | thiophene | distance accumulation |
| 12/30/75 | EM-250F | unleaded gas | Gulf Crest | 0.041 | thiophene | distance accumulation |
| 2/25/75 | EM-254F | unleaded gas | Gulf Crest | 0.041 | thiophene | distance accumulation |
| 5/7/76 | EM-258F | unleaded gas | Gulf Crest | 0.041 | thiophene | distance accumulation |
| | EM-246F | diesel - 2 | Gulf 2D | 0.25 | Ditertiary butyl disulfide | characterization and baseline |

*Applies to distance cars only

TABLE F-2. ANALYSIS OF PHILLIPS UNLEADED GASOLINE, EM-205-F

**PHILLIPS PETROLEUM COMPANY**
PHILTEX PLANT — PHILLIPS, TEXAS

DATE OF SHIPMENT ______
CUSTOMER ORDER NO. ______
INV. OR REQN. NO. ______

UNLEADED GASOLINE BLEND

CONTRACT NUMBER: 68-02-1122

LOT T-817

| | Results | Specification Min. | Specification Max. |
|---|---|---|---|
| Research Octane Number | 93.2 | 91.5 | 93.5 |
| Motor Octane Number | 84.7 | 82 | 85 |
| Ron-Mon | 8.5 | 8 | 10 |
| Reid Vapor Pressure, psia | 10.2 | 9.8 | 10.2 |
| Distillation, ASTM D-86, F | | | |
| 10% | 123 | - | 140 |
| 50% | 199 | - | 250 |
| 95% | 325 | 320 | 350 |
| 100% | 383 | - | 380 |
| API Gravity @ 60 F | 61.6 | - | - |
| FIA Analysis | | | |
| Aromatics % | 24.0 | 24 | 28 |
| Olefins % | 8.3 | 7 | 10 |
| Paraffins % | 67.7 | 62 | 69 |
| ASTM Gum, mg/100 ml | 0.57 | Nonobservable | |
| Stability, hrs | 24+ | 24+ | - |
| Sulfur, ppm | 127(1) | - | 100 |
| Phosphorous, ppm | 1 | - | 30 |
| Lead, g/gallon | 0.00004 | - | 0.01 |
| Diene Number, meq/liter | 0.0 | - | 1 |
| Fuel Composition, LV % (2) | | | |
| Benzene | 0.1 | - | 4 |
| Toluene | 8.1 | - | 15 |
| n-Butane | 8.0 | - | 12 |
| Isopentane | 8.3 | - | 12 |
| n-pentane | 5.4 | - | 8 |

Fuel was inhibited with 5 lbs/1000 bbls of Dupont 22 oxidation inhibitor.

(1) Fails Specification, Waiver obtained from customer.

(2) Benzene and Toluene were determined by infrared analysis by direct calibration techniques.

E. J. Horning
Quality Control Superintendent

## TABLE F-3. ANALYSIS OF GULF CREST UNLEADED REGULAR GASOLINE, EM-212-F
(Prior to Addition of Thiophene)

| Property | Test Method | Results |
|---|---|---|
| Distillation (Deg. F°) (curve attached) | ASTM D-216 | I. B. P. 87° |
| | | 5% 109° |
| | | 10% 119° |
| | | 20% 137° |
| | | 50% 215° |
| | | 70% 260° |
| | | 90% 352° |
| | | 95% 387° |
| | | E. P. 420° |
| | | % Recovered 98.00 |
| | | % Residue .80 |
| | | % Loss 1.20 |
| R.V. P. | ASTM D-323 | 8.1 Corrected |
| V/L calculated | ASTM D-439 | Temp. F° @ V/L = 4 132 |
| | | Temp. F° @ V/L = 10 136 |
| | | Temp. F° @ V/L = 20 141 |
| | | Temp. F° @ V/L = 30 145 |
| | | Temp. F° @ V/L = 45 150 |
| Gravity | ASTM D-287 | API 60.6 @ 60°C |
| | | Specific 0.7366 corrected |
| Lead | ASTM D-3237 | 0.005 g/gal |
| Sulfur | ASTM D-1266 | 0.015 wt. % |
| F. I. A. | ASTM D-1319 | % Aromatics 31.86 |
| | | % Olefins 1.18 |
| | | % Saturates 66.96 |
| Phosphorus | ASTM D-3231 | Temp. 0°C - 0.0008 g/gal |
| Research Octane | ASTM D-2722 | 92.0 |
| Motor Octane | ASTM D-2723 | 83.8 |
| R + M/2 | | 87.9 |

TABLE F-4. ANALYSIS OF GULF CREST UNLEADED GASOLINE, EM-250-F

| | |
|---|---|
| RON | 91.6 |
| MON | 80.2 |
| RVP | 11.1 psi |
| Sp. Gravity | .7316 |
| Pb G/gal | 0.002 |
| S % wt. | 0.041 |
| P g/gal | 0.0008 |
| F.I.A. | % |
| SAT. | 73.4 |
| Oli. | 5.2 |
| Aro. | 21.3 |
| DIST.. | F |
| IBP | 85 |
| 10% | 111 |
| 20% | 125 |
| 50% | 205 |
| 70% | 261 |
| 95% | 395 |
| EP | 427 |
| Res. % | 98.0 |
| Loss % | 0.9 |

TABLE F-5. ANALYSIS OF GULF 2D DIESEL FUEL, EM-176-F
(Used as Base Fuel for EM-246-F)

| Property | Results |
|---|---|
| Gravity, API at 60°F | 36.4 |
| Sulfur, % wt. | 0.11 |
| Flash Pt., °F | 150 |
| Vis. at 100°F | 2.60 cs<br>(34.75 SuS) |
| Cetane No. (Calc) | 47.59 |
| FIA | |
| Aromatics | 25.6 |
| Olefins | 71.7 |
| Saturates | 2.7 |
| Distillation: | |
| IBP, °F | 368 |
| 10%, °F | 424 |
| 20%, °F | 444 |
| 30%, °F | 461 |
| 40%, °F | 479 |
| 50%, °F | 482 |
| 60%, °F | 508 |
| 70%, °F | 525 |
| 80%, °F | 544 |
| 90%, °F | 571 |
| 95%, °F | 598 |
| End Point, °F | 623 |

TABLE F-6. X-RAY FLUORESCENCE ANALYSIS FOR SULFUR OF SEVERAL SwRI FUELS

**EXXON RESEARCH AND ENGINEERING COMPANY**

P.O. BOX 51, LINDEN, N.J. 07036

PRODUCTS RESEARCH DIVISION

R.R. CECIL
Director
Fuels Research Laboratory

April 3, 1975

Gasoline Sulfur
Analysis for SWRI

Ref. No. 7512 1431

Dr. Melvin Ingalls
Southwest Research Institute
8500 Culebra Road
Post Office Drawer 28510
San Antonio, Texas 78284

Dear Dr. Ingalls:

The sulfur analysis results on the gasoline samples you sent us are as follows:

| SWRI Sample Description | Wt. % Sulfur |
|---|---|
| EM-212F | 0.10* |
| EM-217F | <0.01 |
| EM-208F | 0.053 |
| Unlabeled | 0.094 |
| EM-212F | 0.045 |

The second sample labeled EM-212F was received several weeks after the other samples and had a sulfur content of 0.045 wt. %. The analytical method used was x-ray fluorescence.

If I can be of further assistance to you, please contact me.

Yours truly,

Morton Beltzer

M. BELTZER

MB:pc

*Typographical error, should be 0.01 per telecon with M. Beltzer

TABLE F-7. X-RAY FLUORESCENCE ANALYSIS FOR SULFUR OF SwRI FUEL EM-236-F

**EXXON RESEARCH AND ENGINEERING COMPANY**

P.O. BOX 51, LINDEN, N.J. 07036

PRODUCTS RESEARCH DIVISION
R.R. CECIL
Director
Fuels Research Laboratory

June 25, 1975

Sulfur Analysis of SWRI Fuels

Ref. No. 7512 1524

Mr. Melvin Ingalls
Southwest Research Institute
8500 Culebra Road
Post Office Drawer 28510
San Antonio, Texas 78284

Dear Mel:

The results of the sulfur analyses of the fuel samples you sent are as follows:

| Sample Designation | Fuel Sulfur, Wt. % |
|---|---|
| EM 1 | 0.030 |
| EM 2 | 0.030 |
| EM 3 | 0.027 |
| EM 4 | 0.030 |
| EM 5 | 0.031 |
| EM 6 | 0.029 |
| EM 7 | 0.031 |
| EM 8 | 0.030 |
| EM 9 | 0.027 |
| EM 10 | 0.032 |
| EM 11 | 0.031 |
| EM 12 | 0.031 |
| EM 13 | 0.025 |
| EM 14 | 0.031 |
| EM 15 | 0.027 |
| EM 16 | 0.030 |
| EM 17 | 0.030 |
| EM 18 | 0.025 |
| EM 19 | 0.032 |
| EM 20 | 0.030 |

Please let me know if we can be of further help to you.

Yours truly,

M. Beltzer

M. BELTZER

MB:ph

TABLE F-8. COMPARISON OF EXXON X-RAY AND ARMY F&L LAB LAMP SULFUR

| Fuel | | Exxon X-Ray | Army F&L Lab Lamp Sulfur |
|---|---|---|---|
| EM-208F | | 0.053 | 0.0528 |
| EM-212F (w/o thiophene) | | 0.010 | |
| EM-212 (w/ thiophene) | | 0.045 | 0.0440 |
| EM-236 | Barrel 1 | 0.030 | 0.030 |
| " | Barrel 2 | 0.030 | 0.030 |
| " | Barrel 3 | 0.027 | 0.031 |
| " | Barrel 4 | 0.030 | 0.032 |
| " | Barrel 5 | 0.031 | 0.032 |
| " | Barrel 6 | 0.029 | 0.031 |
| " | Barrel 7 | 0.031 | 0.033 |
| " | Barrel 8 | 0.030 | 0.032 |
| " | Barrel 9 | 0.027 | 0.029 |
| " | Barrel 10 | 0.032 | 0.031 |

TABLE F-9. ANALYSIS OF SULFUR IN TEST FUELS
BY U. S. ARMY F&L LABORATORY

| F&L Lab Report No. | Fuel Designation | Number of Times Analyzed | Average Percent Sulfur |
|---|---|---|---|
| 3730 | EM-208-F(B) | 3 | 0.0528 |
| 3818 | EM-212-F | 3 | 0.0440 |
| 3926 | EM-236-F (1) | 2 | 0.030 |
| | " (2) | 2 | 0.030 |
| | " (3) | 1 | 0.031 |
| | " (4) | 1 | 0.032 |
| | " (5) | 1 | 0.032 |
| | " (6) | 1 | 0.031 |
| | " (7) | 1 | 0.033 |
| | " (8) | 1 | 0.032 |
| | " (9) | 1 | 0.029 |
| | " (10) | 1 | 0.031 |
| 4111 | EM-243-F | 3 | 0.042 |
| 4236 | EM-246-F | 1 | 0.246 |
| 4257 | EM-250-F | 2 | 0.041 |
| 4303 | EM-254-F | 2 | 0.041 |
| 4378 (5/12/76) | EM-258-F | 2 | 0.041 |

# APPENDIX G

# RESULTS FROM INDIVIDUAL TESTS OF SULFATE CHARACTERIZATION CARS

TABLE G-1. EXHAUST EMISSIONS FROM A 1972 PLYMOUTH FURY
WITH A 360 CID ENGINE (NO CATALYST)
(LEADED FUEL, 0.051 PERCENT SULFUR)

| | | | Exhaust Emissions, g/km | | | | mg/km | Percent | Percent | |
|---|---|---|---|---|---|---|---|---|---|---|
| Test Date | Test Type | Test Duration | HC | CO | $NO_x$ | BCA $SO_2$ | BCA $H_2SO_4$ | Fuel S as $SO_2$ | Fuel S as $H_2SO_4$ | Total Recovery |
| 10/22/74 | '75 FTP | | 2.91 | 54.42 | 3.68 | ---- | ---- | ----- | --- | ----- |
| 11/7/74 | '75 FTP | | 3.04 | 54.37 | 3.19 | ---- | ---- | ----- | --- | ----- |
| 11/19/74 | '75 FTP | | 3.20 | 60.45 | 3.07 | ---- | ---- | ----- | --- | ----- |
| 11/20/74 | '75 FTP | | 2.42 | 50.91 | 2.80 | ---- | ---- | ----- | --- | ----- |
| 1/14/74 | '75 FTP | | ---- | ----- | ---- | 0.14 | ---- | 94.2 | --- | ----- |
| 2/18/74 | '75 FTP | | ---- | ----- | ---- | 0.14 | ---- | 84.7 | --- | ----- |
| Average | '75 FTP | | 2.89 | 55.04 | 3.19 | 0.14 | ---- | 89.5 | --- | ----- |
| | | | S=.34 | 3.96 | .37 | | | | | |
| | | | Cv=12% | 7% | 12% | | | | | |
| 10/22/74 | 48 kph | 90 min. | 1.59 | 25.5 | ---- | ---- | ---- | ----- | --- | ----- |
| 11/7/74 | 48 kph | 90 min. | 1.35 | 23.5 | 0.35 | ---- | ---- | ----- | --- | ----- |
| 11/18/74 | 48 kph | 90 min. | 1.59 | 37.8 | 0.20 | ---- | ---- | ----- | --- | ----- |
| 11/19/74 | 48 kph | 90 min. | 1.80 | 27.3 | 0.51 | ---- | ---- | ----- | --- | ----- |
| 2/17/75 | 48 kph | 90 min. | 1.52 | 32.6 | 0.66 | 0.09 | ---- | 97.6 | --- | ----- |
| 2/18/75 | 48 kph | 90 min. | 1.24 | 28.2 | 0.50 | 0.08 | ---- | 86.2 | --- | ----- |
| Average | 48 kph | 90 min. | 1.51 | 29.15 | 0.44 | 0.08 | ---- | 91.9 | --- | ----- |
| | | | S=.20 | 5.22 | 0.17 | | | | | |
| | | | Cv=13% | 18% | 39.4% | | | | | |
| 11/8/74 | 96 kph | 60 min. | 1.07 | 7.1 | 2.62 | ---- | ---- | ----- | --- | ----- |
| 11/8/74 | 96 kph | 60 min. | 0.99 | 5.4 | 3.14 | ---- | ---- | ----- | --- | ----- |
| 11/18/74 | 96 kph | 60 min. | 1.33 | 9.8 | 4.60 | ---- | ---- | ----- | --- | ----- |
| 11/21/74 | 96 kph | 60 min. | 0.92 | 4.7 | 4.15 | ---- | ---- | ----- | --- | ----- |
| 1/13/75 | 96 kph | 84 min. | ---- | ----- | ---- | 0.08 | ---- | 100.3 | --- | ----- |
| 1/13/75 | 96 kph | 84 min. | ---- | ----- | ---- | 0.09 | ---- | 107.0 | --- | ----- |
| Average | 96 kph | | 1.08 | 6.75 | 3.63 | 0.08 | ---- | 103.7 | --- | ----- |
| | | | S=.18 | 2.27 | .91 | | | | | |
| | | | Cv=17% | 34% | 25% | | | | | |

TABLE G-2. EXHAUST EMISSIONS FROM A 1972 PLYMOUTH FURY
WITH A 360 CID ENGINE (NO CATALYST)
(UNLEADED FUEL, 0.51 PERCENT SULFUR)

| Test Date | Test Type | Test Duration | Exhaust Emissions, g/km HC | CO | $NO_x$ | BCA $SO_2$ | mg/km BCA $H_2SO_4$ | Percent Fuel S as $SO_2$ | Percent Fuel S as $H_2SO_4$ | Total Recovery |
|---|---|---|---|---|---|---|---|---|---|---|
| 1/28/75 | '75 FTP | | 2.73 | 52.59 | 3.76 | 1.71 | 2.30 | 97.1 | 0.8 | 97.8 |
| 1/29/75 | '75 FTP | | 2.52 | 50.00 | 3.14 | 1.46 | 1.86 | 102.5 | 0.9 | 103.5 |
| Average | '75 FTP | | 2.63 | 51.30 | 3.45 | 1.59 | 2.08 | 99.8 | 0.9 | 100.8 |
| 1/27/75 | 48 kph | 90 min. | 0.96 | 33.7 | 0.38 | 0.08 | 0.11 | 87.1 | 0.1 | 87.3 |
| 1/28/75 | 48 kph | 90 min. | 1.45 | 30.3 | 0.38 | 0.08 | 0.13 | 90.9 | 0.1 | 91.0 |
| Average | 48 kph | 90 min. | 1.21 | 32.0 | 0.38 | 0.08 | 0.12 | 89.0 | 0.1 | 89.1 |
| 1/29/75 | 96 kph | 60 min. | 0.89 | 6.3 | 3.64 | 0.08 | 2.70 | 88.7 | 2.1 | 90.8 |
| 1/29/75 | 96 kph | 60 min. | 1.07 | 8.4 | 3.67 | 0.08 | 1.00 | 87.3 | 0.7 | 88.0 |
| Average | 96 kph | 60 min. | 0.98 | 7.4 | 3.66 | 0.08 | 1.85 | 88.0 | 1.4 | 89.4 |

TABLE G-3. EXHAUST EMISSIONS FROM A 1974 HONDA CVCC CIVIC WITH A 1500cc ENGINE

(Unleaded Fuel, 0.041 Percent Sulfur)

| Test Date | Test Type | Run Duration (Min.) | Exhaust Emissions g/km HC | Exhaust Emissions g/km CO | Exhaust Emissions g/km $NO_x$ | Exhaust Emissions g/km BCA $SO_2$ | mg/km BCA $H_2SO_4$ | Percent Fuel S as $SO_2$ | Percent Fuel S as $H_2SO_4$ | Percent Fuel S Recovered |
|---|---|---|---|---|---|---|---|---|---|---|
| 2/11/75 | '75 FTP | | 0.83 | 2.41 | 0.60 | 0.05 | 0.5 | 77.7 | 0.6 | 78.3 |
| 2/12/75 | '75 FTP | | 0.59 | 2.45 | 0.50 | 0.05 | 0.3 | 85.7 | 0.4 | 86.1 |
| | Avg. '75 FTP | | 0.71 | 2.43 | 0.55 | 0.05 | 0.4 | 81.7 | 0.5 | 82.2 |
| 2/10/75 | 48 kph | 90 | 0.09 | 1.07 | 0.44 | 0.03 | 0.2 | 92.3 | 0.5 | 92.8 |
| 2/19/75 | 48 kph | 90 | 0.05 | 1.08 | 0.29 | 0.04 | 0.2 | 133.6 | 0.5 | 134.1 |
| | Avg. 48 kph | | 0.07 | 1.08 | 0.37 | 0.04 | 0.2 | 113.0 | 0.5 | 113.5 |
| 2/10/75 | 96 kph | 60 | 0.04 | 0.89 | 1.45 | 0.05 | 0.6 | 127.2 | 1.0 | 128.2 |
| 3/12/75 | 96 kph | 30 | 0.00 | 0.23 | 1.34 | 0.04 | 1.1 | 83.5 | 1.7 | 85.2 |
| | Avg. 96 kph | | 0.02 | 0.56 | 1.40 | 0.04 | 0.9 | 105.4 | 1.3 | 106.7 |

TABLE G-4. EXHAUST EMISSIONS FROM A 1975 FORD GRANADA WITH A 351 CID ENGINE (NO CATALYST)
(Unleaded Fuel, 0.041 Percent Sulfur)

| Test Date | Test Type | Run Duration (Min.) | Exhaust Emissions, g/km HC | Exhaust Emissions, g/km CO | Exhaust Emissions, g/km $NO_x$ | Exhaust Emissions, g/km BCA $SO_2$ | mg/km BCA $H_2SO_4$ | Percent Fuel S as $SO_2$ | Percent Fuel S as $H_2SO_4$ | Percent Fuel S Recovered |
|---|---|---|---|---|---|---|---|---|---|---|
| 3/7/75 | '75 FTP | | 1.05 | 5.68 | 2.02 | 0.10 | 0.5 | 91.0 | 0.3 | 91.3 |
| 3/10/75 | '75 FTP | | 0.97 | 5.86 | 2.11 | 0.11 | 0.4 | 89.0 | 0.2 | 89.2 |
| | Average '75 FTP | | 1.01 | 5.77 | 2.07 | 0.10 | 0.5 | 90.0 | 0.3 | 90.3 |
| 3/6/75 | 48 kph | 30 | 0.26 | 1.21 | 0.54 | 0.05 | 0.2 | 83.6 | 0.1 | 83.7 |
| 3/7/75 | 48 kph | 30 | 0.19 | 1.09 | 0.44 | 0.06 | 0.1 | 81.5 | 0.1 | 81.6 |
| | Average 48 kph | | 0.22 | 1.15 | 0.49 | 0.06 | 0.1 | 82.6 | 0.1 | 82.7 |
| 3/6/75 | 96 kph | 30 | 0.16 | 1.75 | 1.85 | 0.06 | 0.3 | 89.4 | 0.3 | 89.7 |
| 3/7/75 | 96 kph | 30 | 0.18 | 1.83 | 1.38 | 0.06 | 0.2 | 108.2 | 0.2 | 108.4 |
| | Average 96 kph | | 0.17 | 1.79 | 1.62 | 0.06 | 0.2 | 98.8 | 0.2 | 99.0 |

NOTE:

For Characterization Tests of:

1975 Federal Plymouth Gran Fury

1975 Federal Chevrolet Impala

1975 California Plymouth Gran Fury

1975 California Chevrolet Impala

See the 3200 km tests of cars EM-1, 2, 3 and 4 in Appendix H.

TABLE G-5. EXHAUST EMISSIONS FROM A 1975 MERCEDES 240D
(Diesel fuel, 0.23% Sulfur)

| Date | Test Type | Duration | g/km HC | g/km CO | g/km $NO_x$ | g/km $SO_2$ | mg/km $H_2SO_4$ | $H_2SO_4$ as % of Fuel S | $SO_2$ as % of Fuel S | Total Recovery |
|---|---|---|---|---|---|---|---|---|---|---|
| 11/18/75 | FTP | | 0.23 | 0.43 | 0.78 | 0.392 | 9.35 | 1.78 | 113.91 | 115.68 |
| 11/19/75 | FTP | | 0.05 | 0.49 | 0.77 | 0.283 | 12.77 | 2.32 | 78.72 | 81.04 |
| 11/20/75 | FTP | | 0.00 | 0.48 | 0.78 | 0.332 | 8.27 | 1.55 | 95.49 | 97.05 |
| Average | | | 0.09 | 0.47 | 0.78 | 0.336 | 10.13 | 1.88 | 96.04 | 97.92 |
| 11/18/75 | SET-7 | 23 min | 0.10 | 0.36 | 0.74 | 0.363 | 9.75 | 2.17 | 123.57 | 125.74 |
| 11/19/75 | SET-7 | 23 min | 0.04 | 0.38 | 0.90 | 0.324 | 11.48 | 2.50 | 108.35 | 110.86 |
| 11/20/75 | SET-7 | 23 min | 0.02 | 0.27 | 0.74 | 0.290 | 8.31 | 2.06 | 110.28 | 112.35 |
| Average | | | 0.05 | 0.34 | 0.79 | 0.326 | 9.85 | 2.24 | 114.07 | 116.32 |
| 11/18/75 | SET-7 | 23 min | 0.05 | 0.34 | 0.71 | 0.213 | 10.05 | 2.29 | 74.22 | 76.51 |
| 11/19/75 | SET-7 | 23 min | 0.02 | 0.37 | 0.83 | 0.277 | 11.02 | 2.37 | 90.91 | 93.28 |
| 11/20/75 | SET-7 | 23 min | 0.02 | 0.30 | 0.77 | 0.279 | 9.91 | 2.28 | 98.46 | 100.74 |
| Average | | | 0.03 | 0.34 | 0.77 | 0.256 | 10.33 | 2.31 | 87.86 | 90.18 |
| 11/18/75 | FET | 12 min | 0.04 | 0.31 | 0.71 | 0.356 | 9.39 | 2.33 | 134.95 | 137.28 |
| 11/19/75 | FET | 12 min | 0.05 | 0.31 | 0.82 | 0.296 | 9.61 | 2.24 | 105.63 | 107.87 |
| 11/20/75 | FET | 12 min | 0.05 | 0.24 | 0.68 | 0.245 | 10.21 | 2.86 | 105.31 | 108.18 |
| Average | | | 0.05 | 0.29 | 0.74 | 0.299 | 9.74 | 2.48 | 115.30 | 117.78 |
| 11/18/75 | SET-7 | 23 min | 0.08 | 0.38 | 0.71 | 0.315 | 10.22 | 2.32 | 109.52 | 111.84 |
| 11/19/75 | SET-7 | 23 min | 0.06 | 0.33 | 0.82 | 0.310 | 11.03 | 2.44 | 104.72 | 107.16 |
| 11/20/75 | SET-7 | 23 min | 0.03 | 0.31 | 0.78 | 0.344 | 9.67 | 2.20 | 119.90 | 122.11 |
| Average | | | 0.06 | 0.34 | 0.77 | 0.323 | 10.31 | 2.32 | 111.38 | 113.70 |
| 11/18/75 | SET-7 | 23 min | 0.05 | 0.33 | 0.78 | 0.342 | 11.42 | 2.56 | 117.56 | 120.12 |
| 11/19/75 | SET-7 | 23 min | 0.01 | 0.36 | 0.81 | 0.277 | 11.70 | 2.58 | 93.59 | 96.17 |
| 11/20/75 | SET-7 | 23 min | 0.03 | 0.33 | 0.79 | 0.229 | 9.89 | 2.25 | 79.93 | 82.18 |
| Average | | | 0.03 | 0.34 | 0.79 | 0.283 | 11.00 | 2.46 | 97.03 | 99.49 |
| 11/19/75 | 48 Accel | 20 min | 0.04 | 0.14 | 0.52 | 0.367 | 3.23 | 1.07 | 185.72 | 186.79 |
| 11/20/75 | 48 Accel | 20 min | 0.02 | 0.04 | 0.44 | 0.248 | 2.12 | 0.87 | 155.40 | 156.27 |
| Average | | | 0.03 | 0.09 | 0.48 | 0.308 | 2.68 | 0.97 | 170.56 | 171.53 |
| 11/19/75 | 48 kph S/S | 20 min | 0.02 | 0.20 | 0.56 | 0.176 | 3.69 | 1.26 | 91.99 | 93.25 |
| 11/20/75 | 48 kph S/S | 20 min | 0.02 | 0.09 | 0.49 | 0.124 | 3.00 | 1.04 | 65.93 | 66.97 |
| Average | | | 0.02 | 0.15 | 0.53 | 0.150 | 3.35 | 1.15 | 78.96 | 80.11 |
| 11/19/75 | 96 Accel | 10 min | 0.01 | 0.38 | 1.00 | 0.313 | 21.85 | 4.53 | 99.21 | 103.75 |
| 11/20/75 | 96 Accel | 10 min | 0.03 | 0.36 | 0.90 | 0.236 | 22.63 | 4.74 | 75.68 | 80.42 |
| Average | | | 0.02 | 0.37 | 0.95 | 0.275 | 22.24 | 4.64 | 87.45 | 92.09 |
| 11/19/75 | 96 kph S/S | 10 min | 0.00 | 0.40 | 1.16 | 0.375 | 13.56 | 2.95 | 124.62 | 127.56 |
| 11/20/75 | 96 kph S/S | 10 min | 0.02 | 0.31 | 0.99 | 0.361 | 12.96 | 2.94 | 125.25 | 128.19 |
| Average | | | 0.01 | 0.36 | 1.08 | 0.368 | 13.26 | 2.94 | 124.94 | 127.88 |

TABLE G-6. EXHAUST SULFUR RECOVERY USING METHOD 8 FOR A 1972 PLYMOUTH WITH 360 CID ENGINE (Leaded Fuel, 0.051% Sulfur)

| Test Date | Test Type | Run Duration | Exhaust Emissions g/km $SO_2$ | Exhaust Emissions g/km $H_2SO_4$ | Percent Fuel S as $SO_2$ | Percent Fuel as $H_2SO_4$ | Percent Fuel Recovered |
|---|---|---|---|---|---|---|---|
| 10/22/74 | 48 kph | 90 min. | 0.07 | none detected | 80 | - | 80 |
| 11/07/74 | 48 kph | 90 min. | 0.06 | none detected | 77 | - | 77 |
| 11/18/74 | 48 kph | 90 min. | 0.08 | none detected | 88 | - | 88 |
| 2/17/75 | 48 kph | 90 min. | 0.05 | none detected | 53 | - | 53 |
| 2/18/75 | 48 kph | 90 min. | 0.07 | none detected | 74 | - | 74 |
| Average | 48 kph | | 0.07 | none detected | 74 | - | 74 |
| | | | | | | | |
| 11/08/74 | 96 kph | 60 min. | 0.07 | none detected | 70 | - | 70 |
| 11/08/74 | 96 kph | 60 min. | 0.08 | none detected | 84 | - | 84 |
| 11/18/74 | 96 kph | 60 min. | 0.08 | none detected | 78 | - | 78 |
| 11/21/74 | 96 kph | 60 min. | 0.08 | none detected | 72 | - | 72 |
| Average | 96 kph | | 0.08 | none detected | 76 | - | 76 |

TABLE G-7. EXHAUST SULFUR RECOVERY USING METHOD 8
FOR A 1972 PLYMOUTH WITH 360 CID ENGINE
(Unleaded Fuel, 0.051% Sulfur)

| Test Date | Test Type | Run Duration | Exhaust Emissions g/km $SO_2$ | Exhaust Emissions g/km $H_2SO_4$ | Percent Fuel S as $SO_2$ | Percent Fuel as $H_2SO_4$ | Percent Fuel Recovered |
|---|---|---|---|---|---|---|---|
| 1/27/75 | 30 mph | 90 min. | 0.06 | 0.0055 | 70 | 3.9 | 74 |
| 1/28/75 | 30 mph | 90 min. | 0.06 | 0.0043 | 75 | 3.2 | 78 |
| Average | 30 mph | | 0.06 | 0.0049 | 72 | 3.6 | 76 |
| 1/29/75 | 60 mph | 60 min. | 0.07 | 0.0037 | 85 | 2.8 | 88 |
| 1/29/75 | 60 mph | 60 min. | 0.07 | 0.0033 | 75 | 2.3 | 77 |
| Average | 60 mph | | 0.07 | 0.0035 | 80 | 2.6 | 83 |

TABLE G-8. EXHAUST SULFUR RECOVERY USING METHOD 8 FOR A 1974 HONDA CIVIC WITH A 1500cc CVCC ENGINE (Unleaded Fuel, 0.041 Percent Sulfur)

| Test Date | Test Type | Test Duration Min. | $SO_2$ by Method 8 | $H_2SO_4$ by Method 8 | Percent Fuel S as $SO_2$ | Percent Fuel S as $H_2SO_4$ | Percent Fuel S Recovered |
|---|---|---|---|---|---|---|---|
| 2/10/75 | 30 mph | 90 | 0.03 | 0.0017 | 81.5 | 3.3 | 84.8 |
| 2/19/75 | 30 mph | 90 | 0.03 | 0.0015 | 84.3 | 3.2 | 87.5 |
| Average | 30 mph | | 0.03 | 0.0016 | 83.0 | 3.2 | 86.2 |
| 2/06/75 | 60 mph | 60 | 0.04 | 0.0050 | 83.7 | 8.5 | 92.2 |
| 2/10/75 | 60 mph | 60 | 0.04 | 0.0032 | 90.4 | 5.2 | 95.6 |
| Average | 60 mph | | 0.04 | 0.0041 | 87.0 | 6.8 | 93.9 |

# APPENDIX H

## SUPPORTING INFORMATION FOR DISTANCE ACCUMULATION CARS

# MSAPC ADVISORY CIRCULAR

U.S. ENVIRONMENTAL PROTECTION AGENCY

OFFICE OF AIR AND WATER PROGRAMS • OFFICE OF MOBILE SOURCE AIR POLLUTION CONTROL



SUBJECT: Alternate Mileage Accumulation Procedure

A. Purpose

The purpose of this Advisory Circular is to provide an alternate mileage accumulation driving schedule for use on public roads where the Durability Driving Schedule as specified in Appendix IV of 40 CFR Part 85 exceeds the legal maximum speed limit.

B. Background

40 CFR 85.074-7, 85.075-7, 85.175-7, and 85.275-7 provide for a modified Durability Driving Schedule if "approved in advance by the Administrator." The reduction in maximum speed limits on public roads to meet the current and anticipated fuel shortages establishes a need for an Alternative Durability Driving Schedule operating within the lowered speed limits.

C. Applicability

This circular is effective immediately and is applicable to gasoline-fueled and Diesel light duty vehicles and light trucks.

D. Procedure

1. Appendix IV of 40 CFR Part 85 describes the basic driving schedule consisting of 11 laps of a 3.7 mile closed course and prescribes the driving mode and speed for each lap.

2. To accommodate highway speed limits, an alternate driving schedule has been devised. In this alternate driving schedule the first nine laps will be driven in the manner described in Appendix IV of 40 CFR Part 85. The 10th lap is to be driven at a constant speed of 50 or 55 miles per hour (mph) (depending on which speed limit is in effect) after a normal acceleration from the stop following lap number 9 and proceeding to a normal deceleration to a stop before lap 11. The 11th lap is begun with a wide-open-throttle acceleration to 50 or 55 mph, as applicable, a fast deceleration to a stop, and three subsequent wide-open-throttle accelerations and fast decelerations at evenly spaced intervals in the 3.7 mile lap.

E. **Discussion**

1. A comparison of the present 70 mph maximum speed durability driving schedule and the alternate 50 or 55 mph schedules is shown in Enclosure 1. It also serves as a guide to those manufacturers who elect to use the alternate 50 or 55 mph maximum speed schedules in laying out a public road route.

2. The comparison is based on an assumed uniform acceleration rate of 3 mph per second (4.4 $ft/sec^2$) and a uniform wide-open-throttle acceleration rate of 5 mph per second (7.3 $ft/sec^2$). The rates of deceleration are also assumed to be uniform with normal deceleration being 6 mph per second (8.8 $ft/sec^2$) and a fast rate of deceleration being 10 mph per second (14.7 $ft/sec^2$).

3. The actual average speed may be somewhat less than the calculated average speed since no allowance is made for driver reaction time.

F. **Approval of Mileage Accumulation Procedure.**

1. Each application for certification must include a description of the mileage accumulation procedure. The regulations require that the procedure be approved or disapproved, in writing, by EPA. EPA will approve an alternate procedure as generally described in this Advisory Circular for manufacturers who accumulate mileage on public roads. Mileage accumulated on dynamometers or test tracks will continue to be required to be consistent with the driving schedule specified in Appendix IV of 40 CFR Part 85.

2. As in the past, EPA will also approve procedures which have substantially the same average speed, distribution of speeds, number of stops per mile, and number of accelerations per mile to the various speeds.

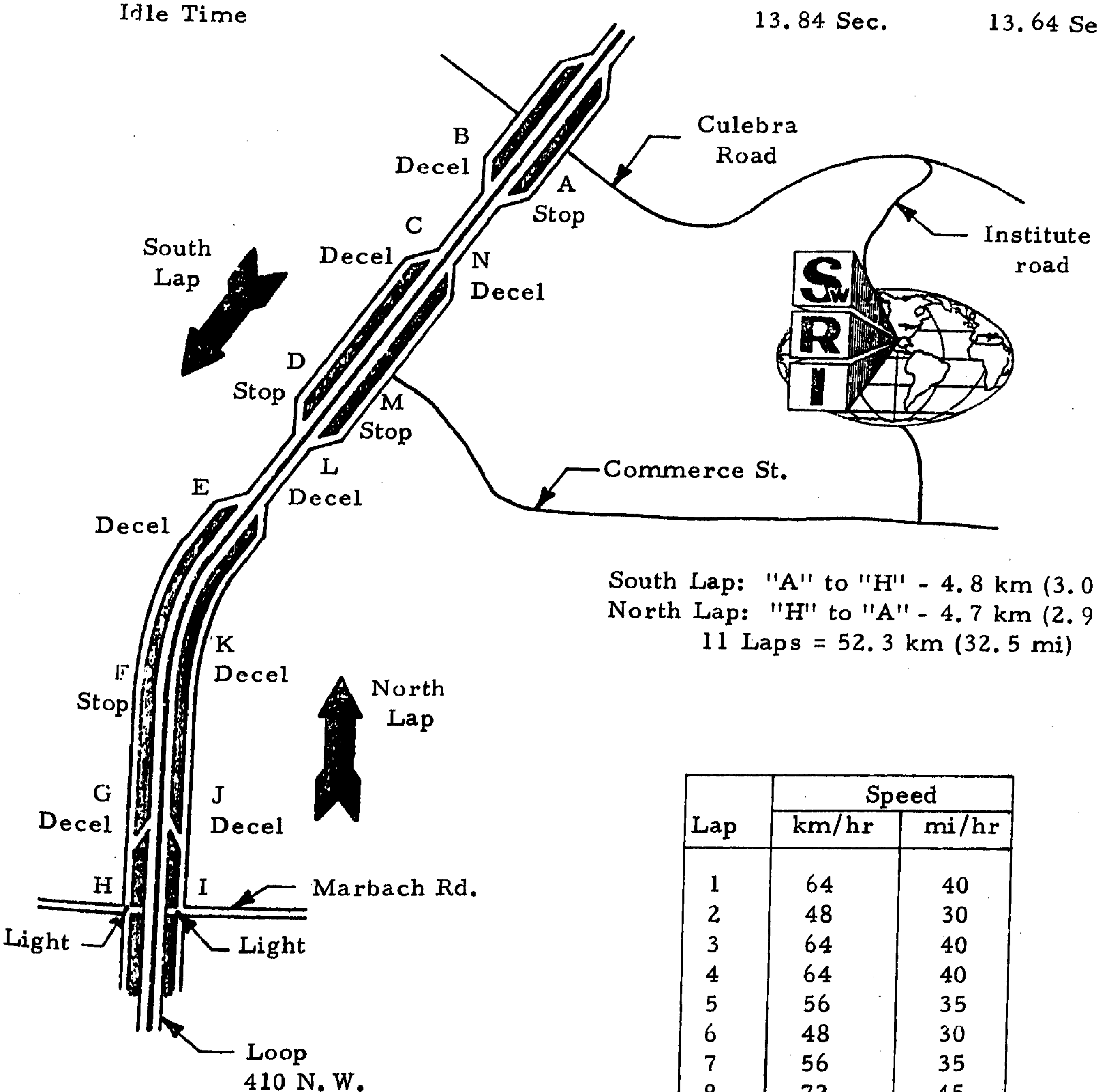
Eric O. Stork
Deputy Assistant Administrator
for Mobile Source Air Pollution Control

Enclosure

ENCLOSURE 1

| Driving Mode | 70 mph Top Speed | 55 mph Top Speed | 50 mph Top Speed |
|---|---|---|---|
| | Events per mile | | |
| Stops | 0.96 | 1.01 | 1.01 |
| Normal acceleration from stop | 0.91 | 0.91 | 0.91 |
| Normal acceleration from 20 mph | 1.11 | 1.11 | 1.11 |
| Wide-open-throttle acceleration and fast deceleration | 0.05 | 0.10 | 0.10 |
| Idle time | 13.64 sec | 13.64 sec | 13.64 sec |
| **Speed-mph** | Percent of Total Miles | | |
| 30 | 16.4 | 16.4 | 16.4 |
| 35 | 23.4 | 23.4 | 23.4 |
| 40 | 21.9 | 21.9 | 21.9 |
| 45 | 6.8 | 6.8 | 6.8 |
| 50 | | | 16.7 |
| 55 | 8.6 | 16.5 | |
| 70 | 8.1 | | |
| Variable (acceleration and deceleration) | 14.8 | 15.0 | 14.8 |
| TOTAL | 100.0 | 100.0 | 100.0 |
| Average speed, total distance traveled divided by total time (including idle time) | 30.21 mph | 29.70 mph | 29.56 mph |
| Hours to complete 50,000 miles | 1655 | 1683 | 1691 |

| Driving Mode | Events Per Mile, 55 mph Top Speed: SwRI Course | AC No. 37 |
|---|---|---|
| Stops | 1.02 | 1.01 |
| Normal Accelerations From Stop | 0.92 | 0.91 |
| Normal Accelerations From 20mph | 1.11 | 1.11 |
| Wide-Open Throttle Accelerations And Fast Deceleration | 0.09 | 0.10 |
| Idle Time | 13.84 Sec. | 13.64 Sec. |




South Lap: "A" to "H" - 4.8 km (3.0 mi)
North Lap: "H" to "A" - 4.7 km (2.9 mi)
11 Laps = 52.3 km (32.5 mi)

| Lap | Speed km/hr | Speed mi/hr |
|---|---|---|
| 1 | 64 | 40 |
| 2 | 48 | 30 |
| 3 | 64 | 40 |
| 4 | 64 | 40 |
| 5 | 56 | 35 |
| 6 | 48 | 30 |
| 7 | 56 | 35 |
| 8 | 72 | 45 |
| 9 | 56 | 35 |
| 10 | 89 | 55 |
| 11 | 89 | 55 |

FIGURE H-1. MODIFIED (AUTOMOBILE) DURABILITY DRIVING SCHEDULE FOR MILEAGE ACCUMULATION ON PUBLIC ROADS

SOUTHWEST RESEARCH INSTITUTE

8500 CULEBRA ROAD • POST OFFICE DRAWER 28510 • SAN ANTONIO, TEXAS 78284

January 13, 1975

MODIFIED DURABILITY DRIVING SCHEDULE FOR

MILEAGE ACCUMULATION ON PUBLIC ROADS

1. Leave Institute Fleet Laboratory

2. Proceed to CULEBRA ROAD via INSTITUTE ROAD, 20 & 40 m.p.h.

3. Stop at CULEBRA

4. Left turn onto CULEBRA and proceed to "A", 410, at 40 m.p.h. (Distance from Fleet Laboratory to "A" is 2.3 miles)

5. Stop at "A", idle 15 sec.

6. Start lap prompter at 1.

7. Accelerate from stop, turn left on access road

8. After left turn, accelerate to lap speed and then decelerate at "B" to 20 m.p.h., as traffic permits.

9. Accelerate to lap speed as you turn onto 410. Continue on 410 to next exit and then decelerate at "C" to 20 m.p.h., as traffic permits then accelerate to lap speed.

11. Continue on FRONTAGE ROAD until a full stop can be safely made at area of point "D". Idle for 15 secs.

12. Accelerate from stop to lap speed and pull onto 410 at next ramp. Continue on 410 to exit ramp.

13. Take exit, then decelerate to 20 m.p.h., at "E".

14. Accelerate to lap speed.

15. Stop at "F" and idle 15 secs.

16. Accelerate to lap speed and continue to "G". Decelerate to 20 m.p.h., at "G" then accelerate to lap speed.



SAN ANTONIO, HOUSTON, CORPUS CHRISTI, TEXAS, AND WASHINGTON, D.C.

17. Stop at traffic light if red, "H" (this can be as long as 33 secs.) If the light is green, proceed and make an additional stop along the North lap as traffic permits.

18. As you pass "H" stop light, push the "lap" prompter and observe the "lap speed".

19. Left turn on MARBACH under 410. Stop at light "I". If light is green, proceed on North lap and make additional stop as traffic permits.

20. Left turn to 410 access at "I".

21. Proceed up 410 to "J" at lap speed.

22. Decelerate at "J" to 20 m.p.h., and then accelerate to lap speed.

23. Continue to "K" at lap speed.

24. Decelerate at "K" to 20 m.p.h., and then accelerate to lap speed.

25. Take ramp to 410 and proceed up 410 to exit ramp at "L".

26. Decelerate at "L" to 20 m.p.h., then accelerate to lap speed.

27. Proceed to "M", then stop and idle 15 secs.

28. Accelerate to lap speed then decelerate at "N" to 20 m.p.h., and then accelerate to lap speed.

29. Take ramp to 410 and continue on 410 to CULEBRA exit ramp.

30. Take CULEBRA exit to stop at "A". Idle 15 secs.

31. Push "lap" prompter for next lap and lap speed.

32. This begins the 3rd lap.

33. Continue with South lap - North lap sequence until lap number 9 is complete.

34. Lap number 10 is run at a steady 55 m.p.h., on 410. Get on 410 at first entrance ramp following the stop at the end of lap number 9 and stay on 410.

35. Lap 10 is completed when you stop at "A" or "H" after pulling off onto the ramp nearest the stop.

36. After stop at "A" or "H" Lap Number 10 is complete.

37. Punch lap button for Lap 11.

38. Accelerate then stop at "B".

39. W.O.T. accelerate to lap speed then fast deceleration to stop at "D".

40. W.O.T. accelerate to lap speed then fast deceleration to stop at "F".

41. W.O.T. accelerate to lap speed then normal deceleration to stop at "H".

42. This completes one cycle of the mileage accumulation.

43. The next cycle of the schedule begins at "H".

44. Complete as many steps per shift as time will allow, then return to Fleet Laboratory.

TABLE H-1. MAINTENANCE SCHEDULE FOR 1975 PLYMOUTH GRAN FURY

## REQUIRED MAINTENANCE SERVICES FOR EMISSION CONTROL AND PROPER VEHICLE PERFORMANCE

| | MILEAGE INTERVALS MILEAGE IN THOUSANDS | | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ENGINE IDLE SPEED & FAST IDLE SPEED | CHECK & RESET AS NECESSARY AT INITIAL 5,000 MILES | | | | | | | | | | | |
| ENGINE OIL | CHANGE EVERY SIX MONTHS | OR | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| ENGINE OIL FILTER | REPLACE AT INITIAL OIL CHANGE AND EVERY 2ND OIL CHANGE THEREAFTER | | | | | | | | | | | |
| EMISSION HOSES | INSPECT EVERY SIX MONTHS | OR | | | | | | | | | | |
| CARBURETOR CHOKE SHAFT | APPLY SOLVENT | | EVERY SIX MONTHS | | | | | | | | | |
| FAST IDLE CAM & PIVOT PIN | APPLY SOLVENT | | EVERY SIX MONTHS | | | | | | | | | |
| COOLING SYSTEM | CHECK AND SERVICE AS REQUIRED | | EVERY SIX MONTHS | | | | | | | | | |
| CRANKCASE INLET AIR CLEANER | CLEAN EVERY 12 MONTHS OR | AT | | | ● | | | ● | | | ● | |
| MANIFOLD HEAT CONTROL VALVE | APPLY SOLVENT | AT | | | ● | | | ● | | | ● | |
| AIR PUMP BELT (IF SO EQUIPPED) | CHECK CONDITION AND TENSION | AT | | | ● | | | ● | | | ● | |
| IGNITION, TIMING, IDLE SPEED, IDLE MIXTURE | CHECK AND ADJUST AS REQUIRED | AT | | | ● | | | ● | | | ● | |
| CARBURETOR AIR FILTER | CLEAN | AT | | | ● | | | | | | ● | |
| CARBURETOR AIR FILTER | REPLACE | AT | | | | | | ● | | | | |
| POSITIVE CRANKCASE VENT VALVE | CHECK OPERATION | AT | | | ● | | | | | | ● | |
| POSITIVE CRANKCASE VENT VALVE | REPLACE | AT | | | | | | ● | | | | |
| VAPOR STORAGE CANISTER FILTER ELEMENT | REPLACE | AT | | | ● | | | ● | | | ● | |
| EXHAUST GAS RECIRCULATION SYSTEM | CHECK OPERATION | AT | | | ● | | | ● | | | ● | |
| SPARK PLUGS (LEADED GAS) | REPLACE | *AT | | | ● | | | ● | | | ● | |
| SPARK PLUGS (WITH CAT. UNLEADED GAS) | REPLACE | **AT | | | | | | ● | | | | |
| IGNITION CABLES, DIST. CAP & ROTOR | CHECK AND REPLACE AS REQUIRED | AT | | | ● | | | ● | | | ● | |
| ORIFICE SPARK ADVANCE CONTROL VALVE | CHECK OPERATION | AT | | | ● | | | ● | | | ● | |
| AUTOMATIC CHOKE | CHECK AND ADJUST AS REQUIRED | AT | | | ● | | | ● | | | ● | |
| VALVE LASH (6 CYLINDER ENGINES) | CHECK AND ADJUST AS REQUIRED | AT | | | ● | | | ● | | | ● | |
| CATALYST OVER TEMP. PROTECTION SYSTEM | CHECK AND REPLACE AS REQUIRED | AT | | | ● | | | ● | | | ● | |
| FUEL FILTER | REPLACE | AT | | | ● | | | ● | | | ● | |

Inspection and service should also be performed anytime a malfunction is observed or suspected. Retain receipts for all vehicle emission services to protect your emissions warranty. *Long Life Plugs—30,000 miles when used with leaded gas and not equipped with catalyst emission control systems. **Long Life Plugs—50,000 miles when used with unleaded gas.

## RECOMMENDED MAINTENANCE SERVICES

The following Certified Car Care maintenance services are recommended by the engineers who designed your car to provide the maximum operating efficiency and enjoyment.

| | | NORMAL | ADDITIONAL SERVICES REQUIRED WITH TRAILER TOW |
|---|---|---|---|
| POWER STEERING | CHECK FLUID LEVEL | EVERY OIL CHANGE | |
| ENG. COMPRTMT. RUB. & PLSTC. COMPNTS. | INSPECT | EVERY 6 MONTHS OR 5,000 MILES | |
| EXHAUST SYSTEM | CHECK FOR LEAKS, MISSING OR DAMAGED PARTS | EVERY 6 MONTHS | |
| BRAKE MASTER CYLINDER | INSPECT FLUID LEVEL | EVERY 6 MONTHS | |
| TRANSMISSION AND REAR AXLE (ALL) | INSPECT FLUID LEVEL | EVERY 6 MONTHS | |
| REAR AXLE | CHANGE LUBRICANT | | EVERY 35,000 MILES |
| TRANSMISSION (MANUAL) (1) | CHANGE OIL | | EVERY 35,000 MILES |
| TRANSMISSION (AUTOMATIC) | CHANGE FLUID, FILTER ADJUST BANDS | | EVERY 25,000 MILES |
| BRAKE AND POWER STEERING HOSES | CHECK FOR DETERIORATION OR LEAKS | EVERY 6 MONTHS | |
| BRAKE HOSES | CHECK FOR DETERIORATION OR LEAKS | EVERY 6 MONTHS | NOT TO EXCEED 5,000 MILES |
| AIR CONDITIONED CARS | CHECK BELTS, SIGHT GLASS AND OPERATION OF CONTROLS | EVERY 6 MONTHS | |
| BALL JOINTS AND STEERING LINKAGE | INSPECT SEALS | EVERY 6 MONTHS | |
| UNIVERSAL JOINTS | INSPECT SEALS | EVERY 6 MONTHS | NOT TO EXCEED 5,000 MILES |
| DRIVE BELTS | CHECK CONDITION AND TENSION | EVERY OIL CHANGE | |
| UPPER AND LOWER CONTROL ARM BUSHINGS | INSPECT | EVERY OIL CHANGE | |
| TIRES | ROTATE | EVERY 10,000 MILES | |
| COOLING SYSTEM | CHECK COOLANT LEVEL<br>DRAIN, FLUSH AND REFILL | EVERY MONTH<br>EVERY 12 MONTHS | |
| RADIATOR HOSE CLAMPS (2 WIRE/SCREW) | TIGHTEN | EVERY 12 MONTHS OR 12,000 MILES | |
| BRAKE LININGS | INSPECT | EVERY 10,000 MILES | |
| FRONT WHEEL BEARINGS | INSPECT (2) LUBRICATE (3) | (Inspect Only) EVERY 25,000 MILES | |
| BALL JOINTS AND TIE ROD ENDS | LUBRICATE | EVERY 3 YEARS OR 35,000 MILES | |

(1) Towing Trailers with Manual Transmission equipped vehicles is not recommended. (2) Whenever drums or rotors are removed to inspect a service brake system
(3) Whenever the brake drums or disc brake rotors are resurfaced.
**NOTE:** Local driving conditions or special equipment such as high performance or heavy duty options may require special service recommendations.

TABLE H-2. MAINTENANCE SCHEDULE FOR 1975 CHEVROLET IMPALA

## COMPLETE VEHICLE MAINTENANCE SCHEDULE

**Color Code:** ☐ Lubrication and General Maintenance ■ Safety ☐ Emission Control

| When To Perform Services (Months or Miles, Whichever Occurs First) | Item No. | Services | OWNER'S SERVICE LOG (Miles) Insert Month, Day, And Mileage (i.e. May/5/8612) In Column Closest To Mileage When Service Is Performed | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 7,500 | 15,000 | 22,500 | 30,000 | 37,500 | 45,000 |
| | | **Lubrication and General Maintenance** | | | | | | |
| Every 6 Months or 7,500 Miles | 1 | *Chassis Lubrication | | | | | | |
| | 2 | •*Fluid Levels Check | | | | | | |
| | 3 | *Engine Oil Change | | | | | | |
| At 1st Oil Chg.—Then Every 2nd | 4 | *Oil Filter Change | | | | | | |
| See Explanation | 5 | Tire Rotation (Steel-Belted Radial) | | | | | | |
| | 6 | Rear Axle Lube Change | | | | | | |
| Every 12 Months | 7 | Air Conditioning Check | | Annual | | Annual | | Annual |
| Every 12 Months or 15,000 Miles | 8 | *Cooling System Check | | | | | | |
| | | —Coolant Change & Hose Replacement | | | | | | |
| Every 30,000 Miles | 9 | Wheel Bearing Repack | | | | | | |
| | 10 | *Auto. Trans. Fluid & Filter Change | | | | | | |
| | 11 | Manual Steering Gear Check | | | | | | |
| | 12 | Clutch Cross Shaft Lubrication | | | | | | |
| | | **Safety Maintenance** | | | | | | |
| Every 6 Months or 7,500 Miles | 13 | Owner Safety Checks | | | | | | |
| | 14 | Tire and Wheel Inspection | | | | | | |
| | 15 | *Exhaust System Check | | | | | | |
| | 16 | *Drive Belt Check | | | | | | |
| | | *—Belt Replacement | | | | | | |
| | 17 | Suspension and Steering Check | | | | | | |
| | 18 | Brake and Power Steering Check | | | | | | |
| Every 12 Months or 15,000 Miles | 19 | Drum Brake and Parking Brake Check | | | | | | |
| | 20 | Throttle Linkage Check | | | | | | |
| | 21 | Underbody Flush & Check | | | | | | |
| | 22 | Bumper Check | | | | | | |
| | | **Emission Control Maintenance** | | | | | | |
| At First 6 Months or 7,500 Miles—Then at 18 Month/22,500 Mile Intervals as Indicated in Log | 23 | Thermo. Controlled Air Cleaner Check | | | | | | |
| | 24 | Carburetor Choke Check | | | | | | |
| | 25 | Engine Idle Speed Adjustment | | | | | | |
| | 26 | EFE Valve Check | | | | | | |
| | 27 | Carburetor Mounting Torque | | | | | | |
| Every 12 Months or 15,000 Miles | 28 | Fuel Filter Replacement | | | | | | |
| | 29 | Vacuum Advance System & Hoses Check | | | | | | |
| | 30 | PCV System Check | | | | | | |
| | | —PCV Valve & Filter Replacement | | | | | | |
| Every 18 Months or 22,500 Miles | 31 | Idle Stop Solenoid Check | | | | | | |
| | 32 | Spark Plug Wires Check | | | | | | |
| Every 22,500 Miles | 33 | Spark Plug Replacement | | | | | | |
| | 34 | Engine Timing Adjustment & Dist. Check | | | | | | |
| Every 24 Months or 30,000 Miles | 35 | Mechanical Valve Lifter Adjustment (L-4 Engine) | | | | | | |
| | 36 | ECS System Check & Filter Replacement | | | | | | |
| | 37 | Fuel Cap, Tank and Lines Check | | | | | | |
| Every 30,000 Miles | 38 | Air Cleaner Element Replacement | | | | | | |

•Also A Safety Service *Also An Emission Control Service

TABLE H-3. 1975 49-STATE PLYMOUTH GRAN FURY (SwRI CAR EM-1)
Monolithic Catalyst, 0.0415% Sulfur Fuel
Emissions Summary - 0 Kilometres

| Date | Test type/ direction | g/km HC | g/km CO | g/km $NO_x$ | g/km $SO_2$ | g/km $H_2SO_4$ | % Fuel S as S in $SO_2$ | % Fuel S as S in $H_2SO_4$ | Total Recovery |
|---|---|---|---|---|---|---|---|---|---|
| 4/24/75 | '75 FTP | 0.36 | 10.58 | 1.07 | 0.063 | 0.00114 | 42.5 | 0.53 | 43.0 |
| 4/25/75 | '75 FTP | 0.43 | 8.87 | 1.08 | 0.075 | 0.00081 | 50.9 | 0.36 | 51.3 |
| Avg. | | 0.39 | 9.73 | 1.08 | 0.069 | 0.00098 | 46.7 | 0.45 | 47.2 |
| 4/24/75 | Accel to 30 | 0.16 | - | 0.85 | 0.017 | 0.00055 | 26.4 | 0.55 | 26.95 |
| 4/25/75 | | 0.11 | 0.38 | 0.72 | 0.033 | 0.00054 | 49.5 | 0.53 | 50.0 |
| Avg. | | 0.14 | 0.38 | 0.78 | 0.026 | 0.00054 | 37.8 | 0.54 | 38.5 |
| 4/24/75 | S/S 30 | 0.03 | 0.01 | 0.78 | 0.009 | 0.00034 | 15.30 | 0.35 | 15.65 |
| 4/25/75 | S/S 30 | 0.03 | 0.00 | 0.59 | 0.006 | 0.00029 | 10.48 | 0.30 | 10.78 |
| Avg. | | 0.03 | 0.01 | 0.68 | 0.008 | 0.00032 | 12.89 | 0.32 | 13.22 |
| 4/24/75 | Accel to 60 | 0.07 | 0.83 | 1.33 | 0.237 | 0.01310 | 323.67 | 11.68 | 335.35 |
| 4/25/75 | | 0.05 | 0.46 | 1.36 | - | - | - | - | - |
| Avg. | | 0.06 | 0.64 | 1.34 | 0.237 | 0.01310 | 323.67 | 11.68 | 335.35 |
| 4/24/75 | S/S 60 | 0.04 | 3.09 | 0.50 | 0.059 | 0.00015 | 86.05 | 0.14 | 86.19 |
| 4/25/75 | S/S 60 | 0.03 | 2.02 | 0.38 | 0.093 | 0.00021 | 133.60 | 0.19 | 133.79 |
| Avg. | | 0.04 | 2.56 | 0.44 | 0.076 | 0.00018 | 109.83 | 0.16 | 109.99 |

TABLE H-4. 1975 49-STATE CHEVROLET IMPALA (SwRI CAR EM-2)
Pelleted Catalyst, 0.0415% Sulfur Fuel
Emissions Summary - 0 Kilometres

| Date | Test type/ direction | g/km HC | g/km CO | g/km $NO_x$ | g/km $SO_2$ * | g/km $H_2SO_4$ | % Fuel S as S in $SO_2$* | % Fuel S as S in $H_2SO_4$ | Total Recovery* |
|---|---|---|---|---|---|---|---|---|---|
| 5/30/75 | '75 FTP | 0.60 | 15.94 | 0.99 | | 0.00090 | | 0.41 | |
| 6/2/75 | '75 FTP | 0.37 | 10.89 | 0.93 | | 0.00025 | | 0.13 | |
| Avg. | | 0.49 | 13.42 | 0.96 | | 0.00058 | | 0.27 | |
| 5/30/75 | Accel to 30 | 0.04 | 0.52 | 0.32 | | 0.00066 | | 0.46 | |
| 6/2/75 | | 0.07 | 1.06 | 0.24 | | 0.00021 | | 0.16 | |
| Avg. | | 0.06 | 0.79 | 0.28 | | 0.00044 | | 0.31 | |
| 5/30/75 | S/S 30 | 0.04 | 1.37 | 0.19 | | 0.00019 | | 0.13 | |
| 6/2/75 | S/S 30 | 0.11 | 5.71 | 0.11 | | 0.00000 | | 0.00 | |
| Avg. | | 0.08 | 3.54 | 0.15 | | 0.00009 | | 0.07 | |
| 5/30/75 | Accel to 60 | 0.09 | 0.73 | 1.02 | | 0.00739 | | 5.42 | |
| 6/2/75 | | 0.09 | 0.81 | 1.03 | | 0.00506 | | 3.81 | |
| Avg. | | 0.09 | 0.77 | 1.03 | | 0.00623 | | 4.62 | |
| 5/30/75 | S/S 60 | 0.01 | 0.17 | 0.72 | | 0.00159 | | 1.31 | |
| 6/2/75 | S/S 60 | 0.01 | 1.21 | 0.59 | | 0.00477 | | 3.73 | |
| Avg. | | 0.01 | 0.69 | 0.66 | | 0.00316 | | 2.52 | |

* $SO_2$ not taken

TABLE H-5. 1975 CALIFORNIA PLYMOUTH GRAN FURY (SwRI CAR EM-3)
Monolithic Catalyst, 0.0415% Sulfur Fuel)
Emissions Summary - 0 Kilometres

| Date | Test type/ direction | g/km | | | | | % Fuel S as S in $SO_2$ | % Fuel S as S in $H_2SO_4$ | Total Recovery |
|---|---|---|---|---|---|---|---|---|---|
| | | HC | CO | $NO_x$ | $SO_2$ | $H_2SO_4$ | | | |
| 6/25/75 | '75 FTP | 0.44 | 6.58 | 0.65 | 0.132 | 0.00113 | 83.86 | 0.49 | 84.07 |
| 6/26/75 | '75 FTP | 0.67 | 7.77 | 0.72 | 0.162 | 0.00210 | 103.66 | 0.91 | 104.57 |
| Avg. | | 0.56 | 7.18 | 0.68 | 0.147 | 0.00161 | 93.76 | 0.70 | 94.32 |
| 6/25/75 | Accel to 30 | 0.04 | 0.24 | 0.72 | 0.024 | 0.00013 | 35.44 | 0.12 | 35.56 |
| 6/26/75 | | 0.04 | 0.17 | 0.70 | 0.010 | 0.00034 | 14.76 | 0.33 | 15.09 |
| Avg. | | 0.04 | 0.20 | 0.71 | 0.017 | 0.00023 | 25.10 | 0.22 | 25.33 |
| 6/25/75 | S/S 30 | 0.03 | 0.03 | 0.80 | 0.014 | 0.00612 | 23.37 | 6.64 | 30.01 |
| 6/26/75 | S/S 30 | 0.03 | 0.06 | 1.15 | 0.011 | 0.01074 | 17.13 | 10.88 | 28.00 |
| Avg. | | 0.03 | 0.04 | 0.98 | 0.013 | 0.00843 | 20.25 | 8.76 | 29.00 |
| 6/25/75 | Accel to 60 | 0.04 | 1.56 | 0.45 | 0.149 | 0.02875 | 175.82 | 22.22 | 198.04 |
| 6/26/75 | | 0.02 | 0.05 | 0.57 | 0.119 | 0.02739 | 158.65 | 23.85 | 182.50 |
| Avg. | | 0.03 | 0.81 | 0.51 | 0.134 | 0.02807 | 167.24 | 23.04 | 190.27 |
| 6/25/75 | S/S 60 | 0.03 | 1.04 | 0.42 | 0.021 | 0.01350 | 27.36 | 11.23 | 38.59 |
| 6/26/75 | S/S 60 | 0.02 | 0.09 | 0.50 | 0.026 | 0.02670 | 32.90 | 22.30 | 55.20 |
| Avg. | | 0.02 | 0.56 | 0.46 | 0.024 | 0.02010 | 30.13 | 16.77 | 46.90 |

TABLE H-6. 1975 CALIFORNIA CHEVROLET IMPALA (SwRI CAR EM-4)
Pelleted Catalyst, 0.0415% Sulfur Fuel)
Emissions Summary - 0 Kilometres

| Date | Test type/ direction | g/km HC | g/km CO | g/km $NO_x$ | g/km $SO_2$ | g/km $H_2SO_4$ | % Fuel S as S in $SO_2$ | % Fuel S as S in $H_2SO_4$ | Total Recovery |
|---|---|---|---|---|---|---|---|---|---|
| 5/27/75 | '75 FTP | 0.29 | 8.67 | 0.86 | - | 0.00142 | - | 0.59 | - |
| 5/29/75 | '75 FTP | 0.41 | 10.01 | 0.86 | - | 0.00116 | - | 0.46 | - |
| 6/19/75 | '75 | 0.41 | 9.40 | 0.84 | 0.120 | 0.00242 | 75.45 | 1.01 | 76.46 |
| Avg. | | 0.37 | 9.36 | 0.85 | 0.120 | 0.00167 | 75.45 | 0.68 | 76.46 |
| 5/27/75 | Accel to | 0.13 | 0.30 | 0.25 | - | 0.00327 | - | 2.11 | - |
| 5/29/75 | 30 | 0.09 | 0.30 | 0.26 | - | - | - | - | - |
| 6/19/75 | | 0.13 | 0.47 | 0.23 | 0.022 | 0.00616 | 22.08 | 4.08 | 26.16 |
| Avg. | | 0.12 | 0.36 | 0.25 | 0.022 | 0.00472 | 22.08 | 3.10 | 26.16 |
| 5/27/75 | S/S 30 | 0.04 | 0.00 | 0.21 | - | 0.04202 | - | 26.22 | - |
| 5/29/75 | S/S 30 | 0.03 | 0.06 | 0.23 | - | 0.02418 | - | 14.42 | - |
| 6/19/75 | S/S 30 | 0.05 | 0.00 | 0.19 | 0.020 | 0.03555 | 20.82 | 24.21 | 45.03 |
| Avg. | | 0.04 | 0.02 | 0.21 | 0.020 | 0.03555 | 20.82 | 24.21 | 45.03 |
| 5/27/75 | Accel to | 0.06 | 2.43 | 0.64 | - | 0.01517 | | 10.84 | - |
| 5/29/75 | 60 | 0.06 | 2.57 | 0.65 | - | 0.00869 | - | 6.14 | - |
| 6/19/75 | | 0.13 | 1.22 | 0.78 | 0.060 | 0.02724 | 62.25 | 18.38 | 80.63 |
| Avg. | | 0.08 | 2.07 | 0.69 | 0.060 | 0.01703 | 62.25 | 11.79 | 80.63 |
| 5/27/75 | S/S 60 | 0.02 | 0.02 | 0.64 | - | 0.01484 | - | 10.83 | - |
| 5/29/75 | S/S 60 | 0.02 | 0.01 | 0.61 | - | 0.01516 | - | 12.05 | - |
| 6/19/75 | S/S 60 | 0.04 | 0.00 | 0.60 | 0.063 | 0.01710 | 71.71 | 12.65 | 84.37 |
| Avg. | | 0.03 | 0.01 | 0.62 | 0.063 | 0.01570 | 71.71 | 11.84 | 84.37 |

TABLE H-7. 1975 49-STATE PLYMOUTH GRAN FURY (SwRI CAR EM-1)
Monolithic Catalyst, 0.0415% Sulfur Fuel)
Emissions Summary - 3200 Kilometres

| Date | Test type/ direction | g/km | | | | | % Fuel S as S in $SO_2$ | % Fuel S as S in $H_2SO_4$ | Total Recovery |
|---|---|---|---|---|---|---|---|---|---|
| | | HC | CO | $NO_x$ | $SO_2$ | $H_2SO_4$ | | | |
| 6/4/75 | '75 FTP | 0.32 | 7.00 | 1.33 | 0.105 | 0.00032 | 73.00 | 0.16 | 73.20 |
| 6/6/75 | '75 FTP | 0.32 | 7.54 | 1.49 | 0.052 | 0.00021 | 44.63 | 0.12 | 44.75 |
| Avg. | | 0.32 | 7.27 | 1.41 | 0.086 | 0.00027 | 58.82 | 0.14 | 58.98 |
| 6/4/75 | Accel to | 0.13 | 0.54 | 0.94 | 0.026 | 0.00010 | 40.39 | 0.10 | 40.49 |
| 6/6/75 | 30 | 0.09 | 1.07 | 1.17 | 0.028 | 0.00014 | 43.11 | 0.14 | 43.25 |
| Avg. | | 0.11 | 0.81 | 1.06 | 0.027 | 0.00012 | 41.75 | 0.12 | 41.87 |
| 6/4/75 | S/S 30 | 0.03 | 0.03 | 0.82 | 0.018 | 0.00276 | 28.41 | 2.91 | 31.32 |
| 6/6/75 | S/S 30 | 0.03 | 0.04 | 0.84 | 0.004 | 0.00203 | 6.13 | 2.20 | 8.33 |
| Avg. | | 0.03 | 0.04 | 0.83 | 0.011 | 0.00240 | 17.27 | 2.56 | 19.83 |
| 6/4/75 | Accel to | 0.08 | 1.61 | 1.33 | 0.186 | 0.00297 | 248.74 | 2.59 | 251.33 |
| 6/6/75 | 60 | - | - | - | - | - | - | - | - |
| Avg. | | 0.08 | 1.61 | 1.33 | 0.186 | 0.00297 | 248.74 | 2.59 | 251.33 |
| 6/4/75 | S/S 60 | 0.02 | 1.62 | 0.57 | 0.122 | 0.00029 | 174.23 | 0.27 | 174.51 |
| 6/6/75 | S/S 60 | - | - | - | - | - | - | - | - |
| Avg. | | 0.02 | 1.62 | 0.57 | 0.122 | 0.00029 | 174.23 | 0.27 | 174.51 |

## TABLE H-8. 1975 49-STATE CHEVROLET IMPALA (SwRI CAR EM-2)
### Pelleted Catalyst, 0.0415% Sulfur Fuel
### Emissions Summary - 3200 Kilometres

| Date | Test type/ direction | HC (g/km) | CO (g/km) | $NO_x$ (g/km) | $SO_2$ (g/km) | $H_2SO_4$ (g/km) | % Fuel S as S in $SO_2$ | % Fuel S as S in $H_2SO_4$ | Total Recovery |
|---|---|---|---|---|---|---|---|---|---|
| 7/8/75 | '75 FTP | 0.46 | 7.20 | 1.28 | | 0.00011 | | 0.06 | |
| 7/18/75 | '75 FTP | 0.34 | 11.98 | 1.22 | 0.056 | 0.00010 | 45.84 | 0.05 | 45.88 |
| Avg. | | 0.40 | 9.59 | 1.25 | 0.056 | 0.00011 | 45.84 | 0.06 | 45.88 |
| 7/8/75 | Accel to 30 | 0.09 | 0.23 | 0.30 | 0.073 | 0.00076 | 99.62 | 0.62 | 100.39 |
| 7/18/75 | | 0.05 | 1.08 | 0.25 | 0.016 | 0.00011 | 21.61 | 0.10 | 21.77 |
| Avg. | | 0.07 | 0.66 | 0.28 | 0.045 | 0.00044 | 60.62 | 0.36 | 61.08 |
| 7/8/75 | S/S 30 | - | - | - | - | - | - | - | - |
| 7/18/75 | S/S 30 | 0.03 | 0.06 | 0.25 | 0.010 | 0.00829 | 13.75 | 7.32 | 21.05 |
| Avg. | | 0.03 | 0.06 | 0.25 | 0.010 | 0.00829 | 13.75 | 7.32 | 21.05 |
| 7/8/75 | Accel to 60 | 0.04 | 0.87 | 1.16 | 0.105 | 0.00504 | 147.61 | 4.06 | 151.67 |
| 7/18/75 | | 0.02 | 0.12 | 0.98 | 0.132 | 0.00861 | 173.03 | 7.39 | 180.39 |
| Avg. | | 0.03 | 0.50 | 1.07 | 0.119 | 0.00428 | 160.32 | 5.73 | 166.03 |
| 7/8/75 | S/S 60 | 0.01 | 1.11 | 0.74 | 0.119 | 0.00182 | 157.36 | 1.44 | 158.80 |
| 7/18/75 | S/S 60 | 0.01 | 0.58 | 0.76 | 0.177 | - | - | - | - |
| Avg. | | 0.01 | 0.85 | 0.75 | 0.148 | 0.00182 | 157.36 | 1.44 | 158.80 |

TABLE H-9. 1975 CALIFORNIA PLYMOUTH GRAN FURY (SwRI CAR EM-3)
Monolithic Catalyst, 0.0415% Sulfur Fuel)
Emissions Summary - 3200 Kilometres

| Date | Test type/ direction | g/km HC | g/km CO | g/km $NO_x$ | g/km $SO_2$ | g/km $H_2SO_4$ | % Fuel S as S in $SO_2$ | % Fuel S as S in $H_2SO_4$ | Total Recovery |
|---|---|---|---|---|---|---|---|---|---|
| 7/15/75 | '75 FTP | 0.20 | 2.90 | 0.71 | - | | | | |
| 7/17/75 | '75 FTP | 0.32 | 3.56 | 0.78 | 0.173 | 0.00616 | 120.92 | 2.89 | 123.80 |
| Avg. | | 0.26 | 3.23 | 0.75 | 0.173 | 0.00616 | 120.92 | 2.89 | 123.80 |
| 7/15/75 | Accel to 30 | 0.04 | 0.08 | 0.67 | 0.042 | 0.00019 | 64.15 | 0.20 | 64.35 |
| 7/17/75 | | - | - | - | 0.029 | 0.00000 | 49.62 | 0.00 | 49.62 |
| Avg. | | 0.04 | 0.08 | 0.67 | 0.036 | 0.00010 | 56.89 | 0.10 | 56.99 |
| 7/15/75 | S/S 30 | 0.02 | 0.00 | 0.67 | 0.019 | 0.00424 | 31.33 | 4.46 | 35.79 |
| 7/17/75 | S/S 30 | 0.03 | 0.11 | 0.56 | 0.018 | 0.00460 | 30.04 | 5.09 | 35.13 |
| Avg. | | 0.03 | 0.06 | 0.62 | 0.019 | 0.00442 | 30.69 | 4.78 | 35.46 |
| 7/15/75 | Accel to 60 | 0.04 | 0.44 | 0.44 | 0.156 | 0.01756 | 213.42 | 15.87 | 229.30 |
| 7/17/75 | | 0.05 | 0.75 | 0.42 | 0.146 | 0.02975 | 187.19 | 25.00 | 212.19 |
| Avg. | | 0.05 | 0.60 | 0.43 | 0.151 | 0.02366 | 200.31 | 20.44 | 220.75 |
| 7/15/75 | S/S 60 | 0.02 | 0.02 | 0.39 | 0.023 | 0.04250 | 34.30 | 41.96 | 76.26 |
| 7/17/75 | S/S 60 | 0.03 | 0.07 | 0.36 | 0.033 | 0.04475 | 47.81 | 41.95 | 89.76 |
| Avg. | | 0.03 | 0.05 | 0.38 | 0.028 | 0.04365 | 41.06 | 41.96 | 83.02 |

TABLE H-10. 1975 CALIFORNIA CHEVROLET IMPALA (SwRI CAR EM-4)
Pelleted Catalyst, 0.0415% Sulfur Fuel)
Emissions Summary - 3200 Kilometres

| Date | Test type | g/km HC | g/km CO | g/km $NO_x$ | g/km $SO_2$ | mg/km $H_2SO_4$ | % Fuel S as S in $SO_2$ | % Fuel S as S in $H_2SO_4$ | Total Recovery |
|---|---|---|---|---|---|---|---|---|---|
| 7/29/75 | '75 FTP | 0.39 | 6.69 | 1.07 | 0.068 | 11.82 | 50.56 | 5.68 | 56.24 |
| 7/31/75 | '75 FTP | 0.49 | 9.09 | 0.94 | 0.050 | 5.96 | 37.72 | 2.79 | 40.50 |
| Avg. | | 0.44 | 7.89 | 1.01 | 0.059 | 8.89 | 44.14 | 4.24 | 48.37 |
| 7/29/75 | Accel to 30 | 0.13 | 0.23 | 0.20 | 0.022 | 16.60 | 26.12 | 12.68 | 38.79 |
| 7/31/75 | | 0.19 | 0.18 | 0.22 | 0.018 | 10.00 | 20.75 | 7.68 | 28.43 |
| Avg. | | 0.16 | 0.21 | 0.21 | 0.020 | 13.30 | 23.44 | 10.18 | 33.61 |
| 7/29/75 | S/S 30 | 0.04 | 0.00 | 0.17 | 0.011 | 30.36 | 13.19 | 24.42 | 37.61 |
| 7/31/75 | S/S 30 | 0.10 | 0.07 | 0.20 | 0.011 | 34.10 | 13.71 | 26.77 | 40.48 |
| Avg. | | 0.07 | 0.04 | 0.19 | 0.011 | 32.23 | 13.45 | 25.60 | 39.05 |
| 7/29/75 | Accel to 60 | 0.16 | 1.31 | 0.75 | 0.067 | 27.90 | 78.46 | 21.40 | 99.86 |
| 7/31/75 | | 0.12 | 1.85 | 0.68 | 0.044 | 27.64 | 54.07 | 22.02 | 76.08 |
| Avg. | | 0.14 | 1.58 | 0.72 | 0.056 | 27.77 | 66.27 | 21.71 | 87.97 |
| 7/27/75 | S/S 60 | 0.03 | 0.00 | 0.69 | 0.025 | 16.11 | 31.49 | 13.02 | 34.09 |
| 7/31/75 | S/S 60 | 0.01 | 0.04 | 0.54 | 0.018 | 19.62 | 25.93 | 18.96 | 44.89 |
| Avg. | | 0.02 | 0.02 | 0.62 | 0.022 | 17.87 | 28.71 | 15.99 | 39.49 |

*TABLE H-11. 1975 49-STATE PLYMOUTH GRAN FURY (SwRI CAR EM-1)*
*Monolithic Catalyst, 0.0415% Sulfur Fuel*
*Emissions Summary - 8050 Kilometres*

| Date | Test type/ direction | g/km HC | CO | $NO_x$ | $SO_2$ | $H_2SO_4$ | % Fuel S as S in $SO_2$ | % Fuel S as S in $H_2SO_4$ | Total Recovery |
|---|---|---|---|---|---|---|---|---|---|
| 6/26/75 | '75 FTP | 0.28 | 8.06 | 1.44 | 0.100 | 0.00076 | 80.54 | 0.39 | 80.94 |
| 7/1/75 | '75 FTP | 0.31 | 8.26 | 1.36 | 0.078 | 0.00096 | 60.86 | 0.47 | 61.34 |
| Avg. | | 0.30 | 8.16 | 1.40 | 0.089 | 0.00086 | 70.70 | 0.43 | 71.14 |
| 6/26/75 | SET-7 | 0.08 | 3.99 | 1.26 | 0.130 | 0.00043 | 152.99 | 0.33 | 153.32 |
| 7/1/75 | SET-7 | 0.10 | 6.76 | 1.21 | 0.103 | 0.00025 | 110.42 | 0.17 | 110.59 |
| Avg. | | 0.09 | 5.38 | 1.24 | 0.117 | 0.00034 | 131.71 | 0.25 | 131.96 |
| 6/26/75 | SET-7 | 0.18 | 11.34 | 1.00 | 0.086 | 0.00039 | 96.43 | 0.29 | 96.71 |
| 7/1/75 | SET-7 | 0.12 | 7.67 | - | 0.084 | 0.00023 | 92.67 | 0.16 | 92.84 |
| Avg. | | 0.15 | 9.51 | 1.00 | 0.085 | 0.00031 | 94.55 | 0.23 | 94.78 |
| 6/26/75 | FET | 0.08 | 4.23 | 1.24 | 0.049 | 0.00038 | 68.51 | 0.35 | 68.85 |
| 7/1/75 | FET | 0.10 | 5.68 | 1.22 | 0.082 | 0.00031 | 106.79 | 0.26 | 107.05 |
| Avg. | | 0.09 | 4.96 | 1.23 | 0.066 | 0.00035 | 87.65 | 0.31 | 87.95 |
| 6/26/75 | FET | 0.09 | 4.27 | 1.20 | 0.054 | 0.00010 | 74.71 | 0.09 | 74.80 |
| 7/1/75 | FET | 0.08 | 4.25 | 1.20 | 0.071 | 0.00020 | 96.71 | 0.18 | 96.89 |
| Avg. | | 0.09 | 4.26 | 1.20 | 0.063 | 0.00015 | 85.71 | 0.14 | 85.85 |
| 6/26/75 | Accel to 30 | 0.05 | 0.59 | 0.72 | 0.024 | 0.00017 | 40.05 | 0.18 | 40.23 |
| 7/1/75 | | 0.13 | 1.53 | 0.85 | 0.009 | 0.00035 | 14.31 | 0.04 | 14.35 |
| Avg. | | 0.09 | 1.06 | 0.79 | 0.017 | 0.00026 | 27.18 | 0.11 | 27.29 |
| 6/26/75 | S/S 30 | 0.02 | 0.06 | 0.61 | 0.002 | 0.00022 | - | 0.26 | - |
| 7/1/75 | S/S 30 | 0.02 | 0.02 | 1.08 | 0.013 | 0.00046 | 22.34 | 0.52 | 22.86 |
| Avg. | | 0.02 | 0.04 | 0.85 | 0.008 | 0.00034 | 22.34 | 0.39 | 22.86 |
| 6/26/75 | Accel to 60 | 0.04 | 0.28 | 1.63 | 0.090 | - | 138.70 | - | - |
| 7/1/75 | | 0.08 | 1.55 | 2.34 | 0.101 | 0.00264 | 143.53 | 2.45 | 145.98 |
| Avg. | | 0.06 | 0.92 | 1.96 | 0.101 | 0.00264 | 143.53 | 2.45 | 145.98 |
| 6/26/75 | S/S 60 | 0.02 | 0.14 | 1.52 | 0.058 | - | 91.84 | - | - |
| 7/1/75 | S/S 60 | 0.03 | 1.96 | 0.76 | 0.069 | 0.00031 | 96.47 | 0.29 | 96.76 |
| Avg. | | 0.03 | 1.05 | 1.14 | 0.064 | 0.00031 | 96.47 | 0.29 | 96.76 |

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## TABLE H-12. 1975 49-STATE CHEVROLET IMPALA (SwRI CAR EM-2)
### Pelleted Catalyst, 0.0415% Sulfur Fuel
### Emissions Summary - 8050 Kilometres

| Date | Test Type | Duration | g/km HC | g/km CO | g/km $NO_x$ | g/km $SO_2$ | mg/km $H_2SO_4$ | $SO_2$ as % Fuel S | $H_2SO_4$ as % Fuel S | Total Recovery |
|---|---|---|---|---|---|---|---|---|---|---|
| 8/27/75 | FTP | | 0.48 | 11.89 | 1.29 | 0.083 | 0.09 | 65.77 | 0.11 | 65.87 |
| 8/29/75 | FTP | | 0.36 | 8.43 | 1.29 | 0.119 | 0.18 | 94.61 | 0.09 | 94.70 |
| Avg. | | | 0.42 | 10.16 | 1.29 | 0.101 | 0.13 | 80.19 | 0.10 | 80.29 |
| 8/27/75 | SET-7 | 20 min | 0.08 | 3.70 | 1.26 | [a] | 0.44 | [a] | 0.30 | |
| 8/29/75 | SET-7 | 20 min | 0.07 | 2.43 | 1.16 | 0.117 | | 132.02 | | |
| Avg. | | | 0.08 | 3.07 | 1.21 | 0.117 | | 132.02 | | |
| 8/27/75 | SET-7 | 28 min | 0.07 | 3.91 | 1.23 | 0.140 | 0.39 | 152.11 | 0.28 | 152.38 |
| 8/29/75 | SET-7 | 28 min | 0.05 | 2.23 | 1.12 | 0.093 | 0.36 | 106.24 | 0.27 | 106.51 |
| Avg. | | | 0.06 | 3.07 | 1.18 | 0.117 | 0.37 | 129.18 | 0.28 | 129.45 |
| 8/27/75 | FET | 12 min | 0.04 | 1.38 | 1.15 | 0.126 | 1.21 | 151.73 | 0.96 | 152.69 |
| 8/29/75 | FET | 12 min | 0.03 | 0.88 | 1.09 | 0.097 | 1.28 | 124.03 | 1.07 | 125.10 |
| Avg. | | | 0.04 | 1.13 | 1.12 | 0.112 | 1.25 | 137.88 | 1.02 | 138.90 |
| 8/27/75 | FET | 12 min | 0.04 | 1.42 | 1.09 | 0.123 | 2.41 | 148.70 | 1.91 | 150.61 |
| 8/29/75 | FET | 12 min | 0.03 | 0.41 | 1.05 | 0.092 | 1.15 | 123.88 | 1.01 | 124.89 |
| Avg. | | | 0.04 | 0.92 | 1.07 | 0.108 | 1.78 | 136.29 | 1.46 | 137.75 |
| 8/27/75 | accel 30 | 20 min | 0.14 | 1.29 | 0.23 | | | | | |
| 8/29/75 | accel 30 | 20 min | 0.07 | 0.19 | 0.46 | 0.028 | 0.09 | 40.40 | 0.08 | 40.45 |
| Avg. | | | 0.11 | 0.74 | 0.35 | | | | | |
| 8/27/75 | S/S 30 | 60 min | 0.03 | 0.36 | 0.29 | | | | | |
| 8/29/75 | S/S 30 | 60 min | 0.02 | 0.04 | 0.61 | 0.018 | 2.93 | 12.05 | 2.97 | 15.02 |
| Avg. | | | 0.03 | 0.20 | 0.45 | | | | | |
| 8/27/75 | accel 60 | 20 min | 0.03 | 0.22 | 1.09 | 0.118 | 6.53 | 132.60 | 5.24 | 137.85 |
| 8/29/75 | accel 60 | 20 min | 0.04 | 0.45 | 1.06 | 0.162 | 4.47 | 223.26 | 4.02 | 227.28 |
| Avg. | | | 0.04 | 0.34 | 1.08 | 0.140 | 5.50 | 177.93 | 4.63 | 182.57 |
| 8/27/75 | S/S 60 | 20 min | 0.04 | 0.26 | 1.23 | 0.130 | 6.72 | 158.74 | 5.37 | 164.11 |
| 8/29/75 | S/S 60 | 20 min | 0.02 | 1.37 | 0.66 | 0.146 | 2.11 | 194.89 | 1.83 | 196.72 |
| Avg. | | | 0.03 | 0.82 | 0.95 | 0.138 | 4.41 | 176.82 | 3.60 | 180.42 |

[a] sample bubbler broken

Table H-13. 1975 CALIFORNIA PLYMOUTH GRAN FURY (SwRI CAR EM-3)
Monolithic Catalyst With Air Pump, 0.0415% Sulfur Fuel
Emissions Summary - 8050 Kilometres

| Date | Test Type | Duration | g/km HC | g/km CO | g/km $NO_x$ | g/km $SO_2$ | mg/km $H_2SO_4$ | $SO_2$ as % Fuel S | $H_2SO_4$ as % Fuel S | Total Recovery |
|---|---|---|---|---|---|---|---|---|---|---|
| 9/2/75 | FTP | | 0.35 | 3.42 | 0.65 | 0.100 | 5.71 | 85.25 | 3.62 | 88.87 |
| 9/4/75 | FTP | | 0.60 | 5.81 | 0.67 | 0.125 | 3.14 | 90.90 | 1.55 | 92.45 |
| Avg. | | | 0.48 | 4.62 | 0.66 | 0.113 | 4.43 | 88.08 | 2.59 | 90.66 |
| 9/2/75 | SET-7 | 23 min | 0.05 | 0.67 | 0.60 | 0.060 | 35.44 | 63.86 | 24.50 | 88.35 |
| 9/4/75 | SET-7 | 23 min | 0.03 | 0.55 | 0.41 | 0.074 | 12.28 | 83.32 | 9.05 | 92.37 |
| Avg. | | | 0.04 | 0.61 | 0.51 | 0.067 | 23.86 | 73.59 | 16.78 | 90.36 |
| 9/2/75 | SET-7 | 23 min | 0.03 | 0.31 | 0.57 | 0.068 | 51.44 | 71.49 | 35.39 | 106.88 |
| 9/4/75 | SET-7 | 23 min | 0.03 | 0.37 | 0.60 | 0.083 | 17.18 | 88.74 | 11.94 | 100.68 |
| Avg. | | | 0.03 | 0.34 | 0.59 | 0.076 | 34.31 | 80.12 | 23.67 | 103.78 |
| 9/2/75 | FET | 12 min | 0.03 | 0.07 | 0.49 | 0.047 | 52.48 | 62.16 | 45.52 | 107.68 |
| 9/4/75 | FET | 12 min | 0.03 | 0.03 | 0.50 | 0.054 | 38.29 | 67.67 | 31.54 | 99.21 |
| Avg. | | | 0.03 | 0.05 | 0.50 | 0.051 | 45.39 | 64.92 | 38.53 | 103.45 |
| 9/2/75 | FET | 12 min | 0.03 | 0.08 | 0.43 | 0.064 | 58.39 | 88.13 | 52.66 | 140.79 |
| 9/4/75 | FET | 12 min | 0.03 | 0.07 | 0.52 | 0.076 | 29.19 | 94.31 | 23.52 | 117.83 |
| Avg. | | | 0.03 | 0.08 | 0.48 | 0.070 | 43.79 | 91.22 | 38.09 | 129.31 |
| 9/2/75 | accel 30 | 20 min | 0.06 | 0.29 | 0.67 | 0.022 | | 33.94 | | |
| 9/4/75 | accel 30 | 20 min | 0.07 | 0.11 | 0.70 | 0.024 | 0.37 | 39.85 | 0.41 | 40.25 |
| Avg. | | | 0.07 | 0.20 | 0.69 | 0.023 | | 36.90 | | |
| 9/2/75 | S/S 30 | 60 min | 0.04 | 0.05 | 0.73 | 0.017 | 4.19 | 29.19 | 4.76 | 33.96 |
| 9/4/75 | S/S 30 | 60 min | 0.05 | 0.00 | 0.60 | 0.017 | 2.65 | 29.19 | 2.95 | 32.14 |
| Avg. | | | 0.05 | 0.03 | 0.67 | 0.017 | 3.42 | 29.19 | 3.86 | 33.05 |
| 9/2/75 | accel 60 | 20 min | 0.04 | 0.16 | 0.47 | 0.106 | 61.74 | 150.87 | 57.29 | 208.16 |
| 9/4/75 | accel 60 | 20 min | 0.03 | 0.05 | 0.54 | — | — | — | — | — |
| Avg. | | | 0.04 | 0.11 | 0.51 | | | | | |
| 9/2/75 | S/S 60 | 20 min | 0.02 | 0.10 | 0.49 | 0.019 | 19.50 | 27.53 | 18.41 | 45.95 |
| 9/4/75 | S/S 60 | 20 min | 0.03 | 0.01 | 0.50 | 0.028 | 36.48 | 39.66 | 34.11 | 73.77 |
| Avg. | | | 0.03 | 0.06 | 0.50 | 0.024 | 27.99 | 33.60 | 26.26 | 59.86 |

## TABLE H-14. 1975 CALIFORNIA CHEVROLET IMPALA (SwRI CAR EM-4) Pelleted Catalyst, 0.0415% Sulfur Fuel) Emissions Summary - 8050 Kilometres

| Test Type | Car Number | HC Emissions g/km 0 km | 3200 km | 8050 km | 16100 km | 24100 km | 32200 km | 48300 km B/A | 64400 km | 80500 km*** |
|---|---|---|---|---|---|---|---|---|---|---|
| FTP | EM-1 | 0.39 | 0.32 | 0.30 | 0.32 | 0.25 | 0.31 | 0.49/0.44 | 0.63 | 0.66/0.59 |
| | EM-2 | 0.49 | 0.40 | 0.42 | 0.34 | 0.35 | 0.39 | 0.36/0.24 | 0.39 | 0.80/3.47 |
| | EM-3 | 0.56 | 0.26 | 0.48 | 0.49 | 0.44 | 0.46** | 0.64/0.41 | 0.57 | 0.68 |
| | EM-4 | 0.37 | 0.44 | 1.12* | 1.68* | 0.42 | 0.27 | 0.43/0.47 | 0.61 | 0.60 |
| SET-7 | EM-1 | ---- | ---- | 0.12 | 0.11 | 0.09 | 0.13 | 0.28/0.39 | 0.51 | 0.31/0.52 |
| | EM-2 | ---- | ---- | 0.07 | 0.11 | 0.12 | 0.12 | 0.11/0.06 | 0.27 | 0.34/1.51 |
| | EM-3 | ---- | ---- | 0.04 | 0.03 | 0.03 | 0.06** | 0.17/0.06 | 0.15 | 0.13 |
| | EM-4 | ---- | ---- | 0.95* | 1.18* | 0.09 | 0.06 | 0.12/0.14 | 0.18 | 0.17 |
| FET | EM-1 | ---- | ---- | 0.09 | 0.06 | 0.06 | 0.07 | 0.26/0.31 | 0.41 | 0.19/0.38 |
| | EM-2 | ---- | ---- | 0.04 | 0.05 | 0.06 | 0.05 | 0.07/0.03 | 0.20 | 0.13/1.35 |
| | EM-3 | ---- | ---- | 0.03 | 0.03 | 0.03 | 0.04** | 0.19/0.07 | 0.20 | 0.12 |
| | EM-4 | ---- | ---- | 0.35* | 0.39* | 0.06 | 0.04 | 0.07/0.10 | 0.13 | 0.08 |
| Accel to 48 kph | EM-1 | 0.14 | 0.11 | 0.09 | 0.09 | 0.03 | 0.03 | 0.12/0.11 | 0.11 | 0.09/0.17 |
| | EM-2 | 0.06 | 0.07 | 0.11 | 0.04 | 0.02 | 0.03 | 0.03/0.02 | 0.43 | 0.05/0.21 |
| | EM-3 | 0.04 | 0.04 | 0.07 | 0.04 | 0.05 | 0.09** | 0.18/0.10 | 0.42 | 0.53/0.09 |
| | EM-4 | 0.12 | 0.16 | 0.21* | 0.21* | 0.08 | 0.11 | 0.16/0.40 | 0.08 | 0.26 |
| 48 kph | EM-1 | 0.03 | 0.03 | 0.02 | 0.03 | 0.04 | 0.03 | 0.05/0.04 | 0.05 | 0.06/0.06 |
| | EM-2 | 0.08 | 0.03 | 0.03 | 0.04 | 0.03 | 0.03 | 0.03/0.02 | 0.24 | 0.05/0.04 |
| | EM-3 | 0.03 | 0.03 | 0.05 | 0.04 | 0.05 | 0.09 | 0.24/0.10 | 0.22 | 0.34/0.10 |
| | EM-4 | 0.04 | 0.07 | 0.10* | 0.07* | 0.07 | 0.04** | 0.05/0.21 | 0.05 | 0.24 |
| Accel to 96 kph | EM-1 | 0.06 | 0.08 | 0.06 | 0.05 | 0.05 | 0.03 | 0.09/0.12 | 0.19 | 0.08/0.31 |
| | EM-2 | 0.09 | 0.03 | 0.04 | 0.02 | 0.04 | 0.05 | 0.05/0.05 | 0.08 | 0.00/0.45 |
| | EM-3 | 0.03 | 0.05 | 0.04 | 0.04 | 0.04 | 0.04** | 0.20/0.11 | 0.15 | 0.16 |
| | EM-4 | 0.08 | 0.14 | 0.15* | 0.02* | 0.06 | 0.04 | 0.10/0.15 | 0.08 | 0.05 |
| 96 kph | EM-1 | 0.04 | 0.02 | 0.03 | 0.02 | 0.02 | 0.03 | 0.15/0.04 | 0.68 | 0.09/0.81 |
| | EM-2 | 0.01 | 0.01 | 0.03 | 0.02 | 0.02 | 0.02 | 0.15/0.02 | 0.19 | 0.06/0.02 |
| | EM-3 | 0.02 | 0.03 | 0.03 | 0.02 | 0.03 | 0.03** | 0.12/0.09 | 0.12 | 0.08 |
| | EM-4 | 0.03 | 0.02 | 0.01* | 0.00* | 0.07 | 0.03 | 0.06/0.18 | 0.09 | 0.06 |

* air injection system leak
**EGR system inoperative
***Duplicate Tests on Cars EM-1 and 2 not averaged. See explanation page 55.

B = Before Maintenance
A = After Maintenance

FTP Standards: '75 Federal = 0.9 g/km
'75 California = 0.6 g/km

TABLE H-15. 1975 49-STATE PLYMOUTH GRAN FURY (SwRI CAR EM-1)
Monolithic Catalyst, 0.0415% Sulfur Fuel
Emissions Summary - 16100 Kilometres

| Date | Test type | g/km HC | g/km CO | g/km $NO_x$ | g/km $SO_2$ | mg/km $H_2SO_4$ | % Fuel S as S in $SO_2$ | % Fuel S as S in $H_2SO_4$ | Total Recovery |
|---|---|---|---|---|---|---|---|---|---|
| 8/11/75 | '75 FTP | 0.40 | 10.16 | 1.69 | 0.130 | 0.61 | 0.29 | 98.86 | 99.14 |
| 8/13/75 | '75 FTP | 0.24 | 7.33 | 1.61 | 0.124 | 1.02 | 0.53 | 97.77 | 98.29 |
| Avg. | | 0.32 | 8.75 | 1.65 | 0.127 | 0.82 | 0.41 | 98.32 | 98.72 |
| 8/11/75 | SET-7 | 0.10 | 4.31 | 1.42 | 0.136 | 0.25 | 0.18 | 153.22 | 153.40 |
| 8/13/75 | SET-7 | 0.10 | 3.97 | 1.38 | 0.094 | 0.38 | 0.29 | 108.26 | 108.54 |
| Avg. | | 0.10 | 4.14 | 1.40 | 0.115 | 0.32 | 0.24 | 130.74 | 130.97 |
| 8/11/75 | SET-7 | 0.13 | 4.97 | 1.37 | 0.064 | 0.08 | 0.06 | 72.62 | 72.67 |
| 8/13/75 | SET-7 | 0.09 | 4.03 | 1.48 | 0.086 | 0.41 | 0.31 | 99.96 | 100.27 |
| Avg. | | 0.11 | 4.50 | 1.43 | 0.075 | 0.25 | 0.19 | 86.29 | 86.47 |
| 8/11/75 | FET | 0.04 | 1.22 | 2.47 | 0.103 | 0.07 | 0.06 | 141.15 | 141.21 |
| 8/13/75 | FET | 0.06 | 1.74 | 1.57 | 0.100 | 1.12 | 1.06 | 144.22 | 145.27 |
| Avg. | | 0.05 | 1.48 | 2.02 | 0.102 | 0.60 | 0.56 | 142.69 | 143.24 |
| 8/11/75 | FET | 0.05 | 1.44 | 1.84 | 0.085 | 0.18 | 0.17 | 121.56 | 121.74 |
| 8/13/75 | FET | 0.07 | 2.66 | 1.76 | 0.083 | 0.65 | 0.60 | 116.59 | 117.19 |
| Avg. | | 0.06 | 2.05 | 1.80 | 0.084 | 0.42 | 0.39 | 119.08 | 119.46 |
| 8/11/75 | Accel to 30 | 0.08 | 0.83 | 0.84 | 0.018 | 0.20 | 0.22 | 30.24 | 30.46 |
| 8/13/75 | | 0.10 | 0.52 | 1.05 | 0.027 | 1.50 | 1.72 | 48.12 | 49.84 |
| Avg. | | 0.09 | 0.68 | 0.95 | 0.023 | 0.85 | 0.97 | 39.18 | 40.15 |
| 8/11/75 | S/S 30 | 0.03 | 0.00 | 0.73 | 0.012 | 0.50 | 0.59 | 21.38 | 21.97 |
| 8/13/75 | S/S 30 | 0.02 | 0.11 | 0.87 | 0.011 | 1.15 | 1.39 | 19.50 | 20.89 |
| Avg. | | 0.03 | 0.06 | 0.80 | 0.012 | 0.83 | 0.99 | 20.44 | 21.43 |
| 8/11/75 | Accel to 60 | 0.04 | 0.31 | 1.91 | 0.147 | 18.95 | 18.64 | 221.15 | 239.80 |
| 8/13/75 | | 0.05 | 1.08 | 2.43 | 0.166 | 8.06 | 9.99 | 314.40 | 324.39 |
| Avg. | | 0.05 | 0.70 | 2.17 | 0.157 | 13.51 | 14.32 | 267.78 | 282.10 |
| 8/11/75 | S/S 60 | 0.02 | 0.77 | 1.55 | 0.066 | 1.58 | 1.62 | 103.54 | 105.16 |
| 8/13/75 | S/S 60 | 0.02 | 1.89 | 0.93 | 0.053 | 1.18 | 1.50 | 103.25 | 104.75 |
| Avg. | | 0.02 | 1.33 | 1.24 | 0.060 | 1.38 | 1.56 | 103.40 | 104.96 |

TABLE H-16. 1975 49-STATE CHEVROLET IMPALA (SwRI CAR EM-2)
Pelleted Catalyst Without Air, 0.0415% Sulfur Fuel
Emissions Summary - 16100 Kilometres

| Test | Date | Test Type | g/km HC | g/km CO | g/km $NO_x$ | g/km $SO_2$ | mg/km $H_2SO_4$ | % Fuel S as S in $H_2SO_4$ | % Fuel S as S in $SO_2$ | Total Recovery |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 & 2 | 9/17/75 | FTP | 0.35 | 9.92 | 1.25 | 0.097 | 1.50 | 0.74 | 75.84 | 76.58 |
| 1 & 2 | 9/19/75 | FTP | 0.34 | 9.69 | 1.38 | 0.074 | 0.49 | 0.26 | 56.77 | 57.03 |
| | | | 0.34 | 9.81 | 1.32 | 0.086 | 1.00 | 0.50 | 66.31 | 66.81 |
| 3 | 9/17/75 | SET-7 | 0.11 | 4.37 | 1.03 | 0.090 | 0.37 | 0.27 | 100.10 | 100.38 |
| 3 | 9/19/75 | SET-7 | 0.10 | 3.35 | 1.28 | 0.089 | 0.56 | 0.39 | 95.12 | 95.51 |
| | | | 0.10 | 3.86 | 1.16 | 0.090 | 0.46 | 0.33 | 97.61 | 97.95 |
| 4 | 9/17/75 | SET-7 | 0.15 | 7.08 | 0.99 | 0.093 | 0.01 | 0.01 | 102.41 | 102.41 |
| 4 | 9/19/75 | SET-7 | 0.08 | 3.39 | 1.16 | 0.095 | 0.26 | 0.19 | 103.79 | 103.98 |
| | | | 0.12 | 5.24 | 1.08 | 0.094 | 0.13 | 0.10 | 103.10 | 103.20 |
| 5 | 9/17/75 | FET | 0.05 | 1.78 | 0.91 | | 0.36 | 0.30 | | |
| 5 | 9/19/75 | FET | 0.04 | 0.96 | 1.10 | 0.056 | 1.33 | 1.08 | 69.46 | 70.53 |
| | | | 0.04 | 1.37 | 1.10 | | 0.84 | 0.69 | | |
| 6 | 9/17/75 | FET | 0.08 | 3.42 | 0.82 | 0.097 | 0.03 | 0.02 | 130.05 | 130.07 |
| 6 | 9/19/75 | FET | 0.03 | 0.89 | 1.08 | 0.077 | 1.35 | 1.12 | 97.83 | 98.95 |
| | | | 0.06 | 2.16 | 0.95 | 0.087 | 0.68 | 0.57 | 113.94 | 114.51 |
| 7 | 9/17/75 | 30 mph | 0.04 | 0.14 | 0.47 | 0.021 | 0.01 | 0.01 | 30.39 | 30.41 |
| 7 | 9/19/75 | accel | 0.04 | 0.21 | 0.45 | 0.022 | 0.06 | 0.06 | 31.42 | 31.47 |
| | | | 0.04 | 0.18 | 0.46 | 0.022 | 0.04 | 0.04 | 30.91 | 30.95 |
| 8 | 9/17/75 | 30 mph | 0.04 | 0.66 | 0.31 | 0.035 | - | - | 51.92 | - |
| 8 | 9/19/75 | SS | 0.03 | 0.01 | 0.42 | - | 3.55 | 3.42 | - | - |
| | | | 0.04 | 0.34 | 0.36 | 0.035 | 3.55 | 3.42 | 51.92 | 55.34 |
| 9 | 9/17/75 | 60 mph | 0.02 | 0.11 | 1.35 | 0.106 | 8.01 | 6.59 | 133.10 | 139.69 |
| 9 | 9/19/75 | accel | 0.02 | 0.04 | 0.43 | 0.125 | - | - | 151.63 | - |
| | | | 0.02 | 0.08 | 0.89 | 0.116 | 8.01 | 6.59 | 142.37 | 139.69 |
| 10 | 9/17/75 | 60 mph | 0.02 | 0.62 | 1.20 | 0.115 | 2.59 | 2.20 | 149.69 | 151.89 |
| 10 | 9/19/75 | SS | 0.01 | 0.08 | 1.25 | | 4.59 | 3.75 | | |
| | | | 0.02 | 0.35 | 1.22 | 0.115 | 4.59 | 3.75 | 149.69 | 151.89 |

*TABLE H-17. 1975 CALIFORNIA PLYMOUTH GRAN FURY (SwRI CAR EM-3)*
Monolithic Catalyst With Air Pump, 0.0415% Sulfur Fuel
Emissions Summary - 16100 Kilometres

| Test | Date | Test Type | g/km HC | g/km CO | g/km $NO_x$ | g/km $SO_2$ | mg/km $H_2SO_4$ | % Fuel S as S in $H_2SO_4$ | % Fuel S as S in $SO_2$ | Total Recovery |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 9/30/75 | FTP | 0.65 | 5.54 | 0.97 | 0.118 | 6.24 | 2.70 | 78.40 | 81.10 |
| 1 | 10/2/75 | FTP | 0.39 | 6.46 | 1.01 | 0.096 | 6.44 | 2.86 | 65.14 | 68.00 |
| 1 | 10/3/75 | FTP | 0.47 | 5.06 | 1.08 | 0.079 | 4.55 | 1.93 | 51.51 | 53.44 |
| | | Avg. | 0.49 | 5.69 | 1.02 | 0.098 | 5.74 | 2.50 | 65.02 | 67.52 |
| 2 | 9/30/75 | SET-7 | 0.04 | 0.55 | 0.71 | 0.060 | 10.05 | 6.72 | 61.32 | 68.04 |
| 2 | 10/2/75 | SET-7 | 0.04 | 0.42 | 0.74 | 0.049 | 37.41 | 24.59 | 49.06 | 73.64 |
| 2 | 10/3/75 | SET-7 | 0.03 | 0.49 | 0.94 | 0.064 | 14.76 | 9.52 | 63.57 | 73.09 |
| | | Avg. | 0.04 | 0.49 | 0.80 | 0.058 | 20.74 | 13.61 | 57.98 | 71.59 |
| 3 | 9/30/75 | SET-7 | 0.03 | 0.29 | 0.74 | 0.079 | 19.25 | 12.96 | 81.07 | 94.03 |
| 3 | 10/2/75 | SET-7 | 0.03 | 0.65 | 0.78 | 0.081 | 35.24 | 23.67 | 83.03 | 106.71 |
| 3 | 10/3/75 | SET-7 | 0.03 | 0.27 | 0.78 | 0.083 | 23.65 | 15.65 | 83.66 | 99.30 |
| | | Avg. | 0.03 | 0.40 | 0.77 | 0.081 | 26.05 | 17.43 | 82.59 | 100.01 |
| 4 | 9/30/75 | FET | 0.03 | 0.05 | 0.60 | 0.038 | 38.64 | 30.79 | 46.00 | 76.79 |
| 4 | 10/2/75 | FET | 0.03 | 0.16 | 0.58 | 0.036 | 59.99 | 46.88 | 43.39 | 90.27 |
| 4 | 10/3/75 | FET | 0.03 | 0.07 | 0.64 | 0.087 | 57.13 | 44.79 | 104.30 | 149.09 |
| | | Avg. | 0.03 | 0.09 | 0.61 | 0.054 | 51.92 | 40.82 | 64.56 | 105.38 |
| 5 | 9/30/75 | SET-7 | 0.03 | 0.22 | 0.69 | 0.059 | 23.86 | 16.19 | 60.79 | 76.97 |
| 5 | 10/2/75 | SET-7 | 0.03 | 0.31 | 0.71 | 0.065 | 50.20 | 34.50 | 68.02 | 102.52 |
| 5 | 10/3/75 | SET-7 | 0.03 | 0.29 | 0.70 | 0.044 | ----- | ----- | 48.40 | ------ |
| | | Avg. | 0.03 | 0.27 | 0.70 | 0.056 | 37.03 | 25.35 | 59.07 | 89.75 |
| 6 | 9/30/75 | SET-7 | 0.03 | 0.74 | 0.73 | 0.072 | 13.37 | 8.91 | 73.74 | 82.65 |
| 6 | 10/2/75 | SET-7 | 0.03 | 0.36 | 0.76 | 0.072 | 47.26 | 32.23 | 75.63 | 107.87 |
| 6 | 10/3/75 | SET-7 | 0.03 | 0.85 | 0.91 | 0.090 | 18.34 | 10.95 | 82.18 | 93.13 |
| | | Avg. | 0.03 | 0.65 | 0.80 | 0.078 | 26.32 | 17.36 | 77.18 | 94.55 |
| 7 | 9/30/75 | 30 mph accel | 0.04 | 0.16 | 0.55 | 0.013 | 0.07 | 0.07 | 22.01 | 22.08 |
| 8 | 9/30/75 | 30 mph S/S | 0.04 | 0.22 | 0.53 | 0.010 | 1.75 | 1.94 | 16.88 | 18.82 |
| 9 | 9/30/75 | 60 mph accel | 0.04 | 0.24 | 0.59 | 0.065 | 62.98 | 54.82 | 86.85 | 141.67 |
| 10 | 9/30/75 | 60 mph S/S | 0.02 | 0.13 | 0.54 | 0.022 | 46.11 | 43.70 | 32.44 | 76.15 |

## TABLE H-18. 1975 CALIFORNIA CHEVROLET IMPALA (SwRI CAR EM-4)
### Pelleted Catalyst With Air Pumps, 0.0415% Sulfur Fuel
### Emissions Summary - 16100 Kilometres

| Test | Date | Test Type | g/km HC | g/km CO | g/km $NO_x$ | g/km $SO_2$ | mg/km $H_2SO_4$ | % Fuel S as S in $H_2SO_4$ | % Fuel S as S in $SO_2$ | Total Recovery |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 9/24/75 | FTP | 2.13 | 17.60 | 1.19 | 0.140 | 0.74 | 0.34 | 97.02 | 97.36 |
| 1 | 9/26/75 | FTP | 1.42 | 9.86 | 0.97 | ----- | 0.86 | 0.43 | ----- | ----- |
| 1 | 9/27/75 | FTP | 1.50 | 11.73 | 1.17 | 0.139 | 0.69 | 0.31 | 94.83 | 95.13 |
| | | Avg. | 1.68 | 11.40 | 1.11 | 0.140 | 0.72 | 0.32 | 95.93 | 96.25 |
| 2 | 9/24/75 | SET-7 | 1.29 | 6.09 | 0.90 | 0.084 | 2.25 | 1.61 | 92.06 | 93.67 |
| 2 | 9/26/75 | SET-7 | 0.77 | 3.16 | 0.76 | 0.057 | 1.44 | 1.00 | 60.53 | 61.53 |
| 2 | 9/27/75 | SET-7 | 1.15 | 5.94 | 0.86 | 0.066 | 1.70 | 1.15 | 68.61 | 69.76 |
| | | Avg. | 1.07 | 5.06 | 0.84 | 0.069 | 1.80 | 1.25 | 73.73 | 74.98 |
| 3 | 9/24/75 | SET-7 | 1.38 | 7.38 | 0.78 | 0.082 | 1.86 | 1.31 | 88.35 | 89.66 |
| 3 | 9/26/75 | SET-7 | 1.04 | 4.81 | 0.76 | 0.082 | 1.59 | 1.09 | 86.73 | 87.82 |
| 3 | 9/27/75 | SET-7 | 1.00 | 5.26 | 0.81 | 0.075 | 1.60 | 1.08 | 78.07 | 79.15 |
| | | Avg. | 1.14 | 5.82 | 0.78 | 0.080 | 1.68 | 1.16 | 84.38 | 85.54 |
| 4 | 9/24/75 | FET | 0.30 | 1.25 | 0.88 | 0.054 | 4.20 | 3.29 | 64.02 | 67.31 |
| 4 | 9/26/75 | FET | 0.39 | 1.18 | 0.66 | 0.054 | 4.69 | 3.74 | 66.19 | 69.92 |
| 4 | 9/27/75 | FET | 0.49 | 1.70 | 0.80 | 0.050 | 4.56 | 3.49 | 58.87 | 62.36 |
| | | Avg. | 0.39 | 1.38 | 0.78 | 0.053 | 4.48 | 3.51 | 63.03 | 66.54 |
| 5 | 9/24/75 | SET-7 | 1.09 | 5.52 | 0.64 | 0.089 | 2.76 | 1.88 | 92.57 | 94.45 |
| 5 | 9/26/75 | SET-7 | 1.10 | 4.53 | 0.72 | 0.091 | 3.57 | 2.52 | 98.19 | 100.71 |
| 5 | 9/27/75 | SET-7 | 1.18 | 6.40 | 0.80 | 0.078 | 2.28 | 1.55 | 81.00 | 82.55 |
| | | Avg. | 1.12 | 5.48 | 0.72 | 0.086 | 2.87 | 1.98 | 90.59 | 92.57 |
| 6 | 9/24/75 | SET-7 | 1.68 | 7.02 | 0.81 | 0.074 | 3.25 | 2.04 | 71.32 | 73.36 |
| 6 | 9/26/75 | SET-7 | 1.16 | 5.54 | 0.73 | 0.079 | 2.91 | 1.98 | 81.91 | 83.89 |
| 6 | 9/27/75 | SET-7 | 1.29 | 7.26 | 0.81 | ----- | 2.74 | 1.83 | ----- | ----- |
| | | Avg. | 1.38 | 6.61 | 0.78 | 0.077 | 2.97 | 1.95 | 76.62 | 78.63 |
| 7 | 9/24/75 | 30 mph accel | 0.21 | 0.35 | 0.15 | 0.013 | 1.87 | 1.52 | 16.09 | 17.60 |
| 8 | 9/24/75 | 30 mph S/S | 0.07 | 0.18 | 0.13 | 0.009 | 7.81 | 8.03 | 13.97 | 22.00 |
| 9 | 9/24/75 | 60 mph accel | 0.02 | 0.14 | 0.30 | 0.060 | 8.35 | 7.04 | 77.76 | 84.80 |
| 10 | 9/24/75 | 60 mph accel | 0.00 | 0.04 | 0.30 | 0.053 | 13.79 | 12.20 | 72.90 | 85.09 |

*TABLE H-19. 1975 49-STATE PLYMOUTH GRAN FURY (SwRI CAR EM-1)*
Monolithic Catalyst, 0.0415% Sulfur Fuel
Emissions Summary - 24100 Kilometres

| Date | Test Type | Duration | g/km HC | g/km CO | g/km $NO_x$ | g/km $SO_2$ | mg/km $H_2SO_4$ | $H_2SO_4$ as % of fuel S | $SO_2$ as % of fuel S | Total Recovery |
|---|---|---|---|---|---|---|---|---|---|---|
| 10/15/75 | FTP | | 0.24 | 6.22 | 1.97 | 0.090 | 3.29 | 1.83 | 76.91 | 78.74 |
| 10/17/75 | FTP | | 0.26 | 7.58 | 1.63 | 0.136 | 1.07 | 0.62 | 120.29 | 120.91 |
| Average | | | 0.25 | 6.90 | 1.80 | 0.113 | 2.18 | 1.23 | 98.60 | 99.83 |
| 10/15/75 | SET-7 | 23 min | 0.09 | 2.77 | 2.06 | 0.116 | 0.58 | 0.36 | 111.14 | 111.50 |
| 10/17/75 | SET-7 | 23 min | 0.09 | 2.84 | 1.74 | 0.087 | 0.47 | 0.37 | 105.75 | 106.12 |
| Average | | | 0.09 | 2.81 | 1.90 | 0.102 | 0.53 | 0.37 | 108.45 | 108.81 |
| 10/15/75 | SET-7 | 23 min | 0.07 | 2.42 | 1.70 | 0.093 | 0.44 | 0.33 | 108.35 | 108.69 |
| 10/17/75 | SET-7 | 23 min | 0.08 | 2.65 | 1.48 | 0.065 | 0.45 | 0.36 | 80.18 | 80.54 |
| Average | | | 0.08 | 2.54 | 1.59 | 0.079 | 0.45 | 0.35 | 94.27 | 94.62 |
| 10/15/75 | FET | 12 min | 0.05 | 1.01 | 1.76 | 0.092 | 0.54 | 0.53 | 137.43 | 137.96 |
| 10/17/75 | FET | 12 min | 0.06 | 1.59 | 1.78 | 0.084 | ----- | ----- | 123.76 | ------ |
| Average | | | 0.06 | 1.30 | 1.77 | 0.088 | 0.54 | 0.53 | 130.60 | 131.13 |
| 10/15/75 | SET-7 | 23 min | 0.09 | 2.93 | 1.58 | 0.095 | 0.30 | 0.24 | 114.84 | 115.07 |
| 10/17/75 | SET-7 | 23 min | 0.10 | 3.55 | 1.44 | 0.068 | 0.26 | 0.21 | 86.12 | 86.33 |
| Average | | | 0.10 | 3.24 | 1.51 | 0.082 | 0.28 | 0.23 | 100.48 | 100.70 |
| 10/15/75 | SET-7 | 23 min | 0.09 | 3.30 | 2.46 | 0.093 | 0.32 | 0.25 | 110.82 | 111.07 |
| 10/17/75 | SET-7 | 23 min | 0.08 | 2.84 | 1.39 | 0.066 | 0.47 | 0.39 | 83.79 | 84.18 |
| Average | | | 0.09 | 3.07 | 1.93 | 0.080 | 0.40 | 0.32 | 97.31 | 97.63 |
| 10/15/75 | 30 mph accel | 20 min | 0.02 | 0.20 | 0.92 | 0.022 | 0.30 | 0.33 | 37.55 | 37.88 |
| 10/17/75 | 30 mph accel | 20 min | 0.04 | 0.14 | 0.88 | 0.029 | 0.43 | 0.53 | 54.53 | 55.06 |
| Average | | | 0.03 | 0.17 | 0.90 | 0.026 | 0.37 | 0.43 | 46.04 | 46.47 |
| 10/15/75 | 30 mph S/S | 60 min | 0.03 | 0.04 | 0.62 | 0.008 | 1.24 | 1.51 | 15.49 | 17.00 |
| 10/17/75 | 30 mph S/S | 60 min | 0.04 | 0.02 | 0.67 | 0.013 | 1.54 | 1.96 | 24.56 | 26.53 |
| Average | | | 0.04 | 0.03 | 0.65 | 0.011 | 1.39 | 1.74 | 20.03 | 21.77 |
| 10/15/75 | 60 mph accel | 20 min | 0.03 | 0.13 | 1.63 | 0.116 | 58.66 | 64.26 | 194.77 | 259.04 |
| 10/17/75 | 60 mph accel | 20 min | 0.06 | 0.15 | 2.25 | 0.064 | 67.02 | 63.96 | 92.83 | 156.79 |
| Average | | | 0.05 | 0.14 | 1.94 | 0.090 | 62.84 | 64.11 | 143.80 | 207.92 |
| 10/15/75 | 60 mph S/S | 20 min | 0.02 | 0.02 | 1.63 | 0.066 | 22.41 | 22.59 | 101.34 | 123.93 |
| 10/17/75 | 60 mph S/S | 20 min | 0.02 | 0.17 | 2.89 | 0.075 | 15.08 | 15.83 | 121.23 | 137.06 |
| Average | | | 0.02 | 0.09 | 2.26 | 0.071 | 18.75 | 19.21 | 111.29 | 130.50 |

## TABLE H-20. 1975 49-STATE CHEVROLET IMPALA (SwRI CAR EM-2)
## Pelleted Catalyst, 0.0415% Sulfur Fuel
## Emissions Summary - 24100 Kilometres

| Date | Test Type | Duration | g/km HC | g/km CO | g/km $NO_x$ | g/km $SO_2$ | mg/km $H_2SO_4$ | $H_2SO_4$ as % of fuel S | $SO_2$ as % of fuel S | Total Recovery |
|---|---|---|---|---|---|---|---|---|---|---|
| 10/30/75 | FTP | | 0.32 | 10.69 | 1.48 | 0.091 | 1.30 | 0.66 | 70.78 | 70.93 |
| 10/31/75 | FTP | | 0.37 | 12.88 | 1.49 | 0.118 | 1.21 | 0.63 | 94.64 | 95.27 |
| Average | | | 0.35 | 11.79 | 1.49 | 0.105 | 1.26 | 0.65 | 82.46 | 83.10 |
| 10/30/75 | SET-7 | 23 min | 0.12 | 6.30 | 1.52 | 0.094 | 1.15 | 0.78 | 97.32 | 98.10 |
| 10/31/75 | SET-7 | 23 min | 0.08 | 2.45 | 1.16 | 0.087 | 0.48 | 0.37 | 104.24 | 104.61 |
| Average | | | 0.10 | 4.38 | 1.34 | 0.091 | 0.82 | 0.58 | 100.78 | 101.36 |
| 10/30/75 | SET-7 | 23 min | 0.12 | 6.18 | 1.37 | 0.089 | 0.78 | 0.55 | 95.86 | 96.41 |
| 10/31/75 | SET-7 | 23 min | 0.17 | 7.93 | 1.41 | 0.097 | 1.10 | 0.80 | 107.46 | 108.26 |
| Average | | | 0.15 | 7.06 | 1.39 | 0.093 | 0.94 | 0.68 | 101.66 | 102.34 |
| 10/30/75 | FET | 12 min | 0.05 | 1.78 | 1.50 | 0.099 | 1.96 | 1.48 | 114.31 | 115.79 |
| 10/31/75 | FET | 12 min | 0.06 | 2.35 | 1.14 | 0.093 | 0.71 | 0.58 | 116.56 | 117.15 |
| Average | | | 0.06 | 2.07 | 1.32 | 0.096 | 1.34 | 1.03 | 115.44 | 116.47 |
| 10/30/75 | SET-7 | 23 min | 0.11 | 5.32 | 1.38 | 0.086 | 0.71 | 0.51 | 93.80 | 94.31 |
| 10/31/75 | SET-7 | 23 min | 0.15 | 8.39 | 1.19 | 0.083 | 0.55 | 0.40 | 93.08 | 93.48 |
| Average | | | 0.13 | 6.86 | 1.29 | 0.085 | 0.63 | 0.46 | 93.44 | 93.90 |
| 10/30/75 | SET-7 | 23 min | 0.08 | 4.26 | 1.32 | 0.079 | 0.90 | 0.69 | 91.27 | 91.96 |
| 10/31/75 | SET-7 | 23 min | 0.15 | 6.96 | 1.33 | 0.081 | 0.49 | 0.35 | 88.70 | 89.06 |
| Average | | | 0.12 | 5.61 | 1.33 | 0.080 | 0.70 | 0.52 | 89.99 | 90.51 |
| 10/30/75 | 30 mph accel | 20 min | 0.03 | 0.21 | 0.53 | 0.018 | 0.17 | 0.16 | 26.12 | 26.29 |
| 10/31/75 | 30 mph accel | 20 min | 0.01 | 0.26 | 0.27 | 0.055 | 0.11 | 0.11 | 82.59 | 82.70 |
| Average | | | 0.02 | 0.24 | 0.40 | 0.037 | 0.14 | 0.14 | 54.36 | 54.50 |
| 10/30/75 | 30 mph S/S | 60 min | 0.03 | 0.00 | 0.52 | 0.013 | 3.25 | 3.30 | 19.81 | 23.11 |
| 10/31/75 | 30 mph S/S | 60 min | 0.03 | 0.00 | 0.63 | 0.007 | 1.52 | 1.58 | 11.53 | 13.11 |
| Average | | | 0.03 | 0.00 | 0.58 | 0.010 | 2.39 | 2.44 | 15.67 | 18.11 |
| 10/30/75 | 60 mph accel | 20 min | 0.03 | 0.86 | 1.32 | 0.075 | 35.61 | 27.41 | 88.05 | 115.46 |
| 10/31/75 | 60 mph accel | 20 min | 0.04 | 1.41 | 1.34 | 0.155 | 32.98 | 28.14 | 202.14 | 230.28 |
| Average | | | 0.04 | 1.14 | 1.33 | 0.115 | 34.30 | 27.78 | 145.10 | 172.87 |
| 10/30/75 | 60 mph S/S | 20 min | 0.01 | 0.02 | 1.23 | 0.073 | 7.26 | 5.59 | 85.55 | 91.14 |
| 10/31/75 | 60 mph S/S | 20 min | 0.03 | 2.90 | 1.11 | ----- | 3.68 | 2.67 | ------ | ------ |
| Average | | | 0.02 | 1.46 | 1.17 | 0.073 | 5.47 | 4.13 | 85.55 | 89.68 |

TABLE H-21. *1975 CALIFORNIA PLYMOUTH GRAN FURY (SwRI CAR EM-3)*
Monolithic Catalyst With Air Pump, 0.0415% Sulfur Fuel
Emissions Summary - 24100 Kilometres

| Date | Test Type | Duration | g/km HC | g/km CO | g/km $NO_x$ | g/km $SO_2$ | mg/km $H_2SO_4$ | $H_2SO_4$ as % of fuel S | $SO_2$ as % of fuel S | Total Recovery |
|---|---|---|---|---|---|---|---|---|---|---|
| 11/3/75 | FTP | | 0.32 | 4.46 | 1.00 | 0.157 | 6.72 | 2.93 | 104.62 | 107.54 |
| 11/5/75 | FTP | | 0.55 | 10.76 | 1.19 | 0.215 | 4.62 | 1.94 | 138.61 | 140.56 |
| Average | | | 0.44 | 7.61 | 1.10 | 0.186 | 5.67 | 2.44 | 121.62 | 124.05 |
| 11/3/75 | SET-7 | 23 min | 0.03 | 0.74 | 0.79 | 0.064 | 9.50 | 6.19 | 63.54 | 69.73 |
| 11/5/75 | SET-7 | 23 min | 0.04 | 1.10 | 0.92 | 0.083 | 5.78 | 3.69 | 80.79 | 84.48 |
| Average | | | 0.04 | 0.92 | 0.86 | 0.074 | 7.64 | 4.94 | 72.17 | 77.11 |
| 11/3/75 | SET-7 | 23 min | 0.03 | 0.47 | 0.87 | 0.071 | 18.00 | 11.81 | 71.33 | 83.13 |
| 11/5/75 | SET-7 | 23 min | 0.03 | 1.06 | 0.88 | 0.084 | 5.39 | 3.69 | 87.79 | 91.48 |
| Average | | | 0.03 | 0.77 | 0.88 | 0.078 | 11.70 | 7.75 | 79.56 | 87.31 |
| 11/3/75 | FET | 12 min | 0.03 | 0.05 | 0.68 | 0.041 | 51.92 | 40.95 | 49.49 | 90.44 |
| 11/5/75 | FET | 12 min | 0.02 | 0.09 | 0.81 | 0.051 | 24.09 | 17.96 | 57.70 | 75.67 |
| Average | | | 0.03 | 0.07 | 0.75 | 0.046 | 38.01 | 29.46 | 53.60 | 83.06 |
| 11/3/75 | SET-7 | 23 min | 0.03 | 0.44 | 0.83 | 0.060 | 50.84 | 31.93 | 58.08 | 90.01 |
| 11/5/75 | SET-7 | 23 min | 0.04 | 1.68 | 0.91 | 0.115 | 8.07 | 5.05 | 110.58 | 115.63 |
| Average | | | 0.04 | 1.06 | 0.87 | 0.088 | 29.46 | 18.49 | 84.33 | 102.82 |
| 11/3/75 | SET-7 | 23 min | 0.03 | 0.53 | 0.80 | 0.082 | 17.48 | 12.11 | 87.26 | 99.38 |
| 11/5/75 | SET-7 | 23 min | 0.03 | 0.78 | 0.88 | 0.087 | 7.09 | 4.79 | 90.01 | 94.80 |
| Average | | | 0.03 | 0.66 | 0.84 | 0.085 | 12.29 | 8.45 | 88.64 | 97.09 |
| 11/3/75 | 30 mph accel | 20 min | 0.04 | 0.00 | 0.78 | 0.009 | 0.08 | 0.09 | 15.55 | 15.64 |
| 11/5/75 | 30 mph accel | 20 min | 0.05 | 0.08 | 0.97 | 0.018 | 0.25 | 0.25 | 27.36 | 27.61 |
| Average | | | 0.05 | 0.04 | 0.88 | 0.014 | 0.17 | 0.17 | 21.46 | 21.63 |
| 11/3/75 | 30 mph S/S | 60 min | 0.04 | 0.00 | 0.75 | 0.013 | 2.85 | 3.33 | 23.44 | 26.77 |
| 11/5/75 | 30 mph S/S | 60 min | 0.05 | 0.08 | 0.84 | 0.017 | 2.40 | 2.58 | 27.08 | 29.86 |
| Average | | | 0.05 | 0.04 | 0.80 | 0.015 | 2.63 | 2.96 | 25.36 | 28.32 |
| 11/3/75 | 60 mph accel | 20 min | 0.04 | 0.93 | 0.77 | 0.127 | 23.58 | 18.77 | 154.63 | 173.40 |
| 11/5/75 | 60 mph accel | 20 min | 0.03 | 0.51 | 1.03 | 0.092 | 28.43 | 21.03 | 125.60 | 146.63 |
| Average | | | 0.04 | 0.72 | 0.90 | 0.110 | 26.01 | 19.90 | 140.12 | 160.02 |
| 11/3/75 | 60 mph S/S | 20 min | 0.03 | 0.04 | 0.72 | 0.025 | 26.40 | 21.71 | 31.34 | 53.05 |
| 11/5/75 | 60 mph S/S | 20 min | 0.02 | 0.02 | 1.17 | 0.026 | 23.25 | 19.64 | 33.38 | 53.02 |
| Average | | | 0.03 | 0.03 | 0.95 | 0.026 | 24.83 | 20.68 | 32.36 | 53.03 |

TABLE H-22. 1975 CALIFORNIA CHEVROLET IMPALA (SwRI CAR EM-4)
Pelleted Catalyst, 0.0415% Sulfur Fuel
Emissions Summary - 24100 Kilometres

| Date | Test Type | Duration | g/km HC | g/km CO | g/km $NO_x$ | g/km $SO_2$ | mg/km $H_2SO_4$ | $H_2SO_4$ as % of fuel S | $SO_2$ as % of fuel S | Total Recovery |
|---|---|---|---|---|---|---|---|---|---|---|
| 11/4/75 | FTP | | 0.48 | 12.22 | 1.10 | 0.101 | 3.46 | 1.54 | 69.06 | 70.60 |
| 11/6/75 | FTP | | 0.37 | 10.83 | 1.19 | 0.136 | 1.49 | 0.66 | 91.43 | 92.09 |
| 11/7/75 | FTP | | 0.40 | 10.28 | 1.14 | 0.082 | 4.74 | 2.16 | 56.71 | 58.86 |
| Average | | | 0.42 | 11.11 | 1.14 | 0.106 | 3.23 | 1.45 | 72.40 | 73.65 |
| 11/4/75 | SET-7 | 23 min | 0.09 | 3.00 | 1.04 | 0.062 | 7.40 | 4.84 | 62.11 | 66.95 |
| 11/6/75 | SET-7 | 23 min | 0.09 | 2.82 | 1.09 | 0.068 | 8.39 | 5.26 | 65.51 | 70.77 |
| 11/7/75 | SET-7 | 23 min | 0.10 | 3.41 | 0.88 | 0.064 | 6.77 | 4.60 | 66.81 | 71.41 |
| Average | | | 0.10 | 3.08 | 1.00 | 0.065 | 7.52 | 4.90 | 64.81 | 69.71 |
| 11/4/75 | SET-7 | 23 min | 0.08 | 3.43 | 1.02 | 0.083 | 7.76 | 5.10 | 83.24 | 88.34 |
| 11/6/75 | SET-7 | 23 min | 0.10 | 4.31 | 1.05 | 0.110 | 8.01 | 5.10 | 106.87 | 111.97 |
| 11/7/75 | SET-7 | 23 min | 0.09 | 3.20 | 0.99 | 0.076 | 10.03 | 6.88 | 80.14 | 87.02 |
| Average | | | 0.09 | 3.65 | 1.02 | 0.090 | 8.60 | 5.69 | 90.08 | 95.78 |
| 11/4/75 | FET | 12 min | 0.05 | 0.86 | 0.89 | 0.066 | 9.08 | 7.01 | 77.89 | 84.90 |
| 11/6/75 | FET | 12 min | 0.07 | 1.47 | 0.94 | 0.064 | 7.23 | 4.99 | 67.55 | 72.54 |
| 11/7/75 | FET | 12 min | 0.05 | 0.73 | 0.84 | 0.051 | 12.94 | 9.36 | 56.47 | 65.83 |
| Average | | | 0.06 | 1.02 | 0.89 | 0.060 | 9.75 | 7.12 | 67.30 | 74.42 |
| 11/4/75 | SET-7 | 23 min | 0.08 | 2.40 | 0.91 | 0.054 | 13.88 | 9.45 | 56.26 | 65.71 |
| 11/6/75 | SET-7 | 23 min | 0.11 | 4.62 | 1.04 | 0.085 | 7.33 | 4.44 | 79.09 | 83.54 |
| 11/7/75 | SET-7 | 23 min | 0.09 | 3.28 | 0.94 | 0.091 | 10.35 | 7.01 | 94.47 | 101.48 |
| Average | | | 0.09 | 3.43 | 0.96 | 0.077 | 10.52 | 6.97 | 76.61 | 83.58 |
| 11/4/75 | SET-7 | 23 min | 0.09 | 3.08 | 0.98 | 0.082 | 11.05 | 7.55 | 85.83 | 93.38 |
| 11/6/75 | SET-7 | 23 min | 0.09 | 2.84 | 1.01 | 0.075 | 9.79 | 6.41 | 75.14 | 81.56 |
| 11/7/75 | SET-7 | 23 min | 0.09 | 2.20 | 0.99 | 0.068 | 14.75 | 9.52 | 67.28 | 76.80 |
| Average | | | 0.09 | 2.71 | 0.99 | 0.075 | 11.86 | 7.83 | 76.08 | 83.91 |
| 11/4/75 | 30 mph accel | 20 min | 0.08 | 0.11 | 0.20 | 0.011 | 6.69 | 5.27 | 12.69 | 17.96 |
| 11/4/75 | 30 mph S/S | 60 min | 0.07 | 0.05 | 0.17 | 0.014 | 30.78 | 26.01 | 18.57 | 44.58 |
| 11/4/75 | 60 mph accel | 20 min | 0.06 | 1.14 | 1.49 | 0.071 | 35.63 | 24.86 | 75.95 | 100.80 |
| 11/4/75 | 60 mph S/S | 20 min | 0.07 | 0.07 | 1.17 | 0.046 | 24.28 | 18.23 | 52.93 | 71.16 |

TABLE H-23. 1975 49-STATE PLYMOUTH GRAN FURY (SwRI CAR EM-1)
Monolith Catalyst, 0.0415% Sulfur Fuel
Emissions Summary - 32200 Kilometres

| Date | Test Type | Duration | g/km HC | g/km CO | g/km $NO_x$ | g/km $SO_2$ | mg/km $H_2SO_4$ | $H_2SO_4$ as % of fuel S | $SO_2$ as % of fuel S | Total Recovery |
|---|---|---|---|---|---|---|---|---|---|---|
| 12/23/75 | FTP | | 0.31 | 10.89 | 2.69 | 0.137 | 0.69 | 0.36 | 105.36 | 105.70 |
| 12/23/75 | SET-7 | 23 min | 0.13 | 5.92 | 2.40 | 0.198 | 2.72 | 1.94 | 216.46 | 218.41 |
| 12/23/75 | SET-7 | 23 min | 0.11 | 4.91 | 2.47 | 0.107 | 0.23 | 0.17 | 121.41 | 121.58 |
| 12/23/75 | FET | 12 min | 0.07 | 2.39 | 3.21 | 0.123 | 0.99 | 0.81 | 152.95 | 153.76 |
| 12/23/75 | SET-7 | 23 min | 0.15 | 7.67 | 1.99 | 0.107 | 0.18 | 0.12 | 113.87 | 113.99 |
| 12/23/75 | SET-7 | 23 min | 0.11 | 4.47 | 1.87 | 0.088 | 0.05 | 0.04 | 99.62 | 99.65 |
| 12/23/75 | 30 mph accel | 20 min | 0.03 | 0.06 | 1.19 | 0.007 | 0.00 | 0.00 | 11.15 | 11.15 |
| 12/23/75 | 30 mph S/S | 30 min | 0.03 | 0.01 | 1.19 | 0.014 | 1.07 | 1.22 | 24.07 | 25.29 |
| 12/23/75 | 60 mph accel | 20 min | 0.03 | 0.76 | 2.58 | 0.151 | 6.68 | 5.36 | 185.03 | 190.39 |
| 12/23/75 | 60 mph S/S | 20 min | 0.03 | 1.59 | 1.91 | 0.107 | 0.68 | 0.55 | 133.06 | 133.61 |

TABLE H-24. 1975 49-STATE CHEVROLET IMPALA (SwRI CAR EM-2)
Pelleted Catalyst, 0.0415% Sulfur Fuel
Emissions Summary - 32200 Kilometres

| Date | Test Type | Duration | g/km HC | g/km CO | g/km $NO_x$ | g/km $SO_2$ | mg/km $H_2SO_4$ | $H_2SO_4$ as % of fuel S | $SO_2$ as % of fuel S | Total Recovery |
|---|---|---|---|---|---|---|---|---|---|---|
| 12/22/75 | FTP | | 0.39 | 10.04 | 2.62 | 0.123 | 2.39 | 1.21 | 95.42 | 96.63 |
| 12/22/75 | SET-7 | 23 min | 0.12 | 6.49 | 2.08 | 0.102 | 0.79 | 0.53 | 105.19 | 105.72 |
| 12/22/75 | SET-7 | 23 min | 0.12 | 5.76 | 2.14 | 0.101 | 0.65 | 0.46 | 108.87 | 109.32 |
| 12/22/75 | FET | 12 min | 0.05 | 1.42 | 1.99 | 0.130 | 1.91 | 1.63 | 170.00 | 171.63 |
| 12/22/75 | SET-7 | 23 min | 0.12 | 5.72 | 2.08 | 0.093 | 2.53 | 1.71 | 96.48 | 98.19 |
| 12/22/75 | SET-7 | 23 min | 0.13 | 5.70 | 1.97 | 0.093 | 0.75 | 0.53 | 100.43 | 100.96 |
| 12/22/75 | 30 mph accel | 20 min | 0.03 | 0.20 | 0.70 | 0.028 | 0.54 | 0.51 | 39.96 | 40.47 |
| 12/22/75 | 30 mph S/S | 30 min | 0.03 | 0.04 | 0.68 | 0.016 | 1.46 | 1.18 | 19.46 | 20.63 |
| 12/22/75 | 60 mph accel | 20 min | 0.05 | 2.38 | 2.49 | 0.169 | 12.07 | 8.72 | 186.39 | 195.11 |
| 12/22/75 | 60 mph S/S | 20 min | 0.02 | 0.54 | 1.98 | 0.137 | 3.51 | 2.88 | 172.65 | 175.53 |

TABLE H-25. 1975 CALIFORNIA PLYMOUTH GRAN FURY (SwRI CAR EM-3)
Monolithic Catalyst, 0.0415% Sulfur Fuel
Emissions Summary - 32200 Kilometres

| Date | Test Type | Duration | g/km HC | g/km CO | g/km $NO_x$ | g/km $SO_2$ | mg/km $H_2SO_4$ | $H_2SO_4$ as % of fuel S | $SO_2$ as % of fuel S | Total Recovery |
|---|---|---|---|---|---|---|---|---|---|---|
| 12/19/75 | FTP | | 0.46 | 3.55 | 3.26* | 0.224 | 11.35 | 5.91 | 178.76 | 184.67 |
| 12/19/75 | SET-7 | 23 min | 0.07 | 0.36 | 3.09* | 0.099 | 38.06 | 28.38 | 112.72 | 141.10 |
| 12/19/75 | SET-7 | 23 min | 0.06 | 0.08 | 3.18* | 0.086 | 49.66 | 37.49 | 99.00 | 136.49 |
| 12/19/75 | FET | 12 min | 0.04 | 0.08 | 3.38* | 0.075 | 45.08 | 39.33 | 99.88 | 139.21 |
| 12/19/75 | SET-7 | 23 min | 0.07 | 0.17 | 2.94* | 0.073 | 56.65 | 41.36 | 81.11 | 122.47 |
| 12/19/75 | SET-7 | 23 min | 0.06 | 0.25 | 2.79* | 0.081 | 33.98 | 24.82 | 90.68 | 115.50 |
| 12/19/75 | 30 mph accel | 20 min | 0.09 | 0.17 | 0.92* | 0.007 | 0.64 | 0.68 | 11.82 | 12.50 |
| 12/19/75 | 30 mph S/S | 30 min | 0.09 | 0.02 | 0.98* | 0.024 | 8.02 | 8.38 | 38.69 | 47.07 |
| 12/19/75 | 60 mph accel | 20 min | 0.04 | 0.08 | 4.22* | 0.069 | 77.11 | 68.69 | 94.43 | 163.11 |
| 12/19/75 | 60 mph S/S | 20 min | 0.03 | 0.03 | 3.72* | 0.025 | 32.53 | 29.28 | 33.97 | 63.24 |

*Failed Vacuum Amplifier in EGR System

TABLE H-26. 1975 CALIFORNIA CHEVROLET IMPALA (SwRI CAR EM-4)
Pelleted Catalyst, 0.0415% Sulfur Fuel
Emissions Summary - 32200 Kilometres

| Date | Test Type | Duration | g/km HC | g/km CO | g/km $NO_x$ | g/km $SO_2$ | mg/km $H_2SO_4$ | $H_2SO_4$ as % of Fuel S | $SO_2$ as % of Fuel S | Total Recovery |
|---|---|---|---|---|---|---|---|---|---|---|
| 12/18/75 | FTP | | 0.27 | 7.97 | 1.25 | 0.056 | 16.15 | 7.87 | 41.50 | 49.37 |
| 12/18/75 | SET-7 | 23 min | 0.06 | 1.08 | 1.54 | 0.072 | 19.11 | 13.21 | 76.67 | 89.88 |
| 12/18/75 | SET-7 | 23 min | 0.06 | 1.33 | 1.28 | 0.040 | 24.26 | 16.99 | 43.20 | 60.19 |
| 12/18/75 | FET | 12 min | 0.04 | 0.11 | 1.16 | 0.064 | 16.41 | 13.39 | 79.75 | 93.15 |
| 12/18/75 | SET-7 | 23 min | 0.06 | 0.71 | 1.23 | 0.060 | 31.42 | 22.43 | 65.44 | 87.87 |
| 12/18/75 | SET-7 | 23 min | 0.07 | 0.37 | 1.07 | 0.058 | 32.86 | 23.07 | 62.70 | 85.78 |
| 12/18/75 | 30 mph Accel | 20 min | 0.11 | 0.23 | 0.15 | 0.031 | 8.26 | 7.22 | 41.36 | 48.58 |
| 12/18/75 | 30 mph S/S | 30 min | 0.04 | 0.02 | 0.18 | 0.029 | 26.63 | 23.48 | 38.61 | 62.08 |
| 12/18/75 | 60 mph Accel | 20 min | 0.04 | 0.11 | 1.38 | 0.050 | 66.98 | 49.05 | 55.57 | 104.63 |
| 12/18/75 | 60 mph S/S | 20 min | 0.03 | 0.01 | 1.15 | 0.017 | 27.20 | 22.55 | 21.73 | 44.28 |

TABLE H-27. 1975 49 STATE PLYMOUTH GRAN FURY (SwRI CAR EM-1)
Monolithic Catalyst, 0.0405% Sulfur Fuel
Emissions Summary - 48300 Kilometres

| Date | Test Type | Duration | g/km HC | g/km CO | g/km $NO_x$ | g/km $SO_2$ | mg/km $H_2SO_4$ | % Fuel S as $H_2SO_4$ | % Fuel S as $SO_2$ | Total Recovery |
|---|---|---|---|---|---|---|---|---|---|---|
| 2/10/76 | FTP | | 0.49 | 12.57 | 1.79 | 0.169 | 1.47 | 0.71 | 125.43 | 126.14 |
| 2/12/76 | FTP | | 0.44 | 11.03 | 2.02 | 0.110 | 1.80 | 0.86 | 79.96 | 80.82 |
| 2/10/76 | SET-7 | | 0.26 | 10.34 | 1.44 | 0.116 | 0.93 | 0.64 | 121.72 | 122.36 |
| 2/12/76 | SET-7 | | 0.21 | 07.17 | 2.03 | 0.067 | 0.95 | 0.67 | 71.19 | 71.86 |
| 2/10/76 | SET-7 | | 0.30 | 11.88 | 1.37 | 0.061 | 0.31 | 0.22 | 64.93 | 65.14 |
| 2/12/76 | SET-7 | | 0.32 | 12.23 | 1.52 | 0.056 | 0.46 | 0.32 | 59.17 | 59.49 |
| 2/10/76 | HWFET | | 0.26 | 11.56 | 1.72 | 0.059 | 0.23 | 0.19 | 75.99 | 76.18 |
| 2/12/76 | HWFET | | 0.31 | 12.26 | 1.73 | 0.028 | 0.20 | 0.17 | 35.73 | 35.90 |
| 2/10/76 | SET-7 | | 0.27 | 11.40 | 1.44 | 0.058 | 0.44 | 0.30 | 60.38 | 60.68 |
| 2/12/76 | SET-7 | | 0.50 | 18.69 | 1.44 | 0.060 | 0.27 | 0.18 | 63.21 | 63.40 |
| 2/10/76 | SET-7 | | 0.27 | 10.80 | 1.55 | 0.064 | 0.26 | 0.18 | 68.78 | 68.97 |
| 2/12/76 | SET-7 | | 0.51 | 20.18 | 1.45 | 0.055 | 0.67 | 0.46 | 58.05 | 58.50 |
| 2/10/76 | 30 mph accel | 20 min | 0.12 | 0.60 | 0.94 | 0.016 | 0.56 | 0.65 | 27.96 | 28.60 |
| 2/12/76 | 30 mph accel | 20 min | 0.11 | 0.91 | 0.82 | 0.019 | 0.46 | 0.51 | 32.15 | 32.66 |
| 2/10/76 | 30 mph | 30 min | 0.05 | 0.00 | 0.98 | 0.011 | 1.20 | 1.39 | 19.57 | 20.97 |
| 2/12/76 | 30 mph | 30 min | 0.04 | 0.00 | 0.75 | 0.021 | 1.20 | 1.38 | 36.69 | 38.07 |
| 2/10/76 | 60 mph accel | 20 min | 0.09 | 3.17 | 1.75 | 0.132 | 1.77 | 1.52 | 173.85 | 175.37 |
| 2/12/76 | 60 mph accel | 20 min | 0.12 | 3.45 | 1.63 | 0.116 | 1.39 | 1.21 | 155.19 | 156.40 |
| 2/10/76 | 60 mph | 20 min | 0.15 | 9.45 | 1.22 | 0.067 | 0.24 | 0.22 | 91.88 | 92.20 |
| 2/12/76 | 60 mph | 20 min | 0.04 | 1.72 | 1.55 | 0.040 | 0.21 | 0.19 | 54.61 | 54.80 |

TABLE H-28. 1975 49-STATE CHEVROLET IMPALA (SwRI CAR EM-2)
Pelleted Catalyst, 0.0405% Sulfur Fuel
Emissions Summary - 48300 Kilometres

| Date | Test Type | Duration | g/km HC | g/km CO | g/km $NO_x$ | g/km $SO_2$ | mg/km $H_2SO_4$ | % fuel S as S in $H_2SO_4$ | % fuel S as S in $SO_2$ | Total Recovery |
|---|---|---|---|---|---|---|---|---|---|---|
| 1/28/76* | LA-4 | | 0.36 | 9.61 | 1.91 | 0.107 | 1.31 | 0.65 | 80.93 | 81.58 |
| 1/30/76** | LA-4 | | 0.24 | 5.22 | 1.60 | 0.078 | 0.78 | 0.42 | 63.45 | 63.87 |
| 1/28/76 | SET-7 | | 0.11 | 4.43 | 1.79 | 0.137 | 3.17 | 2.11 | 139.45 | 141.56 |
| 1/30/76 | SET-7 | | 0.06 | 1.31 | 1.63 | 0.132 | 2.94 | 2.12 | 145.65 | 147.77 |
| 1/28/76 | SET-7 | | 0.10 | 4.23 | 1.69 | 0.126 | 1.08 | 0.75 | 132.66 | 133.41 |
| 1/30/76 | SET-7 | | 0.07 | 2.05 | 1.56 | 0.107 | 1.47 | 1.09 | 122.61 | 123.71 |
| 1/28/76 | HWFET | | 0.07 | 3.08 | 1.53 | 0.137 | 3.03 | 2.15 | 148.67 | 150.82 |
| 1/30/76 | HWFET | | 0.03 | 0.67 | 1.41 | 0.100 | 2.70 | 2.28 | 128.80 | 131.08 |
| 1/28/76 | SET-7 | | 0.11 | 4.67 | 1.46 | 0.099 | 0.48 | 0.34 | 106.00 | 106.34 |
| 1/30/76 | SET-7 | | 0.07 | 2.63 | 1.67 | 0.113 | 1.22 | 0.87 | 122.67 | 123.54 |
| 1/28/76 | SET-7 | | 0.11 | 5.39 | 1.56 | 0.099 | 0.59 | 0.40 | 102.52 | 102.91 |
| 1/30/76 | SET-7 | | 0.05 | 0.76 | 1.55 | 0.068 | 1.87 | 1.40 | 77.60 | 79.00 |
| 1/28/76 | Accel to 30 | | 0.03 | 0.11 | 0.56 | 0.018 | 0.20 | 0.20 | 27.20 | 27.40 |
| 1/30/76 | Accel to 30 | | 0.02 | 0.04 | 0.61 | 0.015 | 0.01 | 0.01 | 23.12 | 23.13 |
| 1/28/76 | S/S 30 | | 0.03 | 2.17 | 0.72 | 0.006 | 2.29 | 2.16 | 8.49 | 10.65 |
| 1/30/76 | S/S 30 | | 0.02 | 0.00 | 0.56 | 0.010 | 0.87 | 0.93 | 16.50 | 17.43 |
| 1/28/76 | Accel to 60 | | 0.05 | 2.28 | 1.65 | 0.177 | 16.01 | 12.37 | 208.81 | 221.18 |
| 1/30/76 | Accel to 60 | | 0.05 | 1.22 | 1.57 | 0.145 | 23.05 | 19.26 | 186.02 | 205.28 |
| 1/28/76 | S/S 60 | | 0.15 | 16.07 | 1.78 | 0.113 | 1.07 | 0.80 | 130.14 | 130.95 |
| 1/30/76 | S/S 60 | | 0.02 | 1.10 | 1.04 | 0.123 | 3.01 | 2.67 | 166.80 | 169.46 |

*Tests on 1/28/76 were done before 30,000 mile maintenance

**Tests on 1/30/76 were done after 30,000 mile maintenance

TABLE H-29. 1975 CALIFORNIA PLYMOUTH GRAN FURY (SwRI CAR EM-3)
Monolithic Catalyst with air injection, 0.0405% Sulfur Fuel
Emissions Summary - 48300 Kilometres

| Date | Test Type | Duration | g/km HC | g/km CO | g/km $NO_x$ | g/km $SO_2$ | mg/km $H_2SO_4$ | % Fuel S as $H_2SO_4$ | % Fuel S as $SO_2$ | Total Recovery |
|---|---|---|---|---|---|---|---|---|---|---|
| 2/9/76 | FTP | | 0.64 | 6.72 | 1.07 | 0.116 | 2.84 | 1.33 | 83.31 | 84.65 |
| 2/19/76 | FTP | | 0.41 | 5.07 | 0.93 | 0.169 | 4.12 | 1.94 | 122.10 | 124.04 |
| 2/6/76 | SET-7 | | 0.19 | 0.93 | 0.87 | 0.093 | 4.23 | 2.80 | 94.04 | 96.83 |
| 2/18/76 | SET-7 | | 0.08 | 0.68 | 0.81 | 0.091 | 6.81 | 4.34 | 89.20 | 93.53 |
| 2/6/76 | SET-7 | | 0.17 | 0.53 | 0.79 | 0.093 | 11.19 | 7.63 | 97.57 | 105.20 |
| 2/19/76 | SET-7 | | 0.06 | 0.70 | 0.77 | 0.097 | 7.38 | 4.67 | 94.53 | 99.21 |
| 2/6/76 | HWFET | | 0.19 | 0.69 | 0.87 | 0.059 | 12.93 | 10.11 | 70.75 | 80.87 |
| 2/19/76 | HWFET | | 0.07 | 0.14 | 0.85 | 0.045 | 14.55 | 11.42 | 54.25 | 65.67 |
| 2/6/76 | SET-7 | | 0.16 | 0.59 | 0.82 | 0.111 | 5.11 | 3.51 | 116.71 | 120.22 |
| 2/19/76 | SET-7 | | 0.05 | 0.59 | 0.76 | 0.113 | 6.96 | 4.68 | 116.37 | 121.06 |
| 2/6/76 | SET-7 | | 0.15 | 0.64 | 0.77 | 0.089 | 5.95 | 4.25 | 96.92 | 101.17 |
| 2/19/76 | SET-7 | | 0.06 | 0.92 | 0.85 | 0.103 | ---- | ---- | 100.96 | ------ |
| 2/6/76 | 30 mph accel | 20 min | 0.18 | 0.27 | 0.79 | 0.013 | 0.40 | 0.46 | 22.43 | 22.89 |
| 2/19/76 | 30 mph accel | 20 min | 0.10 | 0.21 | 0.87 | 0.019 | 0.37 | 0.42 | 33.35 | 33.77 |
| 2/6/76 | 30 mph | 30 min | 0.24 | 0.04 | 0.64 | 0.016 | 0.91 | 1.04 | 27.71 | 28.75 |
| 2/19/76 | 30 mph | 30 min | 0.10 | 0.03 | 0.74 | 0.022 | 0.66 | 0.77 | 39.56 | 40.33 |
| 2/6/76 | 60 mph accel | 20 min | 0.20 | 1.76 | 1.15 | 0.082 | 24.80 | 22.00 | 111.41 | 133.41 |
| 2/19/76 | 60 mph accel | 20 min | 0.11 | 1.62 | 1.04 | 0.088 | 7.25 | 6.43 | 118.92 | 125.35 |
| 2/6/76 | 60 mph | 20 min | 0.12 | 0.05 | 1.17 | 0.030 | 21.22 | 20.14 | 43.86 | 64.00 |
| 2/19/76 | 60 mph | 20 min | 0.09 | 0.04 | 0.96 | 0.030 | 19.66 | 17.08 | 39.68 | 56.76 |

TABLE H-30. 1975 CALIFORNIA CHEVROLET IMPALA (SwRI CAR EM-4)
Pelleted Catalyst 0.0405% Sulfur Fuel
Emissions Summary - 48300 Kilometres

| Date | Test Type | Duration | HC (g/km) | CO (g/km) | $NO_x$ (g/km) | $SO_2$ (g/km) | mg/km $H_2SO_4$ | % Fuel S as $H_2SO_4$ | % Fuel S as $SO_2$ | Total Recovery |
|---|---|---|---|---|---|---|---|---|---|---|
| 2/3/76 | FTP | | 0.43 | 9.03 | 1.81 | 0.103 | 11.08 | 5.48 | 77.78 | 83.26 |
| 2/5/76 | FTP | | 0.47 | 10.37 | 0.99 | 0.072 | 7.58 | 3.64 | 53.06 | 56.70 |
| 2/3/76 | SET-7 | | 0.11 | 2.38 | 0.92 | 0.069 | 24.74 | 16.74 | 71.07 | 87.81 |
| 2/5/76 | SET-7 | | 0.14 | 4.24 | 0.91 | 0.061 | 11.02 | 7.26 | 61.40 | 68.65 |
| 2/3/76 | SET-7 | | 0.12 | 2.78 | 1.07 | 0.073 | 15.04 | 10.05 | 74.44 | 84.49 |
| 2/5/76 | SET-7 | | 0.14 | 3.15 | 0.82 | 0.062 | 11.56 | 7.57 | 62.14 | 69.72 |
| 2/3/76 | HWFET | | 0.07 | 0.78 | 0.86 | 0.062 | 13.83 | 10.65 | 73.52 | 84.17 |
| 2/5/76 | HWFET | | 0.10 | 1.50 | 0.70 | 0.058 | 14.81 | 11.23 | 67.72 | 78.95 |
| 2/3/76 | SET-7 | | 0.13 | 3.05 | 0.95 | 0.061 | 16.56 | 11.05 | 62.43 | 73.47 |
| 2/5/76 | SET-7 | | 0.13 | 3.42 | 0.80 | 0.062 | 11.16 | 7.38 | 63.64 | 71.02 |
| 2/3/76 | SET-7 | | 0.13 | 3.83 | 0.92 | 0.077 | 11.36 | 7.67 | 79.31 | 86.97 |
| 2/5/76 | SET-7 | | 0.50 | 5.32 | 0.83 | 0.080 | 9.76 | 6.36 | 79.97 | 86.33 |
| 2/3/76 | 30 mph accel | 20 min | 0.16 | 1.00 | 0.48 | 0.026 | ----- | ---- | 39.47 | ----- |
| 2/5/76 | 30 mph accel | 20 min | 0.40 | 0.65 | 0.26 | 0.019 | 7.41 | 6.82 | 26.44 | 33.27 |
| 2/3/76 | 30 mph S/S | 30 min | 0.05 | 0.01 | 0.34 | 0.016 | 3.72 | 3.72 | 25.01 | 28.74 |
| 2/5/76 | 30 mph S/S | 30 min | 0.21 | 0.06 | 0.32 | 0.016 | 9.70 | 9.40 | 23.59 | 32.99 |
| 2/3/76 | 60 mph accel | 20 min | 0.10 | 1.75 | 0.96 | 0.103 | 45.90 | 36.18 | 124.13 | 160.31 |
| 2/5/76 | 60 mph accel | 20 min | 0.15 | 2.63 | 0.91 | 0.072 | 17.92 | 13.94 | 85.80 | 99.74 |
| 2/3/76 | 60 mph S/S | 20 min | 0.06 | 0.08 | 0.72 | 0.070 | 17.85 | 14.50 | 86.57 | 101.06 |
| 2/5/76 | 60 mph S/S | 20 min | 0.18 | 0.05 | 0.86 | 0.062 | 18.70 | 15.02 | 75.64 | 90.66 |

TABLE H-31. 1975 49 STATE PLYMOUTH GRAN FURY (SwRI CAR EM-1)
Monolithic Catalyst without Air Injection, 0.0410% Sulfur Fuel
Emissions Summary - 64400 Kilometres

| Date | Test Type | Duration | g/km HC | g/km CO | g/km $NO_x$ | g/km $SO_2$ | mg/km $H_2SO_4$ | % Fuel S as $H_2SO_4$ | % Fuel S as $SO_2$ | Total Recovery |
|---|---|---|---|---|---|---|---|---|---|---|
| 3-25-76 | FTP | | 0.63 | 15.58 | 1.70 | 0.159 | 2.77 | 1.37 | 120.93 | 122.30 |
| 3-25-76 | SET-7 | | 0.45 | 16.12 | 1.61 | 0.083 | 0.47 | 0.31 | 82.58 | 82.88 |
| 3-25-76 | SET-7 | | 0.51 | 19.51 | 1.61 | 0.069 | 0.26 | 0.17 | 68.51 | 68.67 |
| 3-25-76 | HFET | | 0.41 | 16.17 | 1.79 | 0.063 | 0.86 | 0.65 | 73.52 | 74.29 |
| 3-25-76 | SET-7 | | 0.55 | 20.45 | 1.74 | 0.066 | 0.92 | 0.59 | 64.96 | 65.55 |
| 3-25-76 | SET-7 | | 0.53 | 19.63 | 1.52 | 0.075 | 0.88 | 0.57 | 74.30 | 74.87 |
| 3-25-76 | Accel to 30 | 20 min. | 0.11 | 1.08 | 1.09 | 0.018 | 0.48 | 0.51 | 29.25 | 29.76 |
| 3-25-76 | 30 mph S/S | 20 min. | 0.05 | 0.02 | 0.87 | 0.014 | 0.75 | 0.84 | 24.51 | 25.35 |
| 3-25-76 | Accel to 60 | 20 min. | 0.19 | 7.87 | 2.09 | 0.106 | 2.14 | 1.75 | 132.19 | 133.94 |
| 3-25-76 | 60 mph | 20 min. | 0.68 | 22.31 | 2.08 | 0.076 | 0.12 | 0.09 | 95.16 | 95.25 |

TABLE H-32. 1975 49 STATE CHEVROLET IMPALA (SwRI CAR EM-2)
Pelleted Catalyst without Air Injection, 0.0410% Sulfur Fuel
Emissions Summary - 64400 Kilometres

| Date | Test Type | Duration | HC (g/km) | CO (g/km) | $NO_x$ (g/km) | $SO_2$ (g/km) | mg/km $H_2SO_4$ | % Fuel S as $H_2SO_4$ | % Fuel S as $SO_2$ | Total Recovery |
|---|---|---|---|---|---|---|---|---|---|---|
| 3-10-76 | FTP | | 0.39 | 11.91 | 1.99 | 0.115 | 0.90 | 0.46 | 88.86 | 89.31 |
| 3-10-76 | SET-7 | | 0.21 | 8.30 | 1.71 | 0.141 | 0.84 | 0.55 | 140.44 | 140.99 |
| 3-10-76 | SET-7 | | 0.24 | 11.10 | 1.64 | 0.128 | 0.70 | 0.47 | 131.11 | 131.58 |
| 3-10-76 | HFET | | 0.20 | 10.45 | 1.45 | 0.143 | 0.83 | 0.60 | 158.10 | 158.70 |
| 3-10-76 | SET-7 | | 0.34 | 16.11 | 1.41 | 0.110 | 0.12 | 0.08 | 112.36 | 112.44 |
| 3-10-76 | SET-7 | | 0.29 | 13.49 | 1.22 | 0.081 | 0.28 | 0.28 | 87.97 | 88.26 |
| 3-10-76 | Accel to 30 | 20 min. | 0.43 | 11.27 | 0.63 | 0.057 | 0.98 | 0.89 | 80.35 | 81.24 |
| 3-10-76 | 30 mph | 20 min. | 0.24 | 8.40 | 0.79 | 0.057 | 0.10 | 0.10 | 83.53 | 83.63 |
| 3-10-76 | Accel to 60 | 20 min | 0.08 | 5.40 | 1.93 | 0.209 | 2.22 | 1.74 | 249.52 | 251.25 |
| 3-10-76 | 60 mph | 20 min | 0.19 | 17.88 | 1.45 | 0.105 | 0.26 | 0.20 | 127.02 | 127.23 |

TABLE H-33. 1975 CALIFORNIA PLYMOUTH GRAN FURY (SwRI CAR EM-3)
Monolithic Catalyst with Air Injection 0.0410% Sulfur Fuel
Emissions Summary - 64400 Kilometres

| Date | Test Type | Duration | HC (g/km) | CO (g/km) | $NO_x$ (g/km) | $SO_2$ (g/km) | mg/km $H_2SO_4$ | % Fuel S as $H_2SO_4$ | % Fuel S as $SO_2$ | Total Recovery |
|---|---|---|---|---|---|---|---|---|---|---|
| 3-26-76 | FTP | | 0.57 | 5.52 | 1.98 | 0.100 | 4.37 | 2.08 | 72.75 | 74.83 |
| 3-26-76 | SET-7 | | 0.13 | 1.04 | 1.73 | 0.157 | 6.87 | 4.91 | 171.30 | 176.21 |
| 3-26-76 | SET-7 | | 0.14 | 0.88 | 1.83 | 0.119 | 7.78 | 5.06 | 118.87 | 123.93 |
| 3-26-76 | HFET | | 0.20 | 0.21 | 1.11 | 0.067 | 11.41 | 8.14 | 72.64 | 80.79 |
| 3-26-76 | SET-7 | | 0.16 | 0.78 | 1.20 | 0.185 | 8.95 | 5.65 | 178.73 | 184.37 |
| 3-26-76 | SET-7 | | 0.17 | 0.76 | 1.31 | 0.150 | 6.27 | 3.87 | 141.58 | 145.45 |
| 3-26-76 | 30 mph accel | | 0.42 | 0.09 | 1.07 | 0.033 | 3.18 | 2.55 | 40.33 | 42.89 |
| 3-26-76 | 30 mph | | 0.22 | 0.04 | 0.89 | 0.029 | 35.44 | 29.68 | 36.92 | 66.60 |
| 3-26-76 | 60 mph accel | | 0.15 | 0.06 | 1.33 | 0.053 | 49.32 | 39.72 | 64.85 | 104.58 |
| 3-26-76 | 60 mph | | 0.12 | 0.04 | 1.93 | 0.042 | 19.76 | 16.62 | 53.60 | 70.22 |

TABLE H-34. 1975 CALIFORNIA CHEVROLET IMPALA (SwRI CAR EM-4)
Pelleted Catalyst with Air Injection 0.0410% Sulfur Fuel
Emissions Summary - 64400 Kilometres

| Date | Test Type | Duration | g/km HC | g/km CO | g/km $NO_x$ | g/km $SO_2$ | mg/km $H_2SO_4$ | % Fuel S as $H_2SO_4$ | % Fuel S as $SO_2$ | Total Recovery |
|---|---|---|---|---|---|---|---|---|---|---|
| 3-16-76 | FTP | | 0.61 | 12.92 | 1.30 | 0.137 | 6.27 | 2.73 | 91.43 | 94.15 |
| 3-16-76 | SET-7 | | 0.14 | 4.14 | 1.19 | 0.077 | 11.13 | 6.60 | 69.94 | 76.55 |
| 3-16-76 | SET-7 | | 0.16 | 5.60 | 1.04 | 0.078 | 6.97 | 4.19 | 72.22 | 76.41 |
| 3-16-76 | HFET | | 0.13 | 0.37 | 1.10 | 0.090 | 12.87 | 8.56 | 91.91 | 100.48 |
| 3-16-76 | SET-7 | | 0.21 | 10.12 | 0.88 | 0.135 | 8.36 | 5.02 | 123.69 | 128.71 |
| 3-16-76 | SET-7 | | 0.20 | 7.77 | 0.88 | 0.097 | 6.91 | 4.13 | 89.01 | 93.14 |
| 3-16-76 | 30 mph accel. | | 0.08 | 0.54 | 0.65 | 0.023 | ---- | ---- | 34.20 | ------ |
| 3-16-76 | 30 mph | | 0.05 | 0.02 | 0.28 | 0.012 | 2.92 | 2.75 | 17.05 | 19.80 |
| 3-16-76 | 60 mph accel | | 0.08 | 0.27 | 1.43 | 0.078 | 24.02 | 18.01 | 89.15 | 107.16 |
| 3-16-76 | 60 mph | | 0.09 | 0.23 | 1.30 | 0.065 | 8.74 | 6.63 | 75.05 | 81.68 |

TABLE H-35. 1975 49 STATE PLYMOUTH GRAN FURY (SwRI CAR EM-1)
Monolithic Catalyst Without Air Injection 0.0410% Sulfur Fuel
Emissions Summary - 80500 Kilometres

| Date | Test Type | Duration | g/km HC | g/km CO | g/km $NO_x$ | g/km $SO_2$ | mg/km $H_2SO_4$ | % Fuel S as $H_2SO_4$ | % Fuel S as $SO_2$ | Total Recovery |
|---|---|---|---|---|---|---|---|---|---|---|
| 5/7/76 | FTP | | 0.66 | 11.77 | 2.27 | 0.167 | 1.80 | 0.89 | 126.33 | 127.22 |
| 5/11/76 | FTP | | 0.59 | 15.25 | 1.97 | 0.088 | 1.22 | 0.58 | 64.63 | 65.22 |
| 5/7/76 | SET-7 | | 0.26 | 8.21 | 1.98 | 0.118 | 0.81 | 0.54 | 119.61 | 120.14 |
| 5/11/76 | SET-7 | | 0.33 | 11.43 | 2.03 | 0.069 | 0.61 | 0.39 | 68.19 | 68.58 |
| 5/7/76 | SET-7 | | 0.29 | 9.54 | 2.23 | 0.097 | 0.44 | 0.29 | 97.14 | 97.42 |
| 5/11/76 | SET-7 | | 0.53 | 18.30 | 1.86 | 0.042 | 0.42 | 0.28 | 42.81 | 43.09 |
| 5/7/76 | FET | | 0.19 | 6.47 | 2.44 | 0.062 | 0.31 | 0.25 | 74.94 | 75.19 |
| 5/11/76 | FET | | 0.38 | 13.80 | 2.01 | 0.028 | 0.19 | 0.15 | 32.15 | 32.30 |
| 5/7/76 | SET-7 | | 0.32 | 11.55 | 1.87 | 0.084 | 0.22 | 0.15 | 87.20 | 87.35 |
| 5/11/76 | SET-7 | | 0.55 | 19.45 | 1.80 | 0.047 | 0.21 | 0.14 | 46.16 | 46.30 |
| 5/7/76 | SET-7 | | 0.35 | 12.73 | 1.88 | 0.068 | 0.15 | 0.10 | 69.82 | 69.92 |
| 5/11/76 | SET-7 | | 0.68 | 24.45 | 1.66 | 0.058 | 0.40 | 0.26 | 57.24 | 57.50 |
| 5/7/76 | Accel to 30 | 20 min. | 0.09 | 0.79 | 0.99 | 0.021 | 0.15 | 0.17 | 35.66 | 35.83 |
| 5/11/76 | Accel to 30 | 20 min. | 0.17 | 0.89 | 1.23 | 0.019 | 0.14 | 0.16 | 32.70 | 32.86 |
| 5/7/76 | 30 mph | 30 min. | 0.06 | 0.01 | 0.86 | 0.009 | 0.67 | 0.78 | 16.47 | 17.25 |
| 5/11/76 | 30 mph | 30 min. | 0.06 | 0.00 | 0.94 | 0.009 | 0.51 | 0.59 | 15.62 | 16.20 |
| 5/7/76 | Accel to 60 | 20 min. | 0.08 | 2.70 | 2.29 | 0.111 | 1.11 | 0.98 | 150.39 | 151.37 |
| 5/11/76 | Accel to 60 | 20 min. | 0.31 | 10.97 | 2.12 | 0.083 | 0.76 | 0.61 | 102.31 | 102.92 |
| 5/7/76 | 60 mph | 20 min. | 0.09 | 20.86 | 2.20 | 0.043 | 0.16 | 0.13 | 52.51 | 52.64 |
| 5/11/76 | 60 mph | 20 min. | 0.81 | 23.70 | 2.22 | 0.042 | 0.08 | 0.07 | 53.01 | 53.08 |

TABLE H-36. 1975 49 STATE CHEVROLET IMPALA (SwRI CAR EM-2)
Pelleted Catalyst Without Air Injection 0.0410% Sulfur, Fuel
Emissions Summary - 80500 Kilometres

| Date | Test Type | Duration | HC (g/km) | CO (g/km) | $NO_x$ (g/km) | $SO_2$ (g/km) | mg/km $H_2SO_4$ | % Fuel S as $H_2SO_4$ | % Fuel S as $SO_2$ | Total Recovery |
|---|---|---|---|---|---|---|---|---|---|---|
| 4/19/76 | FTP | | 0.80 | 14.74 | 2.04 | 0.120 | 1.13 | 0.55 | 89.94 | 90.49 |
| 5/19/76 | FTP | | 3.47 | 24.43 | 1.76 | 0.170 | 1.56 | 0.73 | 122.61 | 123.34 |
| 4/19/76 | SET-7 | | 0.36 | 8.81 | 2.35 | 0.111 | ---- | ---- | 109.65 | ------ |
| 5/19/76 | SET-7 | | 1.28 | 7.92 | 1.71 | 0.102 | 0.98 | 0.67 | 106.07 | 106.73 |
| 4/19/76 | SET-7 | | 0.38 | 10.59 | 2.16 | 0.112 | ---- | ---- | 112.74 | ------ |
| 5/19/76 | SET-7 | | 1.35 | 8.85 | 1.66 | 0.147 | 0.96 | 0.63 | 148.18 | 148.82 |
| 4/19/76 | HFET | | 0.13 | 3.56 | 2.21 | 0.111 | 1.03 | 0.77 | 126.58 | 127.35 |
| 5/19/76 | HFET | | 0.64 | 3.00 | 1.82 | 0.087 | 1.64 | 1.22 | 98.94 | 100.16 |
| 4/19/76 | SET-7 | | 0.30 | 8.27 | 2.06 | 0.090 | 1.68 | 1.11 | 90.58 | 91.69 |
| 5/19/76 | SET-7 | | 1.96 | 11.83 | 1.59 | 0.144 | 1.40 | 0.94 | 147.67 | 148.60 |
| 4/19/76 | SET-7 | | 0.30 | 8.89 | 2.50 | 0.093 | 2.10 | 1.37 | 92.26 | 93.63 |
| 5/19/76 | SET-7 | | 1.46 | 9.15 | 1.69 | 0.112 | 1.00 | 0.66 | 113.10 | 113.76 |
| 4/19/76 | Accel to 30 | 20 min. | 0.05 | 0.07 | 0.62 | 0.028 | 0.36 | 0.33 | 38.83 | 39.16 |
| 5/19/76 | Accel to 30 | 20 min. | 0.21 | 0.57 | 0.53 | 0.027 | 0.38 | 0.37 | 41.24 | 41.61 |
| 4/19/76 | 30 mph | 30 min. | 0.05 | 0.00 | 0.80 | 0.013 | 0.96 | 0.99 | 19.58 | 20.56 |
| 5/19/76 | 30 mph | 30 min. | 0.04 | 0.02 | 0.60 | 0.017 | 0.28 | 0.28 | 26.04 | 26.32 |
| 4/19/76 | Accel to 60 | 20 min. | 0.00 | 0.50 | 2.26 | 0.130 | 13.36 | 10.25 | 152.19 | 162.44 |
| 5/19/76 | Accel to 60 | 20 min. | 0.45 | 1.88 | 1.64 | 0.077 | 12.31 | 10.63 | 101.86 | 112.49 |
| 4/19/76 | 60 mph | 20 min. | 0.06 | 3.73 | 1.74 | 0.028 | 1.53 | 1.19 | 33.35 | 34.55 |
| 5/19/76 | 60 mph | 20 min. | 0.02 | 0.08 | 1.49 | 0.065 | 5.58 | 4.62 | 81.94 | 86.56 |

## TABLE H-37. 1975 CALIFORNIA PLYMOUTH GRAN FURY (SwRI CAR EM-3)
### Monolithic Catalyst With Air Injection, 0.0410% Sulfur Fuel
### Emissions Summary - 80500 Kilometres

| Date | Test Type | Duration | g/km HC | g/km CO | g/km $NO_x$ | g/km $SO_2$ | mg/km $H_2SO_4$ | % Fuel S as $H_2SO_4$ | % Fuel S as $SO_2$ | Total Recovery |
|---|---|---|---|---|---|---|---|---|---|---|
| 5/12/76 | FTP | | 0.67 | 8.11 | 1.77 | 0.099 | 7.98 | 3.41 | 64.78 | 68.19 |
| 5/14/76 | FTP | | 0.68 | 8.75 | 2.23 | 0.182 | 5.85 | 2.49 | 118.73 | 121.22 |
| | Average | | 0.68 | 8.43 | 2.00 | 0.140 | 6.92 | 2.95 | 91.76 | 94.71 |
| 5/12/76 | SET-7 | | 0.21 | 1.22 | 2.05 | 0.097 | 6.86 | 4.05 | 87.23 | 91.28 |
| 5/14/76 | SET-7 | | 0.15 | 1.24 | 1.77 | 0.089 | 5.15 | 3.14 | 82.62 | 85.76 |
| | Average | | 0.18 | 1.23 | 1.91 | 0.093 | 6.00 | 3.60 | 84.93 | 88.52 |
| 5/12/76 | SET-7 | | 0.16 | 1.22 | 2.01 | 0.091 | 6.13 | 3.86 | 87.12 | 90.98 |
| 5/14/76 | SET-7 | | 0.9 | 1.40 | 1.72 | 0.085 | 4.58 | 2.94 | 83.48 | 86.42 |
| | Average | | 0.12 | 1.31 | 1.86 | 0.088 | 5.36 | 3.40 | 85.30 | 88.70 |
| 5/12/76 | FET | | 0.18 | 0.17 | 2.61 | 0.076 | 11.37 | 8.08 | 82.36 | 90.43 |
| 5/14/76 | FET | | 0.07 | 0.10 | 2.03 | 0.068 | 9.32 | 7.12 | 79.56 | 86.68 |
| | Average | | 0.12 | 0.14 | 2.32 | 0.072 | 10.34 | 7.60 | 80.96 | 88.56 |
| 5/12/76 | SET-7 | | 0.11 | 0.80 | 2.09 | 0.114 | 7.00 | 4.15 | 103.25 | 107.39 |
| 5/14/76 | SET-7 | | 0.09 | 1.38 | 1.80 | 0.105 | 5.73 | 3.69 | 103.29 | 106.98 |
| | Average | | 0.10 | 1.09 | 1.95 | 0.110 | 6.37 | 3.92 | 103.27 | 107.18 |
| 5/12/76 | SET-7 | | 0.11 | 1.15 | 2.13 | 0.114 | 6.16 | 3.89 | 109.74 | 113.63 |
| 5/14/76 | SET-7 | | 0.09 | 0.97 | 1.77 | 0.111 | 3.72 | 2.45 | 111.58 | 114.03 |
| | Average | | 0.10 | 1.06 | 1.95 | 0.112 | 4.94 | 3.17 | 110.66 | 113.83 |
| 5/12/76 | Accel to 30 | 20 min. | 0.53 | 0.10 | 2.14 | 0.027 | 4.90 | 3.87 | 32.46 | 36.33 |
| 5/14/76 | Accel to 30 | 20 min. | 0.09 | 0.08 | 1.37 | 0.018 | 0.25 | 0.27 | 30.74 | 31.01 |
| 5/12/76 | 30 mph | 30 min. | 0.34 | 0.03 | 2.21 | 0.033 | 26.62 | 22.29 | 42.92 | 65.20 |
| 5/14/76 | 30 mph | 30 min. | 0.10 | 0.02 | 1.37 | 0.022 | 1.17 | 1.29 | 36.41 | 37.69 |
| 5/12/76 | Accel to 60 | 20 min. | 0.23 | 1.59 | 2.95 | 0.101 | 20.30 | 15.78 | 120.12 | 135.90 |
| 5/14/76 | Accel to 60 | 20 min. | 0.09 | 1.02 | 2.59 | 0.077 | 16.57 | 13.52 | 95.62 | 109.14 |
| | Average | | 0.16 | 1.30 | 2.77 | 0.089 | 18.44 | 14.65 | 107.87 | 122.52 |
| 5/12/76 | 60 mph | 20 min. | 0.12 | 0.03 | 3.11 | 0.037 | 11.05 | 9.10 | 46.97 | 56.07 |
| 5/14/76 | 60 mph | 20 min. | 0.05 | 0.03 | 2.46 | 0.032 | 18.61 | 16.08 | 42.82 | 58.89 |
| | Average | | 0.08 | 0.03 | 2.79 | 0.034 | 14.83 | 12.59 | 44.90 | 57.48 |

## TABLE H-38. 1975 CALIFORNIA CHEVROLET IMPALA (SwRI CAR EM-4)
### Pelleted Catalyst 0.0405% Sulfur Fuel
### Emissions Summary - 80500 Kilometres

| Date | Test Type | Duration | g/km HC | g/km CO | g/km $NO_x$ | g/km $SO_2$ | mg/km $H_2SO_4$ | % Fuel S as $H_2SO_4$ | % Fuel S as $SO_2$ | Total Recovery |
|---|---|---|---|---|---|---|---|---|---|---|
| 4/27/76 | FTP | | 0.66 | 12.28 | 1.11 | 0.144 | 2.54 | 1.13 | 97.92 | 99.05 |
| 4/29/76 | FTP | | 0.54 | 10.58 | 0.94 | 0.087 | 3.07 | 1.42 | 61.73 | 63.16 |
| | Average | | 0.60 | 11.43 | 1.03 | 0.116 | 2.80 | 1.28 | 79.82 | 81.10 |
| 4/27/76 | SET-7 | | 0.16 | 4.19 | 0.88 | 0.078 | 8.44 | 5.04 | 71.11 | 76.15 |
| 4/29/76 | SET-7 | | 0.19 | 3.49 | 0.85 | 0.074 | 7.73 | 4.94 | 72.07 | 77.00 |
| | Average | | 0.18 | 3.84 | 0.86 | 0.076 | 8.08 | 4.99 | 71.59 | 76.58 |
| 4/27/76 | SET-7 | | 0.18 | 5.48 | 0.95 | 0.086 | 7.13 | 4.39 | 81.05 | 85.44 |
| 4/29/76 | SET-7 | | 0.17 | 5.35 | 0.85 | 0.071 | 4.87 | 3.15 | 69.93 | 73.08 |
| | Average | | 0.18 | 5.42 | 0.90 | 0.078 | 6.00 | 3.77 | 75.49 | 79.26 |
| 4/27/76 | HFET | | 0.09 | 1.38 | 0.93 | 0.054 | ----- | ----- | 55.82 | ----- |
| 4/29/76 | HFET | | 0.08 | 1.35 | 0.83 | 0.041 | 2.79 | 2.03 | 45.65 | 47.69 |
| | Average | | 0.08 | 1.36 | 0.88 | 0.048 | 2.79 | 2.03 | 50.74 | 47.69 |
| 4/27/76 | SET-7 | | ----- | ----- | ----- | 0.072 | 5.21 | ----- | ----- | ----- |
| 4/29/76 | SET-7 | | 0.19 | 3.89 | 0.86 | 0.076 | 5.88 | 3.78 | 74.45 | 78.23 |
| | Average | | 0.19 | 3.89 | 0.86 | 0.074 | 5.54 | 3.78 | 74.45 | 78.23 |
| 4/27/76 | SET-7 | | 0.16 | 4.38 | 0.92 | 0.070 | 7.27 | 4.69 | 69.55 | 74.24 |
| 4/29/76 | SET-7 | | 0.16 | 3.88 | 0.82 | 0.074 | 7.84 | 5.13 | 74.34 | 79.47 |
| | Average | | 0.16 | 4.13 | 0.87 | 0.072 | 7.56 | 4.91 | 71.95 | 76.86 |
| 4/27/76 | Accel to 30 | 20 min. | 0.22 | 0.20 | 0.29 | 0.031 | 3.82 | 3.23 | 39.85 | 43.09 |
| 4/29/76 | Accel to 30 | 20 min. | 0.30 | 0.26 | 0.21 | 0.024 | 4.64 | 3.92 | 31.20 | 35.12 |
| | Average | | 0.26 | 0.23 | 0.25 | 0.028 | 4.23 | 3.58 | 35.53 | 39.11 |
| 4/27/76 | 30 mph | 30 min. | 0.26 | 0.04 | 0.21 | 0.018 | 10.81 | 9.21 | 23.55 | 32.76 |
| 4/29/76 | 30 mph | 30 min. | 0.23 | 0.04 | 0.17 | 0.019 | 10.60 | 9.15 | 25.40 | 34.55 |
| | Average | | 0.24 | 0.04 | 0.19 | 0.018 | 10.70 | 9.18 | 24.48 | 33.66 |
| 4/27/76 | Accel to 60 | 20 min. | 0.06 | 0.24 | 1.02 | 0.047 | 19.17 | 14.58 | 55.27 | 69.85 |
| 4/29/76 | Accel to 60 | 20 min. | 0.04 | 0.12 | 0.84 | 0.025 | 29.78 | 23.64 | 30.71 | 54.35 |
| | Average | | 0.05 | 0.18 | 0.93 | 0.036 | 24.48 | 19.11 | 42.99 | 62.10 |
| 4/27/76 | 60 mph | 20 min. | 0.09 | 0.26 | 1.10 | 0.049 | 6.77 | 5.16 | 57.48 | 62.64 |
| 4/29/76 | 60 mph | 20 min. | 0.04 | 0.09 | 0.82 | 0.030 | 11.42 | 9.55 | 38.59 | 48.14 |
| | Average | | 0.06 | 0.18 | 0.96 | 0.040 | 9.10 | 7.36 | 48.04 | 55.39 |

# APPENDIX I

## SUPPORTING INFORMATION FOR PROCEDURAL DEVELOPMENT STUDY

SOUTHWEST RESEARCH INSTITUTE

8500 CULEBRA ROAD • POST OFFICE DRAWER 28510 • SAN ANTONIO, TEXAS 78284

May 15, 1975

## SWRI SULFATE PRECONDITIONING ROUTE

Important: NO WOT Accels - Accels to be PT and uniform, 3 mph/sec

| | Cumulative Distance Miles |
|---|---|
| 60 sec idle before leaving Emissions Lab | 0 |
| Emissions Lab N to Culebra Rd maingate @ 20-30 mph | 1.030 |
| Right turn on Culebra Rd to Callaghan Rd @ 35 mph | |
| Left turn on Callaghan to Millbank | |
| Left turn 1st street and then quick right on street parallel to Callaghan | |
| Left High Field to Millbank | |
| Right turn on Millbank to Moortown | |
| Right turn on Moortown to Topcraft | |
| Right turn on Topcraft to Callaghan | |
| Right turn on Callaghan, S to Culebra Rd | 2.720 |
| South on Callaghan to Commerce at 35 mph | 3.790 |
| Right turn on Commerce, West on Commerce to Military Dr at 40 mph | 5.739 |
| Right turn on Military Dr to Loop 410 access Rd at 40 mph | 6.248 |
| North on Loop 410 to Culebra Rd | 7.127 |
| Left turn on Culebra Rd and Left turn back on Loop 410 S to Marbach Rd at 55 mph | 10.022 |
| Left turn on Marbach and go East to Military Dr at 30 mph | 11.179 |
| Idle for three minutes | |
| Right turn on Military Dr to IH 10 at 35 mph | 12.070 |
| Left turn on IH 10 East to Gen. McMullen Dr at 55 mph | 16.635 |
| Left turn on Gen. McMullen North to Woodlawn Ave at 35 mph | 20.236 |
| Left turn on Woodlawn to Bandera Rd at 30 mph | 20.471 |
| Right turn on Bandera Rd NW to Loop 410 at 40 mph avg | 23.786 |
| Left turn on Loop 410 S to Ingram Rd Exit at 55 mph | 25.554 |
| Loop 410 S access Rd to Culebra Rd at 40 mph | 26.554 |
| Left on Culebra Rd to main gate SwRI at 40 mph | 27.546 |
| Right at main gate to Emissions Lab | |
| 60 sec Idle at Emissions Lab | 28.935 |

28.935 vs 28.8 miles of AA precondition

Initial run made in 58 min 45 sec (58.75 min)

$\frac{28.935 \text{ miles}}{58.75 \text{ min}}(60) = 29.55$ mph vs 29.8 mph of AA preconditioning

SAN ANTONIO, HOUSTON, CORPUS CHRISTI, TEXAS, AND WASHINGTON, D.C.

Last High Speed (55 mph) = 1.768
Last Mod Speed (40 mph) = 1.992
Last Low Speed (25 and 30 mph) = 1.389 ) = 3.381 miles

Total High Speed = 2.895 miles
4.565 miles
1.768 miles
9.228 miles total

TABLE I-1. DATA SUMMARY PART I, SEQUENCE A, 1975 AMC HORNET (SwRI CAR NO. EM-5) PELLETED CATALYST WITH AIRPUMP, 0.030 PERCENT SULFUR FUEL

| Test Type | Date | Run | g/km HC | g/km CO | g/km $NO_x$ | g/km $SO_2$ | mg/km $H_2SO_4$ | % Fuel S as $H_2SO_4$ | % Fuel S as $SO_2$ | Total Recovery |
|---|---|---|---|---|---|---|---|---|---|---|
| Set 7-1 | 5/20/75 | 1 | 0.07 | 0.31 | 1.11 | 0.061 | 7.97 | 8.34 | 97.07 | 105.41 |
| Set 7-2 | 5/20/75 | 2 | 0.07 | 0.17 | 1.28 | | 16.63 | 17.10 | | |
| Set 7-3 | 5/20/75 | 3 | 0.08 | 0.15 | 1.21 | | 47.20 | 50.75 | | |
| Set 7-4 | 5/20/75 | 4 | 0.07 | 0.10 | 1.22 | | 61.00 | 65.23 | | |
| Set 7-1 | 5/21/75 | 4 | 0.08 | 0.13 | 1.27 | | 18.10 | 19.34 | | |
| Set 7-2 | 5/21/75 | 5 | 0.08 | 0.10 | 1.31 | | 21.59 | 23.16 | | |
| Set 7-3 | 5/21/75 | 6 | 0.08 | 0.20 | 1.25 | | 27.70 | 29.83 | | |
| Set 7-4 | 5/21/75 | 7 | 0.08 | 0.16 | 1.34 | | 35.16 | 38.02 | | |
| Set 7-1 | 5/22/75 | 4 | 0.06 | 0.12 | 1.23 | 0.036 | 33.46 | 36.46 | 61.27 | 97.94 |
| Set 7-2 | 5/22/75 | 5 | 0.05 | 0.06 | 1.30 | - | 37.87 | 42.25 | 57.94 | - |
| Set 7-3 | 5/22/75 | 6 | 0.06 | 0.11 | 1.23 | 0.048 | 36.28 | 39.37 | 79.90 | 119.27 |
| Set 7-4 | 5/22/75 | 7 | 0.06 | 0.03 | 1.28 | 0.045 | 45.47 | 50.10 | 76.55 | 126.65 |
| Cold LA-4 | 5/21/75 | 1 | 0.43 | 5.60 | 1.20 | 0.035 | 1.61 | 1.24 | 41.22 | 42.46 |
| Hot LA-4 | 5/21/75 | 2 | 0.15 | 0.64 | 1.18 | 0.035 | 5.02 | 4.20 | 45.21 | 49.41 |
| FTP | | | 0.27 | 2.78 | 1.19 | 0.035 | 3.55 | | | |
| Cold LA-4 | 5/22/75 | 1 | 0.43 | 4.81 | 1.05 | 0.034 | 10.35 | 8.25 | 41.77 | 50.02 |
| Hot LA-4 | 5/22/75 | 2 | 0.16 | 0.45 | 1.07 | 0.027 | 16.20 | 13.90 | 36.12 | 50.02 |
| FTP | | | 0.28 | 2.33 | 1.06 | 0.030 | 13.69 | | | |
| Cold LA-4 | 5/23/75 | 1 | 0.46 | 4.81 | 1.10 | | 7.96 | 6.08 | | |
| Hot LA-4 | 5/23/75 | 2 | 0.13 | 0.36 | 1.17 | | 20.58 | 17.34 | | |
| FTP | | | 0.27 | 2.28 | 1.14 | | 13.25 | | | |
| FET | 5/21/75 | 3 | 0.09 | 0.25 | 1.13 | 0.024 | 42.06 | 61.17 | 53.15 | 114.33 |
| FET | 5/22/75 | 3 | 0.05 | 0.00 | 1.24 | 0.035 | 64.00 | 75.26 | 63.10 | 138.36 |
| FET | 5/23/75 | 3 | 0.05 | 0.03 | 1.60 | 0.044 | 77.36 | 86.48 | 74.79 | 161.28 |

TABLE I-2. DATA SUMMARY PART I, SEQUENCE A, 1975 AMC HORNET (SwRI CAR NO. EM-6) PELLETED CATALYST WITH AIRPUMP, 0.030 PERCENT SULFUR FUEL

| Test Type | Date | Run | g/km HC | g/km CO | g/km $NO_x$ | g/km $SO_2$ | mg/km $H_2SO_4$ | % Fuel S as $H_2SO_4$ | % Fuel S as $SO_2$ | Total Recovery |
|---|---|---|---|---|---|---|---|---|---|---|
| Set 7-1 | 5/20/75 | 1 | 0.08 | 0.50 | 1.38 | 0.062 | 13.05 | 13.85 | 100.59 | 114.43 |
| Set 7-2 | 5/20/75 | 2 | 0.08 | 0.44 | 1.41 | 0.034 | 14.94 | 15.83 | 55.72 | 71.55 |
| Set 7-3 | 5/20/75 | 3 | 0.08 | 0.14 | 1.45 | 0.034 | 23.19 | 24.45 | 54.79 | 79.24 |
| Set 7-4 | 5/20/75 | 4 | 0.08 | 0.23 | 1.43 | 0.035 | 56.23 | 59.89 | 57.02 | 116.91 |
| Set 7-1 | 5/21/75 | 4 | 0.07 | 0.13 | 1.54 | 0.018 | 39.95 | 43.60 | 30.21 | 73.80 |
| Set 7-2 | 5/21/75 | 5 | 0.07 | 0.44 | 1.43 | 0.037 | 40.51 | 43.78 | 61.13 | 104.91 |
| Set 7-3 | 5/21/75 | 6 | 0.07 | 0.18 | 1.45 | 0.040 | 41.91 | 45.50 | 65.89 | 111.40 |
| Set 7-4 | 5/21/75 | 7 | 0.07 | 0.33 | 1.42 | 0.041 | 40.15 | 43.13 | 67.56 | 110.69 |
| Set 7-1 | 5/22/75 | 4 | 0.06 | 0.13 | 1.12 | 0.034 | 26.35 | 28.95 | 57.56 | 123.27 |
| Set 7-2 | 5/22/75 | 5 | 0.06 | 0.04 | 1.22 | 0.026 | 35.79 | 40.51 | 45.65 | 106.32 |
| Set 7-3 | 5/22/75 | 6 | 0.06 | 0.02 | 1.30 | 0.033 | 43.10 | 47.79 | 56.64 | 112.07 |
| Set 7-4 | 5/22/75 | 7 | 0.06 | 0.05 | 1.40 | | 51.13 | 56.70 | | |
| Cold LA-4 | 5/21/75 | 1 | 0.35 | 4.14 | 1.28 | 0.034 | 3.04 | 2.30 | 39.30 | 41.61 |
| Hot LA-4 | 5/21/75 | 2 | 0.15 | 0.63 | 1.30 | 0.035 | 9.58 | 7.83 | 44.10 | 51.93 |
| FTP | | | 0.24 | 2.14 | 1.29 | 0.035 | 6.77 | | | 49.80 |
| Cold LA-4 | 5/22/75 | 1 | 0.45 | 4.32 | 1.21 | 0.025 | 10.11 | 7.59 | 29.05 | 36.64 |
| Hot LA-4 | 5/22/75 | 2 | 0.14 | 0.43 | 1.25 | | 19.64 | 16.59 | | |
| FTP | | | 0.27 | 2.11 | 1.23 | | 15.55 | | | |
| Cold LA-4 | 5/23/75 | 1 | 0.44 | 3.54 | 1.29 | 0.041 | 10.63 | 8.00 | 47.48 | 55.48 |
| Hot LA-4 | 5/23/75 | 2 | 0.14 | 0.34 | 1.31 | | 21.40 | 17.17 | | |
| FTP | | | 0.27 | 1.71 | 1.30 | | 16.77 | | | |
| FET | 5/21/75 | 3 | 0.08 | 0.01 | 1.70 | 0.028 | 52.89 | 59.44 | 48.46 | 107.90 |
| FET | 5/22/75 | 3 | 0.06 | 0.01 | 1.25 | 0.010 | 88.00 | 102.26 | 17.80 | 120.06 |
| FET | 5/23/75 | 3 | 0.05 | 0.04 | 1.48 | | 75.12 | 84.06 | | |

TABLE I-3. DATA SUMMARY PART I, SEQUENCE B, 1975 AMC HORNET (SwRI CAR NO. EM-5) PELLETED CATALYST WITH AIRPUMP, 0.030 PERCENT SULFUR FUEL

| Test Type | Date | Run | g/km HC | g/km CO | g/km $NO_x$ | g/km $SO_2$ | mg/km $H_2SO_4$ | % Fuel S as $H_2SO_4$ | % Fuel S as $SO_2$ | Total Recovery |
|---|---|---|---|---|---|---|---|---|---|---|
| FTP | 6/3/75 | 1 | 0.43 | 4.62 | 2.04 | | 6.99* | 7.11 | | |
| FTP | 6/4/75 | 1 | 0.40 | 4.51 | 1.65 | | 4.50* | 4.86 | | |
| FTP | 6/5/75 | 1 | 0.42 | 4.62 | 1.88 | | 3.22* | 3.41 | | |
| Set | 6/3/75 | 2 | 0.06 | 0.04 | 1.47 | | 15.27 | 16.61 | | |
| Set | 6/3/75 | 3 | 0.06 | 0.06 | 1.35 | | 14.42 | 15.55 | | |
| Set | 6/4/75 | 2 | 0.11 | 0.14 | 2.05 | | 27.28 | 29.91 | | |
| Set | 6/4/75 | 3 | 0.06 | 0.05 | 2.23 | | 20.70 | 22.29 | | |
| Set | 6/5/75 | 2 | 0.06 | 0.06 | 1.43 | | 18.94 | 21.25 | | |
| Set | 6/5/75 | 3 | 0.06 | 0.09 | 1.46 | | 18.06 | 19.72 | | |
| FET | 6/3/75 | 4 | 0.06 | 0.03 | 1.45 | | 23.96 | 28.04 | | |
| FET | 6/4/75 | 4 | 0.06 | 0.07 | 1.61 | | 26.08 | 31.48 | | |
| FET | 6/5/75 | 4 | 0.06 | 0.06 | 1.81 | | 30.00 | 34.90 | | |

* Non-weighted based on 11.09 actual miles run

TABLE I-4. DATA SUMMARY PART I, SEQUENCE B, 1975 AMC HORNET (SwRI CAR NO. EM-6) PELLETED CATALYST WITH AIRPUMP, 0.030 PERCENT SULFUR FUEL

| Test Type | Date | Run | g/km HC | g/km CO | g/km $NO_x$ | g/km $SO_2$ | mg/km $H_2SO_4$ | % Fuel S as $H_2SO_4$ | % Fuel S as $SO_2$ | Total Recovery |
|---|---|---|---|---|---|---|---|---|---|---|
| FTP | 6/3/75 | 1 | 0.36 | 3.42 | 1.97 | | 9.38* | 9.80 | | |
| FTP | 6/4/75 | 1 | 0.43 | 3.92 | 2.19 | | 13.67* | 16.99 | | |
| FTP | 6/5/75 | 1 | 0.43 | 3.18 | 2.16 | | 16.24* | 14.13 | | |
| Set | 6/3/75 | 2 | 0.06 | 0.03 | 1.36 | | 29.12 | 31.48 | | |
| Set | 6/3/75 | 3 | 0.06 | 0.05 | 1.38 | | 27.04 | 29.32 | | |
| Set | 6/4/75 | 2 | 0.06 | 0.01 | 1.48 | | 32.83 | 34.16 | | |
| Set | 6/4/75 | 3 | 0.06 | 0.01 | 1.36 | | 34.65 | 37.27 | | |
| Set | 6/5/75 | 2 | 0.06 | 0.02 | 1.59 | | 42.59 | 44.95 | | |
| Set | 6/5/75 | 3 | 0.07 | 0.09 | 1.51 | | 26.54 | 29.84 | | |
| FET | 6/3/75 | 4 | 0.05 | 0.01 | 1.45 | | 40.82 | 48.14 | | |
| FET | 6/4/75 | 4 | 0.06 | 0.03 | 1.08 | | 37.24 | 52.93 | | |
| FET | 6/5/75 | 4 | 0.05 | 0.01 | 1.58 | | 42.01 | 50.79 | | |

* Non-weighted based on 11.09 actual miles run

TABLE I-5. DATA SUMMARY PART I, SEQUENCE C, 1975 AMC HORNET (SwRI CAR NO. EM-5) PELLETED CATALYST WITH AIRPUMP, 0.030 PERCENT SULFUR FUEL

| Test Type | Date | Run | g/km HC | g/km CO | g/km $NO_x$ | g/km $SO_2$ | mg/km $H_2SO_4$ | % Fuel S as $H_2SO_4$ | % Fuel S as $SO_2$ | Total Recovery |
|---|---|---|---|---|---|---|---|---|---|---|
| FTP | 6/10/75 | | 0.47 | 4.43 | 1.98 | 0.028 | 4.61 | 4.89 | 33.60 | 38.49 |
| FTP | 6/11/75 | | 0.46 | 4.42 | 2.06 | 0.023 | 6.66 | 7.01 | 37.64 | 44.65 |
| FTP | 6/12/75 | | 0.37 | 4.13 | 2.09 | 0.023 | 3.46 | 3.58 | 35.76 | 39.34 |
| FET | 6/10/75 | 2 | 0.05 | 0.07 | 1.26 | 0.027 | 33.24 | 40.13 | 50.13 | 90.26 |
| FET | 6/11/75 | 2 | 0.04 | 0.03 | 1.56 | 0.026 | 36.13 | 45.53 | 49.57 | 95.10 |
| FET | 6/12/75 | | 0.05 | 0.10 | 1.50 | 0.021 | 24.16 | 29.50 | 39.61 | 69.11 |
| Set | 6/10/75 | 3 | 0.07 | 0.05 | 1.38 | 0.045 | 12.92 | 15.10 | 72.93 | 88.04 |
| Set | 6/10/75 | 4 | 0.06 | 0.23 | 1.27 | 0.051 | 20.54 | 22.34 | 67.11 | 89.45 |
| Set | 6/11/75 | 3 | 0.07 | 0.19 | 1.50 | 0.041 | 12.60 | 14.18 | 69.94 | 84.12 |
| Set | 6/11/75 | 4 | 0.05 | 0.03 | 1.46 | 0.040 | 25.48 | 28.46 | 65.53 | 96.98 |
| Set | 6/12/75 | 3 | 0.07 | 0.08 | 1.43 | 0.041 | 17.88 | 19.78 | 69.52 | 89.30 |
| Set | 6/12/75 | 4 | 0.05 | 0.02 | 1.60 | 0.032 | 25.41 | 26.69 | 50.95 | 77.64 |

TABLE I-6. DATA SUMMARY PART I, SEQUENCE C, 1975 AMC HORNET (SwRI CAR NO. EM-6) PELLETED CATALYST WITH AIRPUMP, 0.030 PERCENT SULFUR FUEL

| Test Type | Date | Run | g/km HC | g/km CO | g/km $NO_x$ | g/km $SO_2$ | mg/km $H_2SO_4$ | % Fuel S as $H_2SO_4$ | % Fuel S as $SO_2$ | Total Recovery |
|---|---|---|---|---|---|---|---|---|---|---|
| FTP | 6/10/75 | | 0.44 | 3.38 | 2.02 | 0.030 | 8.44 | 8.89 | 41.27 | 50.16 |
| FTP | 6/11/75 | | 0.48 | 3.38 | 2.08 | 0.027 | 7.97 | 8.52 | 43.77 | 52.29 |
| FTP | 6/12/75 | | 0.39 | 3.25 | 2.17 | | 12.56 | 12.72 | | |
| FET | 6/10/75 | 2 | 0.04 | 0.00 | 1.29 | 0.036 | 44.30 | 57.04 | 71.50 | 128.54 |
| FET | 6/11/75 | 2 | 0.05 | 0.07 | 1.56 | 0.037 | 38.03 | 46.29 | 68.64 | 114.93 |
| FET | 6/12/75 | 2 | 0.04 | 0.00 | 2.74 | 0.036 | 46.62 | 58.63 | 69.62 | 128.25 |
| Set | 6/10/75 | 3 | 0.06 | 0.03 | 1.60 | 0.038 | 22.33 | 23.31 | 60.28 | 83.59 |
| Set | 6/10/75 | 4 | 0.06 | 0.03 | 1.35 | 0.034 | 33.67 | 38.27 | 59.95 | 98.22 |
| Set | 6/11/75 | 3 | 0.04 | 0.03 | 1.04 | 0.030 | 12.85 | 25.12 | 90.47 | 115.59 |
| Set | 6/11/75 | 4 | 0.09 | 0.04 | 1.85 | 0.040 | 32.83 | 35.83 | 66.71 | 102.54 |
| Set | 6/12/75 | 3 | 0.05 | 0.02 | 1.59 | 0.033 | 31.33 | 33.51 | 53.97 | 87.49 |
| Set | 6/12/75 | 4 | 0.05 | 0.00 | 1.54 | 0.031 | 43.82 | 48.83 | 53.65 | 102.48 |

TABLE I-7. DATA SUMMARY PART I, SEQUENCE D, 1975 AMC HORNET (SwRI CAR NO. EM-5) PELLETED CATALYST WITH AIRPUMP, 0.030 PERCENT SULFUR FUEL

| Test Type | Date | Run | g/km HC | g/km CO | g/km $NO_x$ | g/km $SO_2$ | mg/km $H_2SO_4$ | % Fuel S as $H_2SO_4$ | % Fuel S as $SO_2$ | Total Recovery |
|---|---|---|---|---|---|---|---|---|---|---|
| Set | 6/17/75 | 1 | 0.35* | 3.92* | 1.26 | 0.022 | 9.25 | 9.15 | 33.94 | 43.09 |
| Set | 6/17/75 | 2 | 0.06 | 0.13 | 1.40 | 0.028 | 25.14 | 26.99 | 46.33 | 73.32 |
| Set | 6/17/75 | 3 | 0.05 | 0.13 | 1.91 | 0.023 | 36.02 | 39.80 | 38.97 | 78.77 |
| Set | 6/17/75 | 4 | 0.05 | 0.14 | 1.22 | 0.038 | 38.43 | 44.29 | 66.54 | 110.83 |
| Set | 6/17/75 | 5 | 0.06 | 0.05 | 1.39 | 0.035 | 37.95 | 42.04 | 58.63 | 100.67 |
| Set | 6/17/75 | 6 | 0.06 | 0.02 | 1.42 | 0.031 | 46.41 | 51.21 | 51.69 | 102.90 |
| Set | 6/17/75 | 7 | 0.05 | 0.07 | 1.42 | 0.032 | 41.99 | 46.84 | 55.12 | 101.96 |
| Set | 6/17/75 | 8 | 0.05 | 0.09 | 1.34 | 0.044 | 36.63 | 40.79 | 74.67 | 115.46 |
| Set | 6/17/75 | 9 | 0.06 | 0.03 | 1.48 | 0.025 | 43.53 | 47.42 | 41.58 | 89.01 |
| Set | 6/17/75 | 10 | 0.06 | 0.06 | 1.57 | 0.035 | 41.22 | 45.51 | 59.14 | 104.64 |
| Set | 6/17/75 | 11 | 0.06 | 0.14 | 1.31 | 0.041 | 41.73 | 46.26 | 69.08 | 115.34 |
| Set | 6/17/75 | 12 | 0.06 | 0.07 | 1.35 | 0.028 | 36.11 | 39.85 | 47.87 | 87.72 |
| Set | 6/17/75 | 13 | 0.06 | 0.08 | 1.48 | 0.048 | 46.67 | 50.65 | 80.43 | 131.07 |
| Set | 6/17/75 | 14 | 0.06 | 0.14 | 1.28 | 0.055 | 25.46 | 28.33 | 93.66 | 121.99 |
| Set | 6/17/75 | 15 | 0.06 | 0.07 | 1.36 | 0.035 | 44.55 | 49.27 | 59.62 | 108.90 |
| Set | 6/17/75 | 16 | 0.07 | 0.45 | 1.23 | 0.060 | 25.01 | 28.07 | 102.53 | 130.60 |
| Set | 6/17/75 | 17 | 0.06 | 0.04 | 1.30 | 0.027 | 37.15 | 41.40 | 45.50 | 86.90 |
| Set | 6/17/75 | 18 | 0.06 | 0.14 | 1.38 | 0.042 | 25.61 | 28.78 | 72.91 | 101.69 |
| Set | 6/17/75 | 19 | 0.06 | 0.02 | 1.31 | 0.032 | 43.72 | 49.23 | 54.61 | 103.83 |
| Set | 6/17/75 | 20 | 0.06 | 0.08 | 1.21 | 0.044 | 31.39 | 34.35 | 73.07 | 107.42 |
| *Deleted from average | | | | | | | | | | |
| | Avg. | 1-20 | 0.06 | 0.10 | 1.50 | 0.036 | 35.70 | 39.51 | 61.30 | 100.81 |
| | Std. Dev. | 1-20 | 0.005 | 0.09 | 0.54 | 0.010 | 9.46 | 10.66 | 17.97 | 20.42 |
| Coef. of Var (%) | | 1-20 | 8.3 | 88.9 | 36.4 | 28.5 | 26.6 | 27.0 | 29.3 | 20.3 |
| | Avg. | 4-20 | 0.06 | 0.10 | 1.36 | 0.038 | 37.86 | 42.02 | 65.10 | 107.11 |
| | Std. Dev. | 4-20 | <0.01 | 0.10 | 0.10 | 0.010 | 7.17 | 7.80 | 16.62 | 13.10 |
| Coef. of Var (%) | | 4-20 | 8.2 | 100.0 | 7.3 | 25.3 | 18.9 | 18.6 | 25.5 | 12.2 |

TABLE I-8. DATA SUMMARY PART I, SEQUENCE D, 1975 AMC HORNET (SwRI CAR NO. EM-6) PELLETED CATALYST WITH AIRPUMP, 0.030 PERCENT SULFUR FUEL

| Test Type | Date | Run | g/km HC | g/km CO | g/km $NO_x$ | g/km $SO_2$ | mg/km $H_2SO_4$ | % Fuel S as $H_2SO_4$ | % Fuel S as $SO_2$ | Total Recovery |
|---|---|---|---|---|---|---|---|---|---|---|
| Set | 6/18/75 | 1 | 0.30* | 3.31* | 1.20 | 0.067 | 8.16 | 8.17 | 103.48 | 111.65 |
| Set | 6/18/75 | 2 | 0.06 | 0.12 | 1.34 | 0.046 | 21.13 | 22.90 | 76.32 | 99.22 |
| Set | 6/18/75 | 3 | 0.06 | 0.17 | 1.32 | 0.038 | 23.90 | 26.82 | 66.11 | 92.93 |
| Set | 6/18/75 | 4 | 0.06 | 0.03 | 1.26 | 0.034 | 32.60 | 35.74 | 57.13 | 92.87 |
| Set | 6/18/75 | 5 | 0.06 | 0.07 | 1.37 | 0.037 | 33.55 | 36.04 | 60.79 | 96.83 |
| Set | 6/18/75 | 6 | 0.06 | 0.05 | 1.27 | 0.034 | 41.89 | 45.66 | 55.78 | 101.43 |
| Set | 6/18/75 | 7 | 0.06 | 0.11 | 1.27 | 0.037 | 40.97 | 45.78 | 62.46 | 108.24 |
| Set | 6/18/75 | 8 | 0.06 | 0.03 | 1.48 | 0.042 | 53.24 | 56.46 | 67.62 | 124.08 |
| Set | 6/18/75 | 9 | 0.06 | 0.20 | 1.41 | 0.049 | 28.56 | 31.18 | 82.03 | 113.21 |
| Set | 6/18/75 | 10 | 0.06 | 0.06 | 1.23 | 0.031 | 30.68 | 33.61 | 51.82 | 85.43 |
| Set | 6/18/75 | 11 | 0.05 | 0.06 | 1.33 | ** | 42.62 | 47.03 | * | * |
| Set | 6/18/75 | 12 | 0.06 | 0.19 | 1.36 | 0.050 | 32.92 | 36.26 | 84.58 | 120.84 |
| Set | 6/18/75 | 13 | 0.07 | 0.23 | 1.32 | 0.084 | 24.94 | 27.50 | 141.22 | 168.72 |
| Set | 6/18/75 | 14 | 0.06 | 0.06 | 1.44 | 0.028 | 43.78 | 49.48 | 48.17 | 97.66 |
| Set | 6/18/75 | 15 | 0.06 | 0.04 | 1.42 | 0.035 | 43.67 | 48.76 | 59.68 | 108.44 |
| Set | 6/18/75 | 16 | 0.06 | 0.29 | 1.33 | 0.040 | 31.58 | 35.79 | 70.21 | 106.00 |
| Set | 6/18/75 | 17 | 0.07 | 0.52 | 1.42 | 0.065 | 24.33 | 26.85 | 110.38 | 137.23 |
| Set | 6/18/75 | 18 | 0.06 | 0.04 | 1.33 | 0.037 | 35.23 | 39.41 | 62.68 | 102.10 |
| Set | 6/18/75 | 19 | 0.07 | 0.22 | 1.27 | 0.035 | 33.80 | 37.63 | 59.55 | 97.18 |
| Set | 6/18/75 | 20 | 0.06 | 0.09 | 1.38 | 0.030 | 37.21 | 42.52 | 51.61 | 94.14 |

*Deleted from average
** Sample Vial Broken

| Statistic | Runs | HC | CO | $NO_x$ | $SO_2$ | mg/km $H_2SO_4$ | % Fuel S as $H_2SO_4$ | % Fuel S as $SO_2$ | Total Recovery |
|---|---|---|---|---|---|---|---|---|---|
| Avg. | 1-20 | 0.06 | 0.14 | 1.34 | 0.043 | 33.45 | 36.68 | 72.19 | 108.33 |
| Std. Dev. | 1-20 | < 0.01 | 0.13 | 0.07 | 0.015 | 10.28 | 11.09 | 23.66 | 19.25 |
| Coef. of Var. (%) | 1-20 | 6.2 | 90.4 | 5.5 | 33.7 | 30.7 | 30.2 | 32.8 | 17.8 |
| Avg. | 4-20 | 0.06 | 0.13 | 1.35 | 0.042 | 35.97 | 39.75 | 70.36 | 109.65 |
| Std. Dev. | 4-20 | < 0.01 | 0.13 | 0.07 | 0.015 | 7.56 | 8.20 | 24.48 | 20.51 |
| Coef. of Var. (%) | 4-20 | 7.9 | 95.9 | 5.4 | 34.8 | 21.0 | 20.6 | 34.8 | 18.7 |

TABLE I-9. DATA SUMMARY PART I, SEQUENCE E, 1975 AMC HORNET (SwRI CAR NO. EM-5) PELLETED CATALYST WITH AIR PUMP, 0.030 PERCENT SULFUR FUEL

| Test Type | Date | Run | Fuel Canister | Gaseous Emissions, g/km HC | CO | $NO_x$ | $SO_2$ | mg/km $H_2SO_4$ | % Fuel S as $H_2SO_4$ | % Fuel S as $SO_2$ | Total Recovery |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Set-7 | 6/23/75 | 1 | connected | 0.22 | 2.40 | 1.90 | 0.050 | 21.75 | 21.50 | 75.97 | 97.47 |
| Set-7 | 6/23/75 | 2 | connected | 0.06 | 0.07 | 1.60 | 0.042 | 35.80 | 39.56 | 70.91 | 110.46 |
| Set-7 | 6/23/75 | 3 | connected | 0.06 | 0.03 | 1.83 | 0.041 | 38.18 | 39.70 | 65.66 | 105.36 |
| Set-7 | 6/23/75 | 4 | connected | 0.06 | 0.04 | 1.92 | 0.036 | 49.83 | 51.89 | 57.37 | 109.26 |
| Set-7 | 6/23/75 | 5 | connected | 0.06 | 0.08 | 1.83 | 0.063 | 36.97 | 37.93 | 99.12 | 137.05 |
| Set-7 | 6/23/75 | 6 | connected | 0.07 | 0.06 | 1.88 | 0.059 | | | 93.11 | |
| Set-7 | 6/23/75 | 7 | disconnected | 0.07 | 0.00 | 1.62 | 0.026 | 44.08 | 46.94 | 42.02 | 88.96 |
| Set-7 | 6/23/75 | 8 | disconnected | 0.07 | 0.08 | 1.78 | 0.022 | 48.72 | 48.37 | 33.70 | 82.07 |
| Set-7 | 6/23/75 | 9 | disconnected | 0.06 | 0.04 | 1.31 | 0.027 | 32.63 | 38.83 | 50.01 | 88.84 |
| Set-7 | 6/23/75 | 10 | disconnected | 0.06 | 0.07 | 1.55 | 0.035 | 39.82 | 43.49 | 59.10 | 102.59 |
| Set-7 | 6/23/75 | 11 | disconnected | 0.06 | 0.10 | 1.54 | 0.037 | 45.04 | 51.62 | 65.35 | 116.97 |
| Set-7 | 6/23/75 | 12 | disconnected | 0.06 | 0.10 | 1.96 | 0.028 | 43.95 | 51.32 | 49.21 | 100.53 |

| | |
|---|---|
| Average, all tests | 41.5 |
| Standard Deviation | 5.7 |
| Coefficient of Var. | 13.7% |
| Average, tests 2-5 | 40.2 |
| Standard Deviation | 6.47 |
| Coefficient of Var. | 16.1% |
| Average, tests 7-12 | 42.37 |
| Standard Deviation | 5.55 |
| Coefficient of Var. | 13.1% |

TABLE I-10. SUMMARY OF EMISSION RESULTS, PART II, SEQUENCE A (SET-7 TESTS)
1975 AMC Hornet, EM-5
Pelleted Catalyst With Air, 0.03 Percent Fuel Sulfur
Test Date 7/23/75, All Tests With One Driver

| Test No. | Gaseous Emissions, g/mi HC | CO | $CO_2$ | $NO_x$ | $SO_2$, mg/mi | $H_2SO_4$, mg/mi | Avg. Cat. Temp. °F | % of Fuel "S" as $SO_2$ | $H_2SO_4$ | Total Recovery |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.10 | 0.06 | 489.0 | 2.30 | 65.71 | 37.87 | 914 | 68.68 | 25.87 | 94.55 |
| 2 | 0.10 | 0.03 | 489.0 | 2.15 | 50.85 | 38.42 | 914 | 53.17 | 26.25 | 79.43 |
| 3 | 0.10 | 0.08 | 483.0 | 2.08 | 68.32 | 52.31 | 907 | 72.38 | 36.21 | 108.58 |
| 4 | 0.11 | 0.08 | 491.0 | 1.95 | 53.10 | 58.93 | 916 | 55.26 | 40.06 | 95.32 |
| 5 | 0.09 | 0.11 | 491.0 | 2.09 | 69.51 | 64.89 | 913 | 72.38 | 44.15 | 116.53 |
| 6 | 0.10 | 0.00 | 482.0 | 2.19 | 61.94 | 57.62 | 910 | 65.71 | 39.94 | 105.64 |
| 7 | 0.11 | 0.07 | 497.0 | 2.29 | 81.16 | 61.64 | 910 | 83.54 | 41.46 | 124.99 |
| 8 | 0.05 | 0.05 | 479.0 | 2.32 | 52.10 | 62.13 | 908 | 55.59 | 43.31 | 98.90 |
| 9 | 0.09 | 0.07 | 488.0 | 2.29 | 53.65 | 62.63 | 915 | 56.24 | 42.90 | 99.14 |
| 10 | 0.09 | 0.06 | 480.0 | 2.16 | 66.07 | 59.76 | 912 | 70.43 | 41.62 | 112.05 |
| 11 | 0.10 | 0.06 | 496.0 | 2.23 | 53.15 | 64.38 | 912 | 54.77 | 43.34 | 98.11 |
| 12 | 0.10 | 0.00 | 487.0 | 2.16 | 45.85 | 60.13 | 908 | 48.14 | 41.25 | 89.40 |
| **All Tests** | | | | | | | | | | |
| Average | 0.10 | 0.06 | 488 | 2.18 | 60.12 | 56.73 | 912 | 63.02 | 38.86 | 101.89 |
| Std. Dev. | 0.02 | 0.03 | 5.8 | 0.11 | 10.29 | 9.29 | 2.97 | 10.61 | 6.34 | 12.43 |
| Coef. of Var | 15.7% | 53.9% | 1.2% | 5.1% | 17.1% | 16.4% | 0.3% | 16.8% | 16.3% | 12.2% |
| **Tests 4-12** | | | | | | | | | | |
| Average | 0.09 | 0.06 | 488 | 2.19 | 59.61 | 61.35 | 912 | 62.45 | 42.00 | 104.45 |
| Std. Dev. | 0.02 | 0.04 | 6.6 | 0.12 | 11.04 | 2.45 | 2.83 | 11.28 | 1.50 | 11.38 |
| Coef. of Var | 20.0% | 64.3% | 1.3% | 5.3% | 18.5% | 4.0% | 0.3% | 18.1% | 3.6% | 10.9% |

## TABLE I-11. SUMMARY OF EMISSION RESULTS, PART II SEQUENCE B
## 1975 AMC HORNET, EM-5

Pelleted Catalyst with air, 0.03 percent sulfur fuel
Test date 7/24/7

| Test No. | Test Type | Gaseous Emissions, g/mi HC | CO | $CO_2$ | $NO_x$ | $SO_2$ mg/mi | $H_2SO_4$ mg/mi | Cat. Temp. °F | % of Fuel "S" as $SO_2$ | $H_2SO_4$ | Total Recovery |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 35 mph | 0.00 | 0.06 | 360.0 | 2.42 | 25.00 | 14.32 | 757 | 35.57 | 13.32 | 48.89 |
| 2 | 35 mph | 0.08 | 0.02 | 375.0 | 2.32 | 29.25 | 28.23 | 736 | 39.89 | 25.15 | 65.05 |
| 3 | 35 mph | 0.05 | 0.00 | 354.0 | 2.28 | 44.19 | 30.28 | 753 | 63.85 | 28.58 | 92.43 |
| 4 | 35 mph | 0.08 | 0.08 | 358.0 | 2.35 | 38.83 | 32.00 | 755 | 57.46 | 29.85 | 87.31 |
| 5 | 35 mph | 0.08 | 0.02 | 346.0 | 2.47 | 46.29 | 37.58 | 753 | 68.42 | 36.29 | 104.71 |
| 6 | Set 7 | 0.08 | 0.01 | 495.0 | 2.80 | 121.83 | 156.56 | 921 | 125.81 | 105.63 | 231.45 |
| 7 | Set 7 | 0.08 | 0.07 | 481.0 | 2.75 | 170.78 | 89.30 | 922 | 181.48 | 62.00 | 243.47 |
| Avg. 1-5 | | 0.06 | 0.04 | 358.6 | 2.37 | 36.71 | 28.48 | 751 | 53.04 | 26.64 | 79.68 |
| Std. Dev. 1-5 | | 0.03 | 0.03 | 10.6 | 0.08 | 9.29 | 8.65 | 8.4 | 14.6 | 8.47 | 22.41 |
| Coef. of Var. 1-5 | | 58.2% | 82.2% | 3.0% | 3.2% | 25.3% | 30.36 | 1.1% | 27.5% | 31.79 | 28.13 |
| Avg. 2-5 | | 0.07 | 0.03 | 358.3 | 2.36 | 39.64 | 32.02 | 749 | 57.41 | 29.97 | 87.38 |
| Std. Dev. 2-5 | | 0.02 | 0.03 | 12.2 | 0.08 | 7.61 | 4.01 | 8.8 | 12.51 | 4.66 | 16.58 |
| Coef. of Var. 2-5 | | 28.6% | 100.0% | 3.4 | 3.5% | 19.2% | 12.5% | 1.2% | 21.8% | 15.5% | 19.0% |

## TABLE I-12. SUMMARY OF EMISSION RESULTS, PART II, SEQUENCE C
### 1975 AMC Hornet, EM-5
### Pelleted Catalyst With Air, 0.03 Percent Sulfur Fuel
### Test Date 7/25/75

| Test No. | Test Type | Gaseous Emissions, g/mi HC | CO | $CO_2$ | $NO_x$ | $SO_2$ mg/mi | $H_2SO_4$ mg/mi | Cat. Temp. °F | % of Fuel "S" as $SO_2$ | $H_2SO_4$ | Total Recovery |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 50 mph | 0.06 | 0.06 | 426.0 | 1.87 | 33.60 | 58.63 | 970 | 40.30 | 45.94 | 86.24 |
| 2 | 50 mph | 0.07 | 0.00 | 426.0 | 2.13 | 30.67 | 66.45 | 968 | 36.81 | 52.12 | 88.93 |
| 3 | 50 mph | 0.06 | 0.03 | 429.0 | 1.96 | 27.79 | 63.39 | 971 | 33.16 | 49.41 | 82.57 |
| 4 | 50 mph | 0.05 | 0.00 | 426.0 | 2.10 | 39.30 | 60.75 | 963 | 47.17 | 47.63 | 94.80 |
| 5 | 50 mph | 0.04 | 0.03 | 394.0 | 1.78 | 35.79 | 61.06 | 958 | 46.43 | 51.76 | 98.19 |
| 6 | Set 7 | 0.12 | 0.15 | 484.0 | 2.49 | 59.92 | 71.96 | 907 | 63.32 | 49.69 | 113.00 |
| 7 | Set 7 | 0.10 | 0.04 | 491.0 | 2.58 | 71.43 | 73.45 | 904 | 74.42 | 50.00 | 124.43 |
| Avg. 1-5 | | 0.06 | 0.02 | 420.2 | 1.97 | 33.43 | 62.06 | 966 | 40.77 | 49.37 | 90.15 |
| Std. Dev. | | 0.01 | 0.03 | 14.7 | 0.15 | 4.46 | 2.98 | 5.4 | 6.06 | 2.65 | 6.33 |
| Coef. of Var. | | 16.7% | 104.6% | 3.5 | 7.6% | 13.3% | 4.8% | 0.6% | 14.9% | 5.4% | 7.0% |
| Avg. 2-5 | | 0.06 | 0.02 | 418.8 | 1.99 | 33.39 | 62.91 | 965 | 40.89 | 50.23 | 91.12 |
| Std. Dev. | | 0.01 | 0.02 | 16.6 | 0.16 | 5.15 | 2.64 | 5.7 | 6.99 | 2.11 | 6.87 |
| Coef. of Var. | | 23.5% | 115.5% | 4.0 | 8.0% | 15.4% | 4.2% | 0.6% | 17.1% | 4.2% | 7.5% |

TABLE I-13. SUMMARY OF EMISSION RESULTS, PART II SEQUENCE D (SET-9 TESTS)
1975 AMC Hornet EM-5

Pelleted Catalysts with air, 0.03 percent sulfur fuel
Test date 7/30/75

| Test | Gaseous Emissions, g/mi | | | | $SO_2$ | $H_2SO_4$ | Avg. Cat. | % of Fuel S as | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | HC | CO | $CO_2$ | $NO_x$ | mg/mi | mg/mi | Temp. °F | $SO_2$ | $H_2SO_4$ | Recovery | $\%O_2$ |
| 1 | 0.27 | 0.43 | 504.0 | 2.10 | 9.95 | 51.40 | 921 | 10.07 | 33.99 | 44.06 | 5.38 |
| 2 | 0.11 | 0.05 | 488.0 | 2.38 | 52.25 | 71.17 | 913 | 54.78 | 48.75 | 103.54 | 5.39 |
| 3 | 0.10 | 0.03 | 473.0 | 2.27 | 40.97 | 58.51 | 908 | 44.28 | 41.32 | 85.60 | 5.74 |
| 4 | 0.09 | 0.06 | 471.0 | 2.29 | 50.69 | 70.50 | 909 | 55.08 | 50.06 | 105.13 | 5.71 |
| 5 | 0.09 | 0.07 | 469.0 | 2.29 | 50.05 | 70.50 | 902 | 54.57 | 50.23 | 104.80 | 5.77 |
| 6 | 0.08 | 0.13 | 463.0 | 2.21 | 54.02 | 75.03 | 904 | 59.70 | 54.18 | 113.88 | 5.61 |
| 7 | 0.09 | 0.00 | 477.0 | 2.33 | 50.81 | 69.93 | 904 | 54.52 | 49.02 | 103.53 | 5.77 |
| 8 | 0.09 | 0.09 | 459.0 | 2.21 | 47.55 | 72.53 | 905 | 53.00 | 52.81 | 105.82 | 5.55 |
| 9 | 0.15 | 0.03 | 482.0 | 2.36 | 63.05 | 62.74 | 904 | 66.90 | 43.49 | 110.39 | 5.63 |
| 10 | 0.11 | 0.04 | 474.0 | 2.36 | 41.01 | 76.28 | 903 | 44.20 | 53.71 | 97.91 | 5.50 |
| 11 | 0.09 | 0.07 | 476.0 | 2.30 | 52.19 | 70.15 | 908 | 56.05 | 49.22 | 105.27 | 5.33 |
| 12 | 0.10 | 0.13 | 497.0 | 2.48 | 48.58 | 70.72 | 908 | 49.97 | 47.52 | 97.49 | 5.30 |
| Avg. 1-12 | 0.11 | 0.09 | 477.8 | 2.30 | 46.76 | 68.29 | 907 | 50.26 | 47.86 | 98.12 | 5.56 |
| Std. Div. 1-12 | 0.05 | 0.11 | 13.2 | 0.10 | 12.95 | 7.19 | 5.3 | 14.06 | 5.78 | 18.44 | 0.17 |
| Coef. of Var. 1-12 | 45.8% | 119.7% | 2.8% | 4.2% | 27.8% | 10.5% | 0.6% | 28.0% | 12.1% | 18.8% | 3.1% |
| Avg. 4-12 | 0.10 | 0.07 | 474.2 | 2.31 | 50.88 | 70.93 | 905 | 54.89 | 50.02 | 104.91 | 5.57 |
| Std. Div. 4-12 | 0.02 | 0.04 | 11.1 | 0.08 | 5.85 | 3.82 | 2.49 | 6.24 | 3.34 | 5.21 | 0.17 |
| Coef. of Var. 4-12 | 21.1% | 63.0% | 2.3% | 3.6% | 11.5% | 5.4 | 0.3% | 11.4% | 6.7% | 5.0% | 0.03% |

TABLE I-14. SUMMARY OF EMISSION RESULTS, PART II, SEQUENCE E
1975 California Plymouth, EM-3, SET 7
Monolithic Catalyst, 0.0415 Percent Sulfur Fuel
Test Dates 8/1/75, 8/5/75

| Test No. | Date | Gaseous Emissions g/mi HC | CO | $CO_2$ | $NO_x$ | $SO_2$ mg/mi | $H_2SO_4$ mg/mi |
|---|---|---|---|---|---|---|---|
| 1 | 8-1-75 | 0.05 | 0.47 | 607.0 | 0.76 | 175.67 | 35.72 |
| 2 | | 0.04 | 0.68 | 647.0 | 0.85 | 197.14 | 32.12 |
| 3 | | 0.04 | 0.51 | 615.0 | 0.82 | 153.48 | 27.33 |
| 4 | | 0.05 | 0.66 | 613.0 | 0.81 | 161.06 | 24.57 |
| 5 | | 0.05 | 0.75 | 639.0 | 0.84 | 178.31 | 23.37 |
| 6 | | 0.05 | 0.72 | 630.0 | 0.82 | 160.84 | 23.72 |
| 7 | | 0.12 | 0.83 | 629.0 | 0.83 | 179.91 | 14.08 |
| 8 | | 0.12 | 0.71 | 620.0 | 0.81 | 171.31 | 15.55 |
| 9 | | 0.10 | 0.45 | 629.0 | 0.84 | 152.24 | 26.03 |
| 10 | | 0.05 | 1.01 | 636.0 | 0.80 | 173.91 | |
| 11 | | 0.06 | 1.15 | 599.0 | 0.83 | 178.18 | 18.45 |
| 12 | | 0.04 | 0.76 | 614.0 | 0.84 | 167.35 | 22.97 |
| 13 | | 0.04 | 0.78 | 618.0 | 0.84 | 152.00 | 21.63 |
| 14 | | 0.05 | 1.50 | 649.0 | 0.91 | 211.85 | 18.73 |
| 15 | ↓ | 0.04 | 0.79 | 616.0 | 0.83 | 163.10 | 17.28 |
| 1 | 8-5-75 | 0.06 | 0.51 | 682.0 | 0.92 | 172.12 | 40.08 |
| 2 | | 0.04 | 0.60 | 664.0 | 0.97 | 200.86 | 45.50 |
| 3 | | 0.04 | 0.65 | 658.0 | 0.95 | 168.07 | 40.39 |
| 4 | | 0.04 | 0.48 | 658.0 | 0.91 | 164.43 | 48.55 |
| 5 | | 0.04 | 0.55 | 659.0 | 0.92 | 158.63 | 38.19 |
| 6 | | 0.04 | 0.55 | 639.0 | 0.91 | 139.74 | 43.17 |
| 7 | | 0.04 | 0.71 | 648.0 | 0.91 | 163.93 | 34.52 |
| 8 | | 0.04 | 0.84 | 636.0 | 0.88 | 160.23 | 34.94 |
| 9 | | 0.04 | 0.47 | 658.0 | 0.90 | 149.93 | 36.14 |
| 10 | | 0.04 | 1.04 | 645.0 | 0.91 | 170.57 | 27.31 |
| 11 | | 0.04 | 0.72 | 623.0 | 0.86 | 190.26 | 27.44 |
| 12 | | 0.04 | 0.53 | 632.0 | 0.86 | 140.64 | 29.62 |
| 13 | | 0.04 | 0.68 | 625.0 | 0.87 | 123.08 | 26.08 |
| 14 | | 0.04 | 1.27 | 634.0 | 0.91 | 179.66 | 18.84 |
| 15 | ↓ | 0.03 | 0.54 | 620.0 | 0.88 | 194.46 | 22.06 |

| | |
|---|---|
| Average of tests 4 to 15 on 8/1 and 8/5 | 26.66 |
| Std. Dev. of tests 4 to 15 on 8/1 and 8/5 | 8.95 |
| Coef. of var. of tests 4 to 15 on 8/1 and 8/5 | 33.6% |

TABLE I-14 (Cont'd.) SUMMARY OF EMISSION RESULTS, PART II, SEQUENCE E

1975 California Plymouth, EM-3, SET 7

Monolithic Catalyst, 0.0415 Percent Sulfur Fuel

Test Dates 8/1/75, 8/5/75

| Avg. Catalyst Temp. °F | % Fuel "S" as $SO_2$ | % Fuel "S" as $H_2SO_4$ | Total Recovery | $\%O_2$ | Fuel Wt. grams | Driver | Test No. |
|---|---|---|---|---|---|---|---|
| 963 | 110.50 | 14.68 | 125.19 | 4.36 | 2663 | B | 1 |
| 965 | 116.24 | 12.37 | 128.61 | 4.79 | 2821 | B | 2 |
| 959 | 95.23 | 11.08 | 106.31 | 4.81 | 2679 | B | 3 |
| 960 | 100.27 | 9.99 | 110.27 | 4.74 | 2669 | C | 4 |
| 963 | 106.45 | 9.12 | 115.57 | 4.71 | 2794 | A | 5 |
| 958 | 97.37 | 9.38 | 106.75 | 4.73 | 2758 | C | 6 |
| 955 | 109.08 | 5.58 | 114.65 | 4.73 | 2743 | A | 7 |
| 951 | 105.38 | 6.25 | 111.63 | 4.76 | 2671 | A | 8 |
| 954 | 92.29 | 10.31 | 102.60 | 4.73 | 2738 | C | 9 |
| 954 | 104.20 | ----- | ------ | 4.61 | 2772 | B | 10 |
| 968 | 113.32 | 7.67 | 120.99 | 4.59 | 2625 | B | 11 |
| 958 | 103.89 | 9.32 | 113.20 | 4.69 | 2695 | C | 12 |
| 962 | 93.82 | 8.72 | 102.55 | 4.64 | 2717 | A | 13 |
| 950 | 124.22 | 7.18 | 131.40 | 4.73 | 2821 | B | 14 |
| 951 | 101.01 | 6.99 | 108.01 | 4.73 | 2688 | A | 15 |
| | | | | | | | |
| 940 | 96.38 | 14.66 | 111.04 | 4.48 | 3101 | C | 1 |
| 943 | 115.42 | 17.08 | 132.50 | 4.81 | 3010 | B | 2 |
| 945 | 97.47 | 15.30 | 112.78 | 4.80 | 2988 | B | 3 |
| 937 | 95.36 | 18.40 | 113.76 | 4.83 | 2946 | C | 4 |
| 931 | 91.82 | 14.44 | 106.27 | 4.87 | 2950 | A | 5 |
| 927 | 83.50 | 16.85 | 100.35 | 4.78 | 2854 | C | 6 |
| 926 | 96.46 | 13.27 | 109.74 | 4.83 | 2907 | A | 7 |
| 922 | 96.05 | 13.68 | 109.73 | 4.86 | 2849 | A | 8 |
| 923 | 86.92 | 13.69 | 100.61 | 4.79 | 2935 | C | 9 |
| 919 | 100.75 | 10.54 | 111.29 | 4.79 | 2884 | B | 10 |
| 924 | 116.52 | 10.98 | 127.50 | 4.68 | 2783 | B | 11 |
| 934 | 84.97 | 11.69 | 96.66 | 4.83 | 2804 | C | 12 |
| 927 | 75.08 | 10.39 | 85.47 | 4.81 | 2773 | A | 13 |
| 927 | 107.94 | 7.40 | 115.34 | 4.63 | 2849 | B | 14 |
| 928 | 119.78 | 8.88 | 128.66 | 4.78 | 2780 | A | 15 |

Average of tests
4 to 15 on 8/1 & 8/5 10.47

Std. Dev. of tests
4 to 15 on 8/1 & 8/5 3.31

Coef. of Var. tests
4 to 15 on 8/1 & 8/5 31.6

# APPENDIX J

## SUPPORTING INFORMATION FOR BASELINE STUDIES

TABLE J-1. BASELINE EMISSIONS TEST RESULTS
1975 FORD GRANADA, BASELINE CAR I-3
NO CATALYST, 0.030 PERCENT SULFUR FUEL

| Date | Test Type | Duration | g/km HC | g/km CO | g/km $NO_x$ | g/km $SO_2$ | mg/km $H_2SO_4$ | $H_2SO_4$ as % of fuel S | $SO_2$ as % of fuel S | Total Recovery |
|---|---|---|---|---|---|---|---|---|---|---|
| 10/23/75 | FTP | | 1.01 | 26.63 | 1.65 | 0.063 | 0.78 | 0.64 | 79.98 | 80.62 |
| 11/6/75 | FTP | | 0.94 | 24.00 | 1.60 | 0.069 | 0.97 | 0.76 | 83.08 | 83.84 |
| Average | | | 0.98 | 25.32 | 1.63 | 0.066 | 0.88 | 0.70 | 81.53 | 82.23 |
| 10/23/75 | SET-7 | 23 min | 0.39 | 9.52 | 1.72 | 0.051 | 0.86 | 1.03 | 94.36 | 95.40 |
| 11/6/75 | SET-7 | 23 min | 0.52 | 9.42 | 1.92 | 0.060 | 0.56 | 0.62 | 102.47 | 103.09 |
| Average | | | 0.46 | 9.47 | 1.82 | 0.056 | 0.71 | 0.83 | 98.42 | 99.25 |
| 10/23/75 | SET-7 | 23 min | 0.38 | 10.70 | 1.62 | 0.052 | 0.24 | 0.28 | 91.51 | 91.79 |
| 11/6/75 | SET-7 | 23 min | 0.39 | 9.20 | 1.85 | 0.043 | 0.24 | 0.26 | 71.62 | 71.89 |
| Average | | | 0.39 | 9.95 | 1.74 | 0.048 | 0.24 | 0.27 | 81.57 | 81.84 |
| 10/23/75 | FET | 12 min | 0.25 | 7.84 | 1.52 | 0.055 | 0.43 | 0.56 | 110.42 | 110.99 |
| 11/6/75 | FET | 12 min | 0.30 | 5.25 | 1.78 | 0.074 | 0.47 | 0.55 | 130.68 | 131.22 |
| Average | | | 0.28 | 6.55 | 1.65 | 0.065 | 0.45 | 0.56 | 120.55 | 121.11 |
| 10/23/75 | SET-7 | 23 min | 0.41 | 10.87 | 1.57 | 0.057 | 0.36 | 0.40 | 98.76 | 99.16 |
| 11/6/75 | SET-7 | 23 min | 0.38 | 9.55 | 1.71 | 0.063 | 0.17 | 0.19 | 105.09 | 105.28 |
| Average | | | 0.40 | 10.21 | 1.64 | 0.060 | 0.27 | 0.30 | 101.93 | 102.22 |
| 10/23/75 | SET-7 | 23 min | 0.37 | 10.54 | 1.49 | 0.054 | 0.15 | 0.17 | 93.39 | 93.56 |
| 11/6/75 | SET-7 | 23 min | 0.39 | 10.69 | 2.68 | 0.062 | 0.25 | 0.26 | 101.47 | 101.74 |
| Average | | | 0.38 | 10.62 | 2.09 | 0.058 | 0.20 | 0.22 | 97.43 | 97.65 |

## TABLE J-2. BASELINE EMISSIONS TEST RESULTS
## 1975 DODGE CORONET, BASELINE CAR I-4
## NO CATALYST, 0.030 PERCENT SULFUR FUEL

| Date | Test Type | Duration | g/km HC | g/km CO | g/km $NO_x$ | g/km $SO_2$ | mg/km $H_2SO_4$ | $H_2SO_4$ as % of fuel S | $SO_2$ as % of fuel S | Total Recovery |
|---|---|---|---|---|---|---|---|---|---|---|
| 10/28/75 | FTP | | 0.85 | 9.03 | 1.18 | 0.071 | 0.85 | 0.58 | 74.01 | 74.59 |
| 10/29/75 | FTP | | 0.77 | 10.15 | 1.25 | 0.074 | 1.25 | 0.87 | 78.19 | 79.06 |
| Average | | | 0.81 | 9.59 | 1.22 | 0.073 | 1.05 | 0.73 | 76.10 | 76.83 |
| 10/28/75 | SET-7 | 23 min | 0.51 | 6.02 | 1.19 | 0.052 | 1.95 | 1.87 | 75.81 | 77.68 |
| 10/29/75 | SET-7 | 23 min | 0.41 | 5.15 | 1.30 | 0.053 | 1.18 | 1.15 | 79.58 | 80.73 |
| Average | | | 0.46 | 5.59 | 1.25 | 0.053 | 1.57 | 1.51 | 77.70 | 79.21 |
| 10/28/75 | SET-7 | 23 min | 0.41 | 3.53 | 1.16 | 0.054 | 1.52 | 1.51 | 82.34 | 83.86 |
| 10/29/75 | SET-7 | 23 min | 0.39 | 4.82 | 1.24 | 0.050 | 1.93 | 1.86 | 73.90 | 75.76 |
| Average | | | 0.40 | 4.18 | 1.20 | 0.052 | 1.73 | 1.69 | 78.12 | 79.81 |
| 10/28/75 | FET | 12 min | 0.44 | 2.04 | 1.24 | 0.052 | 1.63 | 1.90 | 93.18 | 95.08 |
| 10/29/75 | FET | 12 min | 0.37 | 2.53 | 1.23 | 0.048 | 2.71 | 3.03 | 81.92 | 84.25 |
| Average | | | 0.41 | 2.29 | 1.24 | 0.050 | 2.17 | 2.47 | 87.55 | 90.02 |
| 10/28/75 | SET-7 | 23 min | 0.45 | 5.04 | 1.35 | 0.058 | 1.52 | 1.42 | 82.41 | 83.84 |
| 10/29/75 | SET-7 | 23 min | 0.34 | 3.74 | 1.39 | 0.053 | 1.90 | 1.92 | 81.97 | 83.89 |
| Average | | | 0.40 | 4.39 | 1.37 | 0.056 | 1.71 | 1.67 | 82.19 | 83.87 |
| 10/28/75 | SET-7 | 23 min | 0.44 | 3.01 | 1.13 | 0.059 | 1.56 | 1.50 | 87.87 | 89.37 |
| 10/29/75 | SET-7 | 23 min | 0.34 | 3.80 | 1.44 | 0.057 | 1.88 | 1.83 | 77.02 | 78.85 |
| Average | | | 0.39 | 3.41 | 1.29 | 0.056 | 1.72 | 1.67 | 82.45 | 84.11 |

TABLE J-3. BASELINE EMISSION TEST RESULTS
1975 HORNET SPORTABOUT, BASELINE CAR IIA-1
PELLETED CATALYST WITH AIR PUMP
(0.030% SULFUR FUEL)

| Test | Date | Test Type | g/km HC | g/km CO | g/km $NO_x$ | g/km $SO_2$ | mg/km $H_2SO_4$ | % Fuel S as S in $H_2SO_4$ | % Fuel S as S in $SO_2$ | Total Recovery |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 10/7/75 | FTP | 0.33 | 2.28 | 1.43 | 0.030 | 9.93 | 9.49 | 44.43 | 53.91 |
| 1 | 10/8/75 | FTP | 0.35 | 3.06 | 1.38 | 0.047 | 7.41 | 7.27 | 71.19 | 78.46 |
| | | Avg. | 0.34 | 2.67 | 1.41 | 0.038 | 8.67 | 8.38 | 57.81 | 66.19 |
| 2 | 10/7/75 | SET-7 | 0.10 | 0.18 | 1.64 | 0.055 | 9.71 | 13.48 | 116.79 | 130.27 |
| 2 | 10/8/75 | SET-7 | 0.11 | 0.25 | 1.79 | 0.036 | 20.94 | 27.03 | 70.63 | 97.66 |
| | | Avg. | 0.10 | 0.22 | 1.72 | 0.046 | 15.32 | 20.26 | 93.71 | 113.96 |
| 3 | 10/7/75 | SET-7 | 0.08 | 0.11 | 1.74 | 0.036 | 13.92 | 18.84 | 75.31 | 94.15 |
| 3 | 10/8/75 | SET-7 | 0.08 | 0.11 | 1.75 | ----- | 27.48 | 37.81 | ----- | ------ |
| | | Avg. | 0.08 | 0.11 | 1.74 | 0.036 | 20.70 | 28.32 | 75.31 | 94.15 |
| 4 | 10/7/75 | FET | 0.07 | 0.05 | 1.81 | 0.032 | 31.47 | 42.13 | 66.45 | 108.58 |
| 4 | 10/8/75 | FET | 0.06 | 0.01 | 1.55 | 0.041 | 44.55 | 69.56 | 97.11 | 166.67 |
| | | Avg. | 0.06 | 0.03 | 1.68 | 0.036 | 38.01 | 55.84 | 81.78 | 137.62 |
| 5 | 10/7/75 | SET-7 | 0.12 | 0.33 | 2.28 | 0.082 | 13.48 | 13.81 | 128.48 | 142.29 |
| 5 | 10/8/75 | SET-7 | 0.09 | 0.40 | 1.75 | 0.037 | 16.46 | 23.35 | 80.99 | 104.34 |
| | | Avg. | 0.10 | 0.36 | 2.02 | 0.060 | 14.97 | 18.58 | 104.74 | 123.32 |
| 6 | 10/7/75 | SET-7 | 0.12 | 0.11 | 1.59 | 0.041 | 9.77 | 12.74 | 82.11 | 94.86 |
| 6 | 10/8/75 | SET-7 | 0.11 | ---- | 1.65 | 0.060 | 18.14 | 23.95 | 121.71 | 145.66 |
| | | Avg. | 0.12 | 0.11 | 1.62 | 0.050 | 13.96 | 18.34 | 101.91 | 120.26 |
| | Avg. of 8 SET-7's | | 0.10 | 0.21 | 1.77 | 0.050 | 16.24 | 21.38 | 96.57 | 115.60 |

## TABLE J-4. BASELINE EMISSION TEST RESULTS 1975 CALIFORNIA CHEVROLET IMPALA, BASELINE CAR IIB-1 PELLETED CATALYST WITH AIR PUMP, 0.0415 PERCENT SULFUR FUEL

| Date | Test Type | Duration | g/km HC | g/km CO | g/km $NO_x$ | g/km $SO_2$ | mg/km $H_2SO_4$ | $H_2SO_4$ as % of fuel S | $SO_2$ as % of fuel S | Total Recovery |
|---|---|---|---|---|---|---|---|---|---|---|
| 11/6/75 | FTP | | 0.37 | 10.83 | 1.19 | 0.136 | 1.49 | 0.66 | 91.43 | 92.09 |
| 11/7/75 | FTP | | 0.40 | 10.28 | 1.14 | 0.082 | 4.74 | 2.16 | 56.71 | 58.86 |
| Average | | | 0.39 | 10.56 | 1.17 | 0.109 | 3.12 | 1.41 | 74.07 | 75.48 |
| 11/6/75 | SET-7 | 23 min | 0.09 | 2.82 | 1.09 | 0.068 | 8.39 | 5.26 | 65.51 | 70.77 |
| 11/7/75 | SET-7 | 23 min | 0.10 | 3.41 | 0.88 | 0.064 | 6.77 | 4.60 | 66.81 | 71.41 |
| Average | | | 0.10 | 3.12 | 0.99 | 0.066 | 7.58 | 4.93 | 66.16 | 71.09 |
| 11/6/75 | SET-7 | 23 min | 0.10 | 4.31 | 1.05 | 0.110 | 8.01 | 5.10 | 106.87 | 111.97 |
| 11/7/75 | SET-7 | 23 min | 0.09 | 3.20 | 0.99 | 0.076 | 10.03 | 6.88 | 80.14 | 87.02 |
| Average | | | 0.10 | 3.76 | 1.02 | 0.093 | 9.02 | 5.99 | 93.51 | 99.50 |
| 11/6/75 | FET | 12 min | 0.07 | 1.47 | 0.94 | 0.064 | 7.23 | 4.99 | 67.55 | 72.54 |
| 11/7/75 | FET | 12 min | 0.05 | 0.73 | 0.84 | 0.051 | 12.94 | 9.36 | 56.47 | 65.83 |
| Average | | | 0.06 | 1.10 | 0.89 | 0.058 | 10.09 | 7.18 | 62.01 | 69.19 |
| 11/6/75 | SET-7 | 23 min | 0.11 | 4.62 | 1.04 | 0.085 | 7.33 | 4.44 | 79.09 | 83.54 |
| 11/7/75 | SET-7 | 23 min | 0.09 | 3.28 | 0.94 | 0.091 | 10.35 | 7.01 | 94.47 | 101.48 |
| Average | | | 0.10 | 3.95 | 0.99 | 0.088 | 8.84 | 5.73 | 86.78 | 92.51 |
| 11/6/75 | SET-7 | 23 min | 0.09 | 2.84 | 1.01 | 0.075 | 9.79 | 6.41 | 75.14 | 81.56 |
| 11/7/75 | SET-7 | 23 min | 0.09 | 2.20 | 0.99 | 0.068 | 14.75 | 9.52 | 67.28 | 76.80 |
| Average | | | 0.09 | 2.52 | 1.00 | 0.072 | 12.27 | 7.97 | 71.21 | 79.18 |

TABLE J-5. BASELINE EMISSIONS TEST RESULTS
1975 CALIFORNIA PLYMOUTH GRAN FURY, BASELINE CAR IIB-6
MONOLITHIC CATALYST WITH AIR PUMP (0.0415% SULFUR FUEL)

| Test | Date | Test Type | HC (g/km) | CO (g/km) | $NO_x$ (g/km) | $SO_2$ (g/km) | mg/km $H_2SO_4$ | % Fuel S as S in $H_2SO_4$ | % Fuel S as S in $SO_2$ | Total Recovery |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 10/2/75 | FTP | 0.39 | 6.46 | 1.01 | 0.096 | 6.44 | 2.86 | 65.14 | 68.00 |
| 1 | 10/3/75 | FTP | 0.42 | 5.06 | 1.08 | 0.079 | 4.55 | 1.93 | 51.51 | 53.44 |
| | | Avg | 0.40 | 5.76 | 1.04 | 0.088 | 5.50 | 2.40 | 58.33 | 60.73 |
| 2 | 10/2/75 | SET-7 | 0.04 | 0.42 | 0.74 | 0.049 | 37.41 | 24.59 | 49.06 | 73.64 |
| 2 | 10/3/75 | SET-7 | 0.03 | 0.49 | 0.94 | 0.064 | 14.76 | 9.52 | 63.57 | 73.09 |
| | | Avg. | 0.04 | 0.46 | 0.84 | 0.057 | 26.09 | 17.06 | 56.28 | 73.37 |
| 3 | 10/2/75 | SET-7 | 0.03 | 0.65 | 0.78 | 0.081 | 35.24 | 23.67 | 83.03 | 106.71 |
| 3 | 10/3/75 | SET-7 | 0.03 | 0.27 | 0.78 | 0.083 | 23.65 | 15.65 | 83.66 | 99.30 |
| | | Avg. | 0.03 | 0.46 | 0.78 | 0.082 | 29.45 | 19.66 | 83.34 | 103.00 |
| 4 | 10/2/75 | FET | 0.03 | 0.16 | 0.58 | 0.036 | 59.99 | 46.88 | 43.39 | 90.27 |
| 4 | 10/3/75 | FET | 0.03 | 0.07 | 0.64 | 0.087 | 57.13 | 44.79 | 104.30 | 149.09 |
| | | Avg. | 0.03 | 0.12 | 0.61 | 0.062 | 58.56 | 45.84 | 73.85 | 119.68 |
| 5 | 10/2/75 | SET-7 | 0.03 | 0.31 | 0.71 | 0.065 | 50.20 | 34.50 | 68.02 | 102.52 |
| 5 | 10/3/75 | SET-7 | 0.03 | 0.28 | 0.70 | 0.044 | ----- | ----- | 48.40 | ------ |
| | | Avg. | 0.03 | 0.30 | 0.70 | 0.054 | 50.20 | 34.50 | 58.21 | 102.52 |
| 6 | 10/2/75 | SET-7 | 0.03 | 0.36 | 0.76 | 0.072 | 47.26 | 32.23 | 75.63 | 107.87 |
| 6 | 10/3/75 | SET-7 | 0.03 | 0.85 | 0.91 | 0.090 | 18.34 | 10.95 | 82.18 | 93.13 |
| | | Avg. | 0.03 | 0.60 | 0.84 | 0.081 | 32.80 | 21.59 | 78.91 | 100.50 |
| | Avg. of 8 SET-7's | | 0.03 | 0.45 | 0.79 | 0.068 | 32.41 | 21.59 | 69.19 | 93.75 |

TABLE J-6. BASELINE EMISSIONS TEST RESULTS
197X FORD PINTO, BASELINE CAR IV-4
DEGUSSA 3-WAY CATALYST PLUS OXIDATION CATALYST WITH AIR
(0.030% FUEL SULFUR)

| Test | Date | Test Type | g/km HC | g/km CO | g/km $NO_x$ | g/km $SO_2$ | mg/km $H_2SO_4$ | % Fuel S as S in $H_2SO_4$ | % Fuel S as S in $SO_2$ | Total Recovery |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 10/6/75 | FTP | 0.09 | 1.05 | 0.43 | 0.048 | 35.08 | 38.99 | 82.21 | 121.20 |
| 1 | 10/7/75 | FTP | 0.11 | 0.97 | 0.37 | 0.021 | 13.84 | 16.99 | 40.30 | 57.29 |
| | | Avg. | 0.10 | 1.01 | 0.40 | 0.034 | 24.46 | 27.99 | 61.26 | 89.25 |
| 2 | 10/6/75 | SET-7 | 0.01 | 0.09 | 0.61 | 0.047 | 63.87 | 96.08 | 107.94 | 204.02 |
| 2 | 10/7/75 | SET-7 | 0.01 | 0.10 | 0.59 | 0.039 | 61.64 | 97.96 | 93.98 | 191.94 |
| | | Avg. | 0.01 | 0.10 | 0.60 | 0.043 | 62.63 | 97.02 | 100.96 | 197.98 |
| 3 | 10/6/75 | SET-7 | 0.01 | 0.01 | 0.53 | 0.032 | 58.64 | 87.40 | 73.65 | 161.05 |
| 3 | 10/7/75 | SET-7 | 0.01 | 0.09 | 0.54 | 0.040 | 46.56 | 72.22 | 95.30 | 167.51 |
| | | Avg. | 0.01 | 0.05 | 0.54 | 0.036 | 52.60 | 79.81 | 84.48 | 164.28 |
| 4 | 10/6/75 | FET | 0.01 | 0.00 | 0.66 | 0.037 | 43.58 | 70.79 | 91.07 | 161.86 |
| 4 | 10/7/75 | FET | 0.01 | 0.02 | 0.84 | 0.033 | 59.90 | 98.83 | 83.05 | 181.89 |
| | | Avg. | 0.01 | 0.02 | 0.75 | 0.035 | 51.74 | 84.81 | 87.06 | 171.87 |
| 5 | 10/6/75 | SET-7 | 0.01 | 0.09 | 0.69 | 0.032 | 39.55 | 59.46 | 74.72 | 134.18 |
| 5 | 10/7/75 | SET-7 | 0.00 | 0.03 | 0.57 | ----- | 57.64 | 91.76 | ----- | ------ |
| | | Avg. | <0.01 | 0.06 | 0.63 | 0.032 | 48.60 | 75.61 | 74.72 | 134.18 |
| 6 | 10/6/75 | SET-7 | 0.01 | 0.01 | 0.57 | 0.021 | 37.20 | 58.98 | 51.71 | 110.68 |
| 6 | 10/7/75 | SET-7 | 0.00 | 0.11 | 0.48 | 0.025 | 42.51 | 65.49 | 58.94 | 124.44 |
| | | Avg. | <0.01 | 0.06 | 0.52 | 0.023 | 39.86 | 62.24 | 55.33 | 117.56 |
| | Avg. of 8 SET-7's | | 0.01 | 0.07 | 0.57 | 0.034 | 50.95 | 78.67 | 79.46 | 156.26 |

TABLE J-7. BASELINE EMISSION TEST RESULTS
197X PINTO, BASELINE CAR IV-17
TWC-9 3-WAY CATALYST, NO AIR INJECTION, 0.030 PERCENT SULFUR FUEL

| Date | Test Type | Duration | g/km HC | g/km CO | g/km $NO_x$ | g/km $SO_2$ | mg/km $H_2SO_4$ | $H_2SO_4$ as % of fuel S | $SO_2$ as % of fuel S | Total Recovery |
|---|---|---|---|---|---|---|---|---|---|---|
| 10/28/75 | FTP | | 0.30 | 4.63 | 0.71 | 0.051 | 0.53 | 0.58 | 86.74 | 87.33 |
| 10/29/75 | FTP | | 0.26 | 5.01 | 0.72 | 0.055 | ---- | ---- | 94.90 | ------ |
| Average | | | 0.28 | 4.82 | 0.72 | 0.053 | 0.53 | 0.58 | 90.82 | 91.40 |
| 10/28/75 | SET-7 | 23 min | 0.09 | 1.79 | 0.18 | 0.049 | 0.06 | 0.09 | 113.35 | 113.44 |
| 10/29/75 | SET-7 | 23 min | 0.08 | 1.46 | 0.66 | 0.053 | 0.15 | 0.22 | 123.40 | 123.62 |
| Average | | | 0.09 | 1.63 | 0.42 | 0.051 | 0.11 | 0.16 | 118.38 | 118.53 |
| 10/28/75 | SET-7 | 23 min | 0.08 | 1.53 | 0.68 | 0.048 | 0.14 | 0.20 | 110.39 | 110.60 |
| 10/29/75 | SET-7 | 23 min | 0.08 | 1.45 | 0.67 | 0.051 | 0.04 | 0.06 | 119.96 | 120.02 |
| Average | | | 0.08 | 1.49 | 0.68 | 0.050 | 0.09 | 0.13 | 115.18 | 115.31 |
| 10/28/75 | FET | 12 min | 0.06 | 0.73 | 0.73 | 0.043 | 0.14 | 0.23 | 106.98 | 107.21 |
| 10/29/75 | FET | 12 min | 0.04 | 0.49 | 0.68 | 0.056 | 0.16 | 0.27 | 152.02 | 152.29 |
| Average | | | 0.05 | 0.61 | 0.71 | 0.050 | 0.15 | 0.25 | 129.50 | 129.75 |
| 10/28/75 | SET-7 | 23 min | 0.09 | 1.64 | 0.74 | 0.049 | 0.03 | 0.05 | 114.99 | 115.03 |
| 10/29/75 | SET-7 | 23 min | 0.08 | 1.36 | 0.74 | 0.057 | 0.21 | 0.33 | 136.88 | 137.21 |
| Average | | | 0.09 | 1.50 | 0.74 | 0.053 | 0.12 | 0.19 | 125.94 | 126.12 |
| 10/28/75 | SET-7 | 23 min | 0.08 | 1.31 | 0.69 | 0.053 | 0.11 | 0.18 | 128.16 | 128.34 |
| 10/29/75 | SET-7 | 23 min | 0.08 | 1.23 | 0.72 | 0.050 | 0.08 | 0.12 | 125.27 | 125.39 |
| Average | | | 0.08 | 1.27 | 0.71 | 0.052 | 0.10 | 0.15 | 126.69 | 126.87 |

## TABLE J-8. BASELINE EMISSION TEST RESULTS
## 1975 MERCEDES 240D, BASELINE CAR III-7
## DIESEL POWERED, NO CATALYST, 0.23 PERCENT SULFUR FUEL

| Date | Test Type | Duration | g/km HC | g/km CO | g/km $NO_x$ | g/km $SO_2$ | mg/km $H_2SO_4$ | $H_2SO_4$ as % of Fuel S | $SO_2$ as % of Fuel S | Total Recovery |
|---|---|---|---|---|---|---|---|---|---|---|
| 11/18/75 | FTP | | 0.23 | 0.43 | 0.78 | 0.392 | 9.35 | 1.78 | 113.91 | 115.68 |
| 11/19/75 | FTP | | 0.05 | 0.49 | 0.77 | 0.283 | 12.77 | 2.32 | 78.72 | 81.04 |
| Average | | | 0.14 | 0.46 | 0.78 | 0.338 | 11.06 | 2.05 | 96.32 | 98.36 |
| 11/18/75 | SET-7 | 23 min | 0.10 | 0.36 | 0.74 | 0.363 | 9.75 | 2.17 | 123.70 | 125.86 |
| 11/19/75 | SET-7 | 23 min | 0.04 | 0.38 | 0.90 | 0.324 | 11.48 | 2.50 | 108.35 | 110.86 |
| Average | | | 0.07 | 0.37 | 0.82 | 0.344 | 10.62 | 2.34 | 116.03 | 118.36 |
| 11/18/75 | SET-7 | 23 min | 0.05 | 0.34 | 0.71 | 0.213 | 10.05 | 2.29 | 74.23 | 76.53 |
| 11/19/75 | SET-7 | 23 min | 0.02 | 0.37 | 0.83 | 0.277 | 11.02 | 2.37 | 90.88 | 93.24 |
| Average | | | 0.04 | 0.36 | 0.77 | 0.245 | 10.54 | 2.33 | 82.56 | 84.89 |
| 11/18/75 | FET | 12 min | 0.04 | 0.31 | 0.71 | 0.356 | 9.39 | 2.33 | 134.97 | 137.30 |
| 11/19/75 | FET | 12 min | 0.05 | 0.31 | 0.82 | 0.296 | 9.61 | 2.24 | 105.65 | 107.89 |
| Average | | | 0.05 | 0.31 | 0.77 | 0.326 | 9.50 | 2.29 | 120.31 | 122.60 |
| 11/18/75 | SET-7 | 23 min | 0.08 | 0.38 | 0.71 | 0.315 | 10.22 | 2.32 | 109.57 | 111.89 |
| 11/19/75 | SET-7 | 23 min | 0.06 | 0.33 | 0.82 | 0.310 | 11.03 | 2.44 | 104.74 | 107.18 |
| Average | | | 0.07 | 0.36 | 0.77 | 0.313 | 10.63 | 2.38 | 107.16 | 109.54 |
| 11/18/75 | SET-7 | 23 min | 0.05 | 0.33 | 0.78 | 0.342 | 11.42 | 2.56 | 117.56 | 120.13 |
| 11/19/75 | SET-7 | 23 min | 0.01 | 0.36 | 0.81 | 0.277 | 11.70 | 2.58 | 93.54 | 96.12 |
| Average | | | 0.03 | 0.35 | 0.80 | 0.310 | 11.56 | 2.57 | 105.55 | 108.13 |

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16. ABSTRACT

This report describes the testing of four groups of cars for sulfate and sulfur dioxide exhaust emissions. The collection and analytical techniques used for sulfate and sulfur dioxide are described. Emissions rates in grams per kilometre are presented for a variety of test cycles. In addition to sulfates and sulfur dioxide, gaseous emissions of hydrocarbons (HC), carbon monoxide (CO) and oxides of nitrogen ($NO_x$) are reported in grams per kilometre. Total particulate weight on the sulfate filter was determined on two of the groups of cars. For these same two groups of cars, the sampling tunnel residue from each test car was examined by X-ray fluorescent techniques.

The first of the car groups was tested to characterize sulfate emissions from eight automobiles. Four of these were gasoline powered catalyst cars, three were gasoline powered noncatalyst cars, and one was diesel powered. The second group, four catalyst cars, was operated for 80,500 km (50,000 miles) to determine the effect of distance accumulation on sulfate emissions. The third group, two 1975 production catalyst cars, was part of the EPA sulfate procedural development testing. The last group, eight cars, was part of the EPA sulfate baseline. Of these cars, six were production 1975 models (including one diesel), and two were experimental cars with three-way catalysts.

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|---|---|---|
| Air Pollution<br>Exhaust Emissions<br>Catalytic Converters<br>Sulfuric Acid<br>Sulfur Dioxide<br>Sulfates | Federal Test Procedure<br>Sulfate Emission Test<br>Highway Fuel Economy Test | |

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