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EFFECT OF GASOLINE ADDITIVES ON GASEOUS EMISSIONS

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EFFECT OF GASOLINE ADDITIVES ON GASEOUS EMISSIONS

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FOREWORD

This report presents a summary of work performed by the Fuels Combustion Research Group, Bartlesville Energy Research Center, Bureau of Mines, for the Environmental Protection Agency, (EPA), Office of Research and Monitoring under Interagency agreement number EPA-IAG-097(D).

Mr. John E. Sigsby, Jr., was the Project Officer for EPA. The program at Bartlesville was directed by R. W. Hurn, Research Supervisor; J. R. Allsup, Mechanical Engineer, was the Project Leader; Frank Cox, Research Chemist, was responsible for the analytical development work and was assisted by D. E. Seizinger, Research Chemist, and Dr. James Vogh, Research Chemist. Others who contributed to the experimental work were L. Wilson, D. Thompson, S. Bishop, and L. Nichols, Engineering Technicians. J. M. Clingenpeel, Chemical Engineer, and R. F. Stevens, Mechanical Engineering Technician, assisted in the aldehyde and other routine chemical measurements.

OBJECTIVE

The need to assess the effects of fuel additives upon auto emissions has become increasingly pressing as the number and variety of additive materials have been expanded to meet a growing desire for increased engine life and performance. To be complete, such an assessment must include not only information pertinent to the direct contribution of the additives themselves to the appearance or composition of objectionable pollutants, but also the indirect contribution resulting from the use of these materials.

The primary objective of this study is to provide data to the Environmental Protection Agency (EPA) which will serve as a basis to establish the methodology essential to standardization of additive effect testing. A complete and meaningful test methodology of this type necessarily involves two elements: 1. determination of the levels and composition of emitted pollutants, and; 2. control and management of the emission source. The first element is the basic concern since the capability to establish the amounts and types of objectionable materials emitted by a source is requisite to recognition of the extent and/or existence of objectionable materials. This study is intended to supply basic analytical concepts and procedures which may be applicable to additive effect testing. Control and management of emission sources must be applied with discretion in accordance with the desired goal. Specifically, ignition spark timing and dwell are independent of any effect caused by the use of a gasoline additive while air-fuel ratio and idle speed may be markedly affected by carburetor and induction system deposits which may, in turn, be altered by the use of an additive. Insofar as the control and management of these parameters are concerned, as well as pretest preparation of the emission sources, the methodology described in this report is considered by the investigators to be compatible with the production of meaningful data for the determination of gasoline additive effects. On the other hand, it is not within the scope of the study objective to establish a standard mileage accumulation procedure, but rather to produce data derived from: 1. Vehicles in "typical" user service, and; 2. engines under controlled duty cycle conditions.

The secondary objective, a natural extension of the primary objectives discussed above, is to provide data indicating the effect, if any, of each of two fuel additives upon the character and/or composition of pollutants emitted by two test engines and three test vehicles.

EXPERIMENTAL APPARATUS

A. Engines and Vehicles

Gaseous emissions from three 1972 Chevrolet Impalas and two Chevrolet stationary engines were measured. The vehicles were 1972 models with 350 cubic-inch-displacement (CID) engines, two-barrel carburetors, and automatic transmissions. Mileage on the vehicles at the time of acquisition ranged from 1,500 to 3,000 miles; therefore, no break-in mileage was accumulated. The stationary engines were new 1972 350-CID Chevrolet engines with two-barrel carburetors. They were coupled to eddy-current dynamometers via automatic transmissions. Stationary engine break-in was according to the EPA 28-hour schedule (table 1). Vehicle inspection and refueling were conducted by technicians assigned to the project.

B. Fuel

Due to delays in receipt of the EPA fuel, the program was begun using Indolene clear as the basic fuel. Approximately 5,200 miles were accumulated on the three vehicles using Indolene fuel. One test cycle with stationary engine B using clear fuel for 5,000 miles and F310 for 5,000 miles was completed before the change to EPA fuel was made. Inspection data for the Indolene and EPA fuels are given in tables 2 and 3, respectively.

C. Instrumentation

Analyses of exhaust components which were included in the program and are considered to be routine are:

1. Total hydrocarbon (HC) by flame ionization detection (FID)--Beckman 400.
2. Nitrogen dioxide (NO_2) and oxides of nitrogen (NO_x) by chemiluminescence--Thermo Electron 10A.
3. Carbon monoxide (CO) and carbon dioxide (CO_2) by nondispersive infrared (NDIR)--Beckman 315.
4. Detailed hydrocarbon by gas-liquid chromatography (GLC) and FID--modified Perkin-Elmer 900 (1-2).
5. Total aldehydes by 3-methyl-2-benzothiazolone hydrozone (MBTH) colorimetry--Spectronic 20 (3).

The samples for total aldehyde analysis were metered directly from the constant volume sampling (CVS) system into the MBTH reagent solution. With this exception, samples for all routine analyses were collected from the CVS system in light-proof Tedlar bags.

Instrumentation prepared for additive specific exhaust components include:

1. F&M 810 chromatograph fitted with FID, alkali flame, and elctron capture as optional detectors.
2. F&M 810 chromatograph fitted with FID and alkali flame parallel detectors and two-pen recorder.
3. Perkin-Elmer 900 fitted with a Coulson electrolytic conductivity detector (figure 1).
4. F&M 810 chromatograph oven system fitted with modified Beckman DU spectrophotometer (figure 2).

TABLE 1. - New engine break-in procedure (28 hours)

1. Warm up engine to 180° F coolant outlet temperature at 1,000 rpm, no load. Set spark advance and best idle according to manufacturer's specifications.

2. Run 1 hour at 1,500 rpm, no load, automatic spark advance and fuel flow. Shut down, retorque cylinder heads, and drain and change lubricating oil.

3. Run cycle 1:

RPM	Manifold vacuum, inches Hg	Time, hours
1,500	15.0	1.0
2,000	14.0	1.0
2,400	14.0	1.0
2,600	14.0	1.0
2,000	11.0	1.0
		5.0

4. Run cycle 2:

RPM	Manifold vacuum, inches Hg	Time, hours
1,500	7.0	0.2
2,000	7.0	.6
2,500	7.0	1.0
3,000	7.0	1.0
2,000	7.0	.2
		3.0

5. Repeat cycle 2.

6. Run cycle 3:

RPM	Manifold vacuum, inches Hg	Time, hours
2,000	WOT*	1.0
2,500	WOT	1.0
3,000	WOT	1.0
3,500	WOT	.5
2,800	WOT	.5
		4.0 x 4 cycles = 16 hours

* Wide open throttle.

TABLE 2. - Inspection data for Indolene Motor Fuel HO III

	ASTM method	Specification control limit	Sample No. D-18032
API gravity	D287	58.0-61.0	59.1
Distillation, %F:			
Initial boiling point	D86	75-95	94
10% Evap.	D86	120-135	133
50% Evap.	D86	200-230	224
90% Evap.	D86	300-325	323
Maximum	D86	NMT 415	412
10% Slope	D86	NMT 3.2	2.7
Reid Vapor Pressure	D323	8.7-9.2	8.7
Oxidation stability, min.	D525	NLT 600	1440+
Gum, mg/100 ml (after Heptane wash)	D381	NMT 4.0	1.6
TMEL, grm. lead/gal	D526	Nil	0.02
Sulfur weight, %	D1266	NMT 0.10	0.017
Olefin, %	D1319	NMT 10	5.6
Aromatic, %	D1319	NMT 35	32.6
Saturates, %	D1319	Remainder	61.8
Octane Research (Clear)	D2699	96.0-98.5	97.1
Octane Research (3 cc TEL/gal)	D2699	NLT 103.0	104.1
Phosphorus, gms/gal	ACM 21.00	NMT 0.01	0.0
Sensitivity (Clear)		7.0-10.5	10.3
Sensitivity (3 cc TEL/gal)		NMT 9.0	8.3

TABLE 3. - Inspection data for unleaded gasoline blend

	Results	Specification Minimum	Specification Maximum
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 at 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/gal	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

NOTE.-Fuel was inhibited with 5 lbs/1000 bbls of Du Pont 22 oxidation inhibitor.

1/ Fails specification, waiver obtained from customer.
2/ Benzene and toluene were determined by infrared analysis by direct calibration techniques.

EXPERIMENTAL PROCEDURES

The methods for analysis of HC, NO_2, NO_x, CO, and CO_2 are well established and will not be discussed in detail.

A. Organic Manganese Analysis--Methodology

Sample collection was accomplished by drawing diluted exhaust from the CVS system with a Metal Bellows pump. The sample was pumped through a 4 in x 3/8 in O.D. stainless steel column packed with Chromosorb 102 at ice temperature. Sample flow was measured with a rotometer placed downstream from the collection column.

The sample was recovered and analyzed according to the following procedure:

1. To prevent loss of light sensitive manganese compounds, workup should be carried out in semi-darkness.
2. Backflush the Chromosorb 102 collection column with acetone to a total volume of about 5 ml.
3. To the acetone solution, add 0.2 ml of a sec-butylbenzene solution of a known weight of cyclopentadienylmanganesetricarbonyl (CMT-internal standard).
4. Extract the acetone solution three times with 2 ml volumes of pentane.
5. Bubble dry nitrogen through the pentane solution until it is evaporated to about 0.3 ml of organic (upper) phase (water generally separates from the organic material upon evaporation).
6. Note the exact volume of the organic layer.
7. Inject 20 µl into a chromatograph equipped with a flame photometric detector (modified Beckman DU).
8. Quantitate by peak height relative to that of the CMT internal standard.

Fuel, lube oil, and intake valve deposits were also analyzed for organic manganese content. The fuel was diluted to a specific volume with a benzene solution of CMT and injected into the chromatograph. Methylcyclopentadienylmanganesetricarbonyl (MCMT) content was calculated from relative peak heights. The lube oil was also analyzed in this manner. Weighed samples of deposits from the manifold side of the intake valves were digested in a known volume of benzene containing CMT and chromatographed.

Conditions for the chromatographic determination were:

1. Column: 11-1/2 feet x 1/8 in O.D. stainless steel tubing packed with 4 pct Apiezon L on 90/100 mesh Anachrom ABS.
2. Carrier: helium flowing at 55 cc/min
3. Temperature program: 8° C/min from 100° C to 180° C
4. Emission line measured: 403.3 mµ

B. Inorganic Manganese Analysis--Methodology

A Gelman, Type A, glass fiber filter was placed in the sample line as near as possible to the CVS system. As sample was drawn by the sample pump for delivery to the Chromosorb 102 column, exhaust particulates were collected on the filter. Since MCMT has an appreciable vapor pressure, it was assumed that all organic manganese was swept through and only inorganic manganese retained by the filter. The filter was analyzed for inorganic manganese in the following manner.

1. Place the entire glass fiber filter in a Teflon beaker and digest with 3N HCl near 80° C for 15 minutes.
2. Quantitatively transfer beaker contents to a plastic filtering apparatus containing an acid washed cellulose membrane.
3. Thoroughly wash the filtering apparatus and retained solids with 3N HCl.
4. Transfer the filtrate first to a Teflon beaker for heat evaporation to a few milliliters, then to a 25 ml volumetric flask.
5. Dilute to volume with 1.5N HCl and analyze by atomic absorption (flame) spectroscopy.
6. Use 1.5N HCl as an instrument blank and correct data according to the value obtained from parallel analysis of an unused glass fiber filter.

Deposits from the manifold side of the intake valves and combustion chamber deposits were semi-quantitatively analyzed for total manganese content by neutron activation analysis.

C. Analyses for Nitrogen Compounds--Methodology

Sample collection for nitrogen compound analysis is exceptionally difficult due to their wide variety of chemical and physical properties. Several collection methods were attempted but proved to be inadequate. As a result, vapor samples were taken directly from the CVS system (or bag) and injected into the PE-900 chromatograph via a 25cc gas sample loop.

Differences in the properties of the nitrogen compounds made it necessary to analyze with three separate chromatographic columns. Chromatographic conditions for the analysis of ammonia, light aliphatic amines, and pyridine were:

1. Column: 10 feet x 1/8 in O.D. stainless steel tubing packed with 15 pct Carbowax 600 plus 10 pct KOH on 80/100 mesh Gas-Chrom R
2. Carrier: Helium flowing at 48 cc/min
3. Temperature program: Hold at 25° C for 2 minutes, then program at 5° C/min to 120° C

Substances such as acetonitrile, pyrrolidine, and cyclohexylamine can also be analyzed on this column.

Chromatographic conditions for the analysis of all of the preceding nitrogen compounds (but with less resolution), N-nitros amines, nitroso aromatics, nitro aromatics, aromatic nitriles, and aromatic amines were:

1. Column: 3 feet x 1/8 in O.D. stainless steel tubing packed with 15 pct Carbowax 1540 plus 10 pct KOH on 80/100 mesh GC-22
2. Carrier: helium flowing at 52 cc/min
3. Temperature program: Hold at 35° C for 2 minutes, then program at 6.5° C/min to 180° C

Molecular size for this column is limited to about C_8.

Chromatographic conditions for the analysis of cyanogen, hydrogen cyanide, nitromethane, and acetonitrile were:

1. Column: 2-1/2 feet x 1/8 in O.D. stainless steel tubing packed with Carbopack B treated with 3 to 4 drops of H_3PO_4
2. Carrier: helium flowing at 42-1/2 cc/min
3. Temperature program: -70° C for 6 minutes then 13° C/min to 180° C

Detection capability for the nitrogen analyses was provided by a Coulson electrolytic conductivity cell. Nickel wire was used as the reduction catalyst, the furnace temperature was 700° C, and the hydrogen flow through the quartz catalyst tube was 17 cc/min. To prevent moisture condensation, the conductivity cell was warmed by heating tape from the furnace exit to the gas-water mixing chamber.

D. Emission Measurement--Methodology

Initially, all engines to be tested (both vehicle and stationary) were adjusted to factory specifications. Engine parameters were then periodically checked during the study and, in this case, were found to remain very nearly constant. In additive testing, ignition timing and dwell are independent of additive effects and should be kept consistent throughout any series of tests. On the other hand, air-fuel ratio and idle speed may be influenced by the action of an additive upon carburetor and induction system deposits and, therefore, should not be mechanically altered during a series of tests unless it can be determined that a change in those parameters is due to some malfunction. For mileage accumulation, the vehicles were put into "typical" user service by assignment of the vehicles to BERC employees whose normal routes consisted of about equal amounts of city and highway driving. The stationary engines were operated repetitively over the LA-4 test schedule in order to accumulate mileage. Prior to testing, each vehicle was driven for 10 minutes at 50 mph to purge the charcoal canister (evaporative loss trap), then immediately placed in a soak area at about 75° F and allowed to stand overnight. Stationary engine test preparation consisted of a shut-down period lasting at least five hours. Exhaust was tested as the vehicles and engines were being operated according to the LA-4 test schedule on chassis and stationary engine dynamometers. A single CVS bag sample was collected at a constant rate for the duration of the test. The Roots blower in the CVS pumped a nominal 330 cfm. This sample was analyzed for total HC, NO_2, NO_x, CO, CO_2, and individual hydrocarbon compounds. CO, HC, and NO_x were calculated in accordance with the Federal Register, Vol. 36, No. 128, Friday, July 2, 1971, section 1201.87.

A test cycle for the engine or vehicle, includes a period of mileage accumulation with additive-free fuel (4,000-5,000 miles) to establish baseline emissions and a period of mileage accumulation with the fuel plus additive to establish the effect, if any, of the additive upon emission levels or trends. Four test cycles were completed with the two stationary engines; each engine being tested with AK33X additive at 0.125gMn per gallon fuel and F310 additive at 14.2 ml additive plus carrier per gallon fuel. Mileage accumulation with additive-containing fuel was 4,000-5,000 miles.

One test cycle was completed with each of three vehicles. After baseline emissions were established (approximately 5,000 miles) one vehicle was switched to fuel containing AK33X, F310 was added to the fuel for the second vehicle, and the third vehicle remained on additive-free fuel. Slightly more than 9,000 miles were accumulated with additive-containing fuel.

As each test cycle was completed, each engine (both stationary and vehicle) was disassembled and photographed. Samples of engine deposits were taken and, when AK33X had been the additive used, the deposits were analyzed for organic manganese. The oil from the engines and vehicle using AK33X was also analyzed for organic manganese.

RESULTS AND DISCUSSION

A. Manganese Determination-Methodology Background

The primary objective of the study is to provide methodology which can be applied to the determination of the effect of gasoline additives upon emissions and the fate of the additive itself. While the method for organic manganese analysis was developed specifically for this program, the method (or modifications of the method) should be applicable to the analysis of other organo-metallic compounds. As for inorganic manganese analyses, atomic absorption methods are well established for this and other metallic ions.

Chromosorb 102 was very effective as a sample collection medium. Retention capability was high and recovery from the column was simple and efficient. A collection efficiency check was made by applying 0.943 μg of CMT to the upstream end of the 4 in x 3/8 in O.D. Chromosorb 102 column. After exposure to 275 liters of CVS exhaust flowing at 12 liters/min, nearly 99 pct (0.932 μg) of the sample was recovered by direct analysis of the acetone wash. A large variety of porous polymers is commercially available. Stability and diverse physical and chemical properties (pore size, surface area, acid-base properties, polarity, etc) make them likely candidates for application to collection of other volatile organo-metallics.

In the early stages of method development, n-tridecane was added to the recovered sample to minimize loss of the MCMT during evaporation. No problems occured with small chromatographic injections, but when the sample size was increased to 20 µl, the n-C_{13} caused MCMT peak spreading. Chromatographic response, in terms of peak height, was then dependent upon sample size as well as concentration. This problem was circumvented by replacing n-C_{13} with sec-butylbenzene. MCMT evaporative loss with sec-butylbenzene was about 5 pct, but addition of the internal standard (CMT) before the extraction process negates work-up losses. One possible improvement to the method might be to remove most of the moisture from the porous polymer column with a dry nitrogen purge prior to recovery, wash the column with acetone (or pentane), add the internal standard, evaporate to a small volume, and inject a portion into the chromatograph.

The detection system (figure 1) for organic manganese analysis consisted of a Beckman DU Spectrophotometer equipped with standard photomultiplier and flame attachments and the Spectral Energy Recording Adapter (SERA) to allow transfer of the photomultiplier signal to a strip chart recorder. The only modification to the system was interchange of the burner oxygen and fuel supply lines. Oxygen and fuel supplied to the burner in this manner produce an exceptionally small flame which, in turn, allows more precise optical focus by limiting the volume in which the sample is oxidized. Chromatographic effluent was fed to the flame through a heated line connected to the sample capillary of the burner.

Nickel, iron, and chromium trifluoracetylacetonates have been chromatographed and detected in this laboratory with the manganese instrumentation. The less stable corresponding manganese chelate decomposed within the chromatographic system. One consideration to be given with respect to chromatographic flame emission analysis is that, although the method may (in many instances) be made specific for the desired element, the triple resonance line of manganese is relatively intense. When coupled with the chromatograph as little as 10^{-11} moles of manganese can be detected with each injection. The sensitivity for other elements may limit the usefulness of the method. Trace quantities of some elements, such as phosphorous and lead, are not suited to detection by flame emission.

B. Manganese Determination--Test Results

Figure 3 shows the results of a typical analysis. It is apparent from this chromatogram that; (1) only extremely high concentrations of hydrocarbons are capable of producing interference (and then only if they are eluted from the column with the internal standard or desired compound), (2) peak quality is good, and (3) complete separation of the desired components is achieved. The peaks in the figure represent 1.07×10^{-10} moles CMT (known quantity) and 3.79×10^{-11}

moles MCMT (calculated value). The sample was prepared according to the procedure given previously and calculation back to the CVS exhaust concentration gives a value of 5.10×10^{-2} ppb. Thus, the gaseous sample stream concentration that is detectable by the method is less than 2×10^{-2} ppb.

The procedure for manganese determination was developed early in the program; therefore, the data for AK33X additive related materials are complete. Figures 4A, 5A, and 6A show the manganese present in the exhaust when AK33X is a fuel component. The organic manganese (MCMT) maximum exhaust levels varied considerably for the two stationary engines and the vehicle ranging from 1 μg/mile to 5 μg/mile. Expressed in other terms, these values represent CVS exhaust concentrations of 1.40×10^{-2} ppb and 7.45×10^{-2} ppb, respectively. Up to 0.042 percent of the MCMT consumed was emitted unaltered and no organic fragments of the molecule were detectable in the exhaust. Under similar conditions, Ethyl Corporation has previously reported (4) considerably higher values. Engine characteristics, proportional sampling, trapping methods, or the inability of the Ethyl Corporation method to detect the organic molecule itself may have been factors in the differences in the reported values; but the most likely contributor was the exceptionally high concentration of manganese (1.25 gMn/gal) in the fuel used for the Ethyl Corporation tests.

It is interesting to note, though not unlikely, that comparison of figures 4 with 4A, 5 with 5A, and 6 with 6A show that changes in hydrocarbon emission levels are generally accompanied by corresponding changes in MCMT emission levels. Both hydrocarbon and MCMT emissions were increasing at 4,000-5,000 miles with additive. The stationary engine cycles were terminated at about this point. Continued mileage accumulation with the vehicle shows hydrocarbons and MCMT decreasing somewhat to an apparent stabilization. The hydrocarbon emission trend using AK33X additive is more easily recognizable by direct comparison of the total hydrocarbon emissions to those using clear fuel or F310 additive (figure 11). The values for figure 11 were taken from the detailed hydrocarbon analysis tables contained in Appendix A.

Inorganic manganese emissions from the stationary engines, figures 5A and 6A, tend to increase along with the MCMT emissions. Figure 4A, however, fails to indicate a trend for inorganic manganese emissions from the vehicle. One possible explanation for this is the relatively mild duty cycle of the stationary engines (repetitive Federal test cycles) in comparison to the vehicle (user service). This assumption was given credence by visual comparison of combustion chamber deposits (to be discussed later in this report).

Manganese mass balance was low with an exhaust emission range of 4 to 30 percent of ingested material. Since the combustion efficiency of MCMT was 99.4 pct or better, this is due largely to engine and exhaust system retention of inorganic manganese. Intake manifold deposits ranged from 4.2 pct to 5.7 pct manganese (only 0.03 pct or less of this was MCMT). From 7.3 pct to 13.1 pct of the combustion chamber deposits was manganese. Nonhomogeneity of particulates within the CVS stream and losses within the CVS system could contribute to erroneous values for the inorganic manganese actually emitted, but program emphasis was not placed upon particulate sampling.

Engine lube oil used in conjunction with AK33X additive testing was analyzed for MCMT content and found to range from 0.95 μg/ml to 2.68 μg/ml depending upon mileage accumulation and lube oil added during the test cycle. Lack of test procedure information (MCMT lube oil levels immediately before addition of make-up oil) prevents quantitation of MCMT bypass, but estimates made from the levels found in the oil indicate approximately 2 μg/mile. This is comparable to the MCMT levels released to the atmosphere through the exhaust system. Insofar as a potential health hazard is concerned, organic manganese in the lube oil should be given special consideration for two reasons: (1) it is retained by solution in a definite volume of liquid as opposed to eventual dilution by diffusion in the atmosphere and (2) lube oil is an efficient U.V. light filter which prevents photochemical decomposition (there was no detectable difference between fresh samples and those exposed to fluorescent lighting for up to five months).

Periodic checks of the fuel confirmed that the manganese concentration was within 15 pct of the desired level.

C. Nitrogen Compound Determination--Methodology Background

Isolation of the proposed nitrogen bearing compounds from exhaust would be an awesome project within itself. Nonspecific detection systems produce complex exhaust chromatograms in which not all components appear individually, especially those present at low concentrations. The development of the chromatographic techniques for analysis of these compounds was undertaken with this in mind.

Four types of detection systems with some degree of specificity were available; electron capture, alkali flame ionization, microcoulometry, and electrolytic conductivity. Electron capture was considered primarily for confirmation of the presence of aromatic nitro compounds and N-nitrosoamines, the latter to be accomplished by conversion to nitramines with hydrogen peroxide and trifluoroacetic anhydride or trifluoroacetic acid. With careful attention to parameter adjustments, alkali flame ionization can be made to differentiate between most organic nitrogen compounds and hydrocarbons with essentially complete specificity. The response of nitrogen compounds to alkali flame, however, is not solely dependent upon the number of nitrogen atoms, but also the molecular structure. Nitro compound and hydrogen cyanide responses were comparatively small and ammonia failed to respond detectably. The failure of ammonia to respond led to experiments in which ammonia was mixed with the carrier gas to reduce amine tailing. A column packed with Ucon LB550X-KOH on Chromosorb W was being considered at that time for amine separation and the effectiveness of ammonia in the carrier was demonstrated, but detector specificity for nitrogen compounds as compared to hydrocarbons was decreased from complete to about 10:1. Another characteristic of the alkali flame detector which was considered in judging its applicability was its extreme sensitivity to temperature and gas flow fluctuations.

The remaining two detectors are comparable in terms of nitrogen sensitivity and selectivity. The selectivity is good for both, and both respond to any nitrogen compound which is reduced to ammonia when exposed to nickel catalyst in a hydrogen atmosphere at elevated temperatures. The Coulson electrolytic conductivity detector was chosen over the Dohrmann microcoulometer because of its relative simplicity of operation and maintenance. The electrolytic conductivity cell requires no periodic cleaning, electrode maintenance, or electrolyte preparation; up to the point of bubble formation within the electrode capillary, hydrogen and carrier flows can be varied over a considerable range without significant damage to peak quality or detector response; light coke deposits can easily be removed from the nickel wire catalyst by in situ treatment with oxygen; and the detector functions satisfactorily with background signals up to about 4 mV. The cell water and/or water conditioning resins must be changed periodically when the background signal becomes excessive, but under normal conditions, this occurs only after several weeks of continuous operation.

The variety of nitrogen compounds of interest was considered when selecting materials for chromatographic columns. Liquid phases containing nitrogen compounds were rejected a priori to minimize the probability of excessive background signal and reduced peak signal due to column bleed. The acid-base properties of the compounds to be separated were considered as the principal factor in determining chromatographic behavior. Several column materials and variations were tested before those which performed acceptably for the entire spectrum of compounds to be analyzed. Chromosorb 103 and several variations of Carbowax-KOH combinations were tested for amine analysis. Porapak Q, S, and QS, Carbosieve B, and Carbopack A were tested for hydrogen cyanide analysis. The neutral compounds were found to give good quality chromatograms when separated by the columns prepared for analysis of the basic or acidic components.

The nitrogen compound classes proposed for study were amines, pyridines, N-nitrosoamines, and nitro compounds. Individual compounds included were hydrogen cyanide and cyanogen. On first analysis, it appears that the basic compounds (amines and pyridines) can be isolated from the remaining compounds via salt formation with hydrochloric acid and extraction of the neutral and acidic compounds. Further examination, however, reveals that the neutral and acidic compounds become sensitized, to various degrees, to hydrolysis upon addition of mineral acid. Furthermore, hydrolysis of compounds containing the $-C \equiv N$ group produces ammonium ion and N-nitrosoamines produce secondary amines; thus interfering with the analysis of the basic compounds. At best, this method of collection and/or isolation is applicable to the basic compounds, and only then if consideration is given to the fact that some of the analyzed components may be hydrolysis products of non-basic nitrogenous compounds.

Not only the wide range of physical properties (vapor pressure, solubility, acid base character, etc.) but also the complex chemistry of these nitrogen compounds is responsible for the difficulty in their collection, recovery, and analysis. Common exhaust products with which these compounds may react under favorable conditions include water, nitrogen oxides (plus water), aldehydes, ketones, phenols, and unsaturates. In addition, reactions may take place among the nitrogen bearing species. Hydrogen cyanide may polymerize, nitroso compounds may dimerize or react with aromatic amines, and ammonia or amines add to nitriles under favorable conditions. The presence of some nitrogen compounds enhances the reactivity of other nitrogen compounds. For instance, ammonia enters into the addition of hydrogen cyanide to aldehydes or ketones, and alkylamines or pyridines act as condensing agents for nitroparaffins and aldehydes or ketones.

In light of the foregoing discussion, it is evident that (1) reactions may proceed during sample collection and processing and (2) maintenance of sample integrity during this period is likely to be difficult.

Initial efforts concerning sample collection were based on the idea of class separation during sampling. A sample collection train was constructed consisting of a wet cation exchange column, a wet anion exchange column, and a cold trap at dry ice temperature. A methanol scrubber at ice temperature was subsequently installed upstream from the cold trap to prevent plugging by water freeze-out. The ion exchange resins were wetted by water condensed from the sample stream. Hopefully, amines and pyridines would be retained by the cation exchange column, hydrogen cyanide (and possibly nitroparaffins) retained by the anion exchange column, and neutral compounds trapped by the cold solvent. The system was tested by spiking an exhaust stream with the various compounds. When practical, known quantities were injected; but the purities of hydrogen cyanide, cyanogen, and N-nitrosoamines were not known and only manufacturer estimates were available for the aqueous solutions of light aliphatic amines. Recovery calculations were based on the detector response to pyridine (known purity) and the number of nitrogen atoms per molecule as well as detector response to equivalent amounts of the individual compounds injected directly into the chromatograph. The system was partially successful. Amine and pyridine recoveries from the cation exchange column were in the 50 to 75 percent range with comparable nitrile and N-nitrosoamine recoveries from the cold solvent scrubber. Minimum detection levels were estimated for those compounds recoverable from this system. These levels for undiluted exhaust were:

1. Pyridine - 0.02 ppm
2. Aromatic amines - 0.02 ppm
3. C_1-C_4 aliphatic amines - 0.10 ppm
4. Nitriles - 0.30 ppm
5. C_2-C_4 N-nitrosoamines - 0.15 ppm

These figures are only estimates since the efficiency of the system and test repeatability were not considered to be adequate. Hydrogen cyanide, cyanogen, and nitroparaffins were, for practical purposes, lost; however, the chromatographic technique for these compounds had not yet been fully developed.

Methanol alone cannot be used as a solvent for scrubbing the sample stream. Chromatograms of a methanol solution of the various nitrogen compounds gave peaks which did not correspond to any of the individual compounds. Some of these unidentified peaks diminished or grew upon standing, giving evidence of slow, continuing reactions within the solution. Water solutions of formic and acetic acid were also checked for potential as scrubber solutions, but experimentation indicated that the basic nitrogen compounds could not be concentrated by evaporation and recovered in the original form.

All of the previously discussed sample collection techniques failed to establish the presence of nitrogen bearing compounds (other than NO_x) in auto exhaust even with F310 additive present in the fuel. This is not surprising since testing with synthetic samples gave evidence that none of the techniques were sufficiently quantitative or repeatable.

At this point, a different approach was taken in an effort to demonstrate the presence or absence of the nitrogen compounds in exhaust at some detectable limit that could be established with a reasonable degree of confidence. Direct chromatographic injection of the exhaust (discussed in the Experimental Procedures Section of this report) provides a means to obtain an exhaust component profile that is least likely to be altered from the true composition. No intermediate sampling or recovery steps are involved with this technique, and the chromatographic response can be related directly back to the exhaust concentration. Even with this simple introduction system, some precautions are essential. Separate, preconditioned syringes and sample loops are necessary for acidic or basic component analysis. For instance, total loss of small amounts of ammonia results for subsequent injection into the sample loop used for hydrogen cyanide analysis.

The chromatographic system for the analysis of nitrogen compounds is illustrated in figure 2. The Coulson electrolytic conductivity detector was calibrated with known quantities of pyridine and the response found to be very nearly 5×10^{-10} nitrogen atom per millivolt. Operating at 4 mV full scale the noise level is slightly less than one division (0.04 mV). Considering the detection limit to be twice the noise level, 4×10^{-11} nitrogen atom becomes the limit. With a 25 cc sample loop, this converts to 0.04 ppm nitrogen atom in the diluted (CVS) exhaust. This is up to twenty times less sensitive than the estimated detection limits for the sampling train collection technique, but the reliability of direct, gaseous sampling tends to compensate for this loss. Results of CVS exhaust analyses by direct injection were:

1. HCN - 1.0-1.5 ppm found and confirmed.
2. CH_3NO_2 - 0.2-0.3 ppm found and confirmed.
3. NCCN - trace possible but presence not confirmed.
4. CH_3CN - trace possible but low levels are rapidly destroyed by exhaust.
5. NH_3 - possible exhaust component but interference peak prevented definite identification.

Nitrogen compounds either not present or present at levels below 0.04 ppm include:

1. Aliphatic and aromatic amines
2. Pyridine
3. C_3 and larger aliphatic and aromatic nitriles
4. C_2 and larger aliphatic and aromatic nitro compounds
5. C_2-C_4 N-nitrosoamines

Hydrogen cyanide and nitromethane consistently appear in exhaust chromatograms regardless of the presence of F310 additive in the fuel. Though relatively stable in exhaust, the appearance of cyanogen was intermittent and could be due to sample syringe hold-over from previous analysis of synthetics. This is also true of acetonitrile, but experimental evidence shows this compound to be unstable in exhaust as well. Vapor samples give a chromatographic peak near the retention time of ammonia even in the absence of the compound, thus small quantities could be present and remain hidden. No chromatographic peaks appeared corresponding to any of the remaining nitrogen compounds, so, if present, their exhaust concentrations were below the detection limit.

Chromatography of the basic nitrogen compounds is illustrated in figures 12 and 13. Amines and pyridine were separated to show peak quality. Approximate locations are indicated for other amines and compounds representative of the neutral classes which are eluted from these columns. Vapor samples injected downstream from the column have shown that the major portion of the tailing effect takes place within the detector rather than the column. Figures 14 and 15 are chromatograms of synthetic and exhaust components, respectively, which are eluted from the Carbopack B-H_3PO_4 column. For figure 15A, 25 cc of gaseous sample was drawn from the sample line and immediately injected into the chromatograph. Samples for figures 15B, 15C, and 15D were taken from a single CVS cold-start bag after aging 1 hour, 1.5 hours, and 2 hours in the absence of light. Comparison of the exhaust chromatograms can leave little doubt that there is continuous sample deterioration. With age, hydrogen cyanide decreases and nitromethane decreases and/or is swamped by a growing peak. Peak A diminishes with time and peaks B, C, D, E, and F appear and grow at various times and rates. Little effort was directed toward identification of the lettered peaks, but oxides of nitrogen are eluted in areas A-B and E-F giving responses similar to those of the aged exhaust sample.

D. Nitrogen Compound Determination--Test Results

The methodology for nitrogen compound analysis was not adequately developed in time to obtain meaningful data pertinent to the effect of F310 additive on nitrogenous emissions.

Routine emission measurements, however, failed to show any trends that might be attributable to the presence of F310 additive in the fuel (figures 7, 8, and 10).

ENGINE DEPOSITS

A. Induction System

1. Carburetor

Carburetor throats and bases were examined for deposit buildup. The deposits were found to be almost equally independent of fuel additive or duty cycle. Deposits on the carburetor bases are, as well as the following items, shown pictorally in Appendix B.

2. Intake Manifold Passages

The deposits were generally equal in amount from both additives in the stationary engines. The F310 additive resulted in softer tar-like deposits in the intake passages of the stationary engines compared to more crusty deposits resulting from all other engine and vehicle conditions. The clear fueled vehicle contained more deposits in the intake passages than did the other vehicles or engines. The F310 additive vehicle produced unusually clean intake passages as compared to those of the other two vehicles or the stationary engines even after F310 use. This suggests that the cleaning ability of the additive is dependent upon duty cycle. It is reasonable to postulate that the higher air flow and turbulence in the intake manifold associated with the more severe duty of the vehicle would lead to cleaner surfaces provided the deposits produced were comparable in consistency to those produced by the lighter duty cycle.

3. Intake Valves

The intake valve stems had considerably less deposits in both vehicles and engines using the F310 than the clear or AK33X additive, independent of duty cycle. In addition the deposit material was generally softer and more pliable using the F310. The vehicle using the clear fuel produced the greatest amount of valve stem deposit.

B. Combustion Chamber

1. Piston Heads

Deposits produced on the piston heads while using the F310 were generally heavier in amount and more flaky in composition than the other conditions. The AK33X produced deposits that were very fine, almost powdery in composition while the clear fuel resulted in deposit composition intermediate between the two. Deposits from the F310 and clear tests were similar in color with a typical black-grey color. In contrast, the deposits produced from the AK33X were an unusual reddish-tan color. The color was characteristic of the combustion chamber surfaces when AK33X was used independent of engine or vehicle duty cycle. Some color photographs are included in Appendix B to show the characteristic color associated with the AK33X additive.

2. Engine Head

Deposits on the engine heads were similar in amounts and composition to deposits on the piston heads just described; the major exception being extremely white deposits on the exhaust valve face of the stationary engines which used F310. This effect was present but much less pronounced with the vehicles than with the engines suggesting a duty effect.

3. Spark Plugs

Spark plug deposits from the AK33X fuel again showed the characteristic reddish color and, in addition, on one stationary engine the deposits were so great that the spark gap was being bridged. The deposits were still very soft and fine. The vehicle using AK33X did not have nearly so great a quantity of plug deposits as the engine, also the second engine test with the AK33X additive resulted in less plug deposits than the first test. Undoubtedly the duty cycle has a great effect on plug deposits using the AK33X additive. The plug deposits from tests other than those using AK33X were similar in color and composition.

4. Exhaust Valve Stems

Deposits on all the exhaust valve stems were similar in amounts and composition. The reddish color continued on the exhaust valves using the AK33X, while the valves of the engine using F310 exhibited a pronounced white color. The white color, however, was not present on the valve stems of the vehicle using F310.

CONCLUSIONS

The methodology for control and management of the vehicles and engines, pretest preparation, test operation, and sampling for routine exhaust measurements is discussed in detail in the Emission Measurement section of this report. This methodology was selected on the basis of previous knowledge and experience prior to this study and is, therefore, not a product of the study. While the investigators feel that the procedures are applicable to gasoline additive testing, they should not be considered as procedural recommendations.

Two analytical methods were developed, with varied degrees of success, for the study. The method for specific analysis of the MCMT molecule was successful with a detection capability at the 10^{-2} ppb level in vapor samples. Up to 0.042 percent of the antiknock compound in AK33X additive was found to survive the combustion process and exhaust emissions were in the 1 to 5 μg/mile range. The analytical method for exhaust nitrogen compounds was only partially successful and was not developed early enough to determine if F310 additive had any effect upon exhaust emissions. For vapor samples, the detection capability of the technique described in this report is 0.04 ppm nitrogen atom. Hydrogen cyanide at 1.0 to 1.5 ppm and nitromethane at 0.2 to 0.3 ppm were found in CVS exhaust samples. Traces of cyanogen and acetonitrile were indicated but not firmly established. Continuous sample deterioration with respect to nitrogen compounds was illustrated by consecutive analyses of an aging exhaust sample.

Tests with AK33X additive gave the following results:

1. No organic fragments of the MCMT molecule were found in the exhaust.
2. MCMT in the exhaust increased with mileage for the first 4,000 to 5,000 miles then decreased somewhat to a stable level.
3. Generally, changes in MCMT exhaust level were accompanied by corresponding changes (in the same direction) in hydrocarbon level.
4. MCMT levels in the lube oil ranged from 0.95 μg/mile to 2.68 μg/mile; UV light filtration by the oil prevented photochemical decomposition.
5. With a mild duty cycle, inorganic manganese emissions gradually increased with mileage (at least for the first 5,000 miles); there was essentially no change upon mileage accumulation with a more severe duty cycle.
6. Manganese mass balances were low (4 to 30 pct); deposit analysis showed that much of the manganese was retained by the engine.

No test results were obtained for exhaust nitrogen compounds, but routine emission measurements gave no indication of trends that might be attributable to the presence of F310 additive in the fuel.

The effect of duty cycle upon engine deposits was indicated by:

1. Exceptionally clean intake manifold passages using F310 additive with the vehicle (more severe duty cycle).
2. Exceptionally white deposits on the exhaust valve faces using F310 additive with the stationary engines (mild duty cycle).
3. Heavy spark plug deposits using AK33X with the stationary engines (mild duty cycle).

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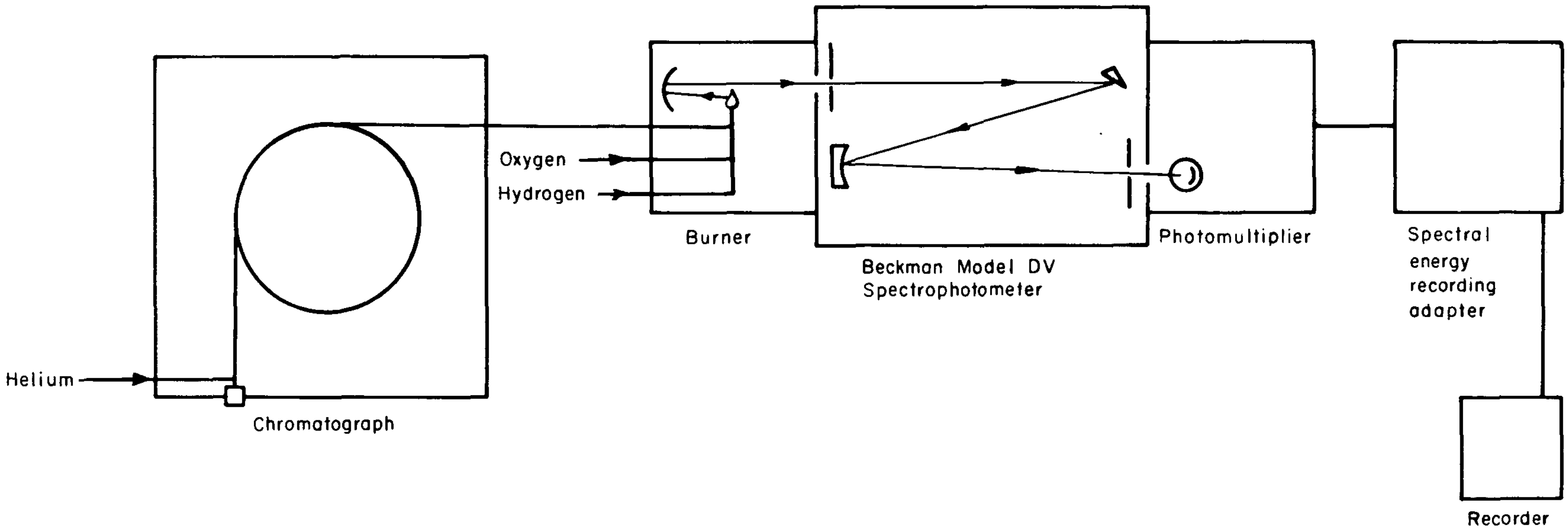


FIGURE 1.-The detection system for organic manganese analysis.

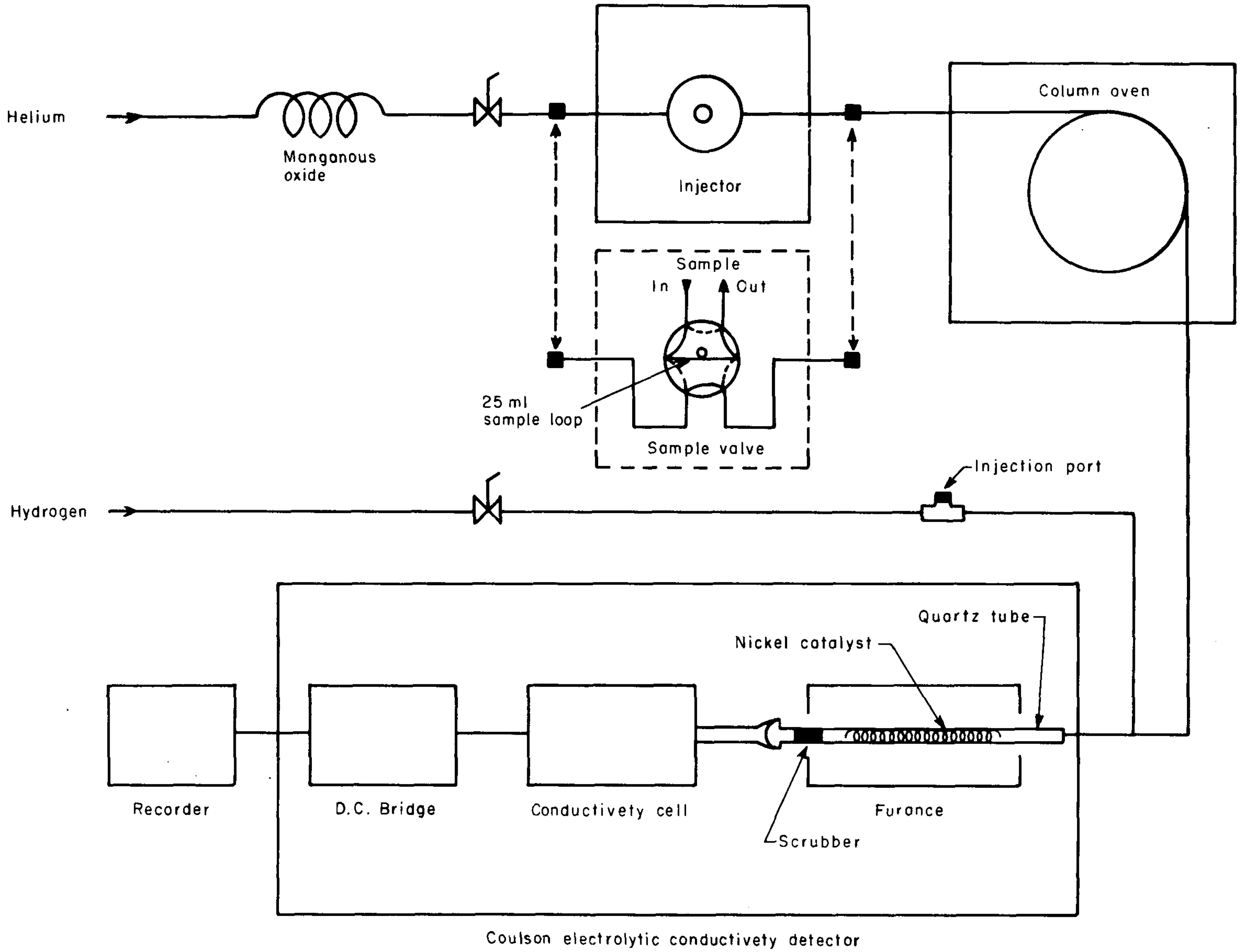


FIGURE 2.-Chromatographic system for analysis of nitrogen compounds.

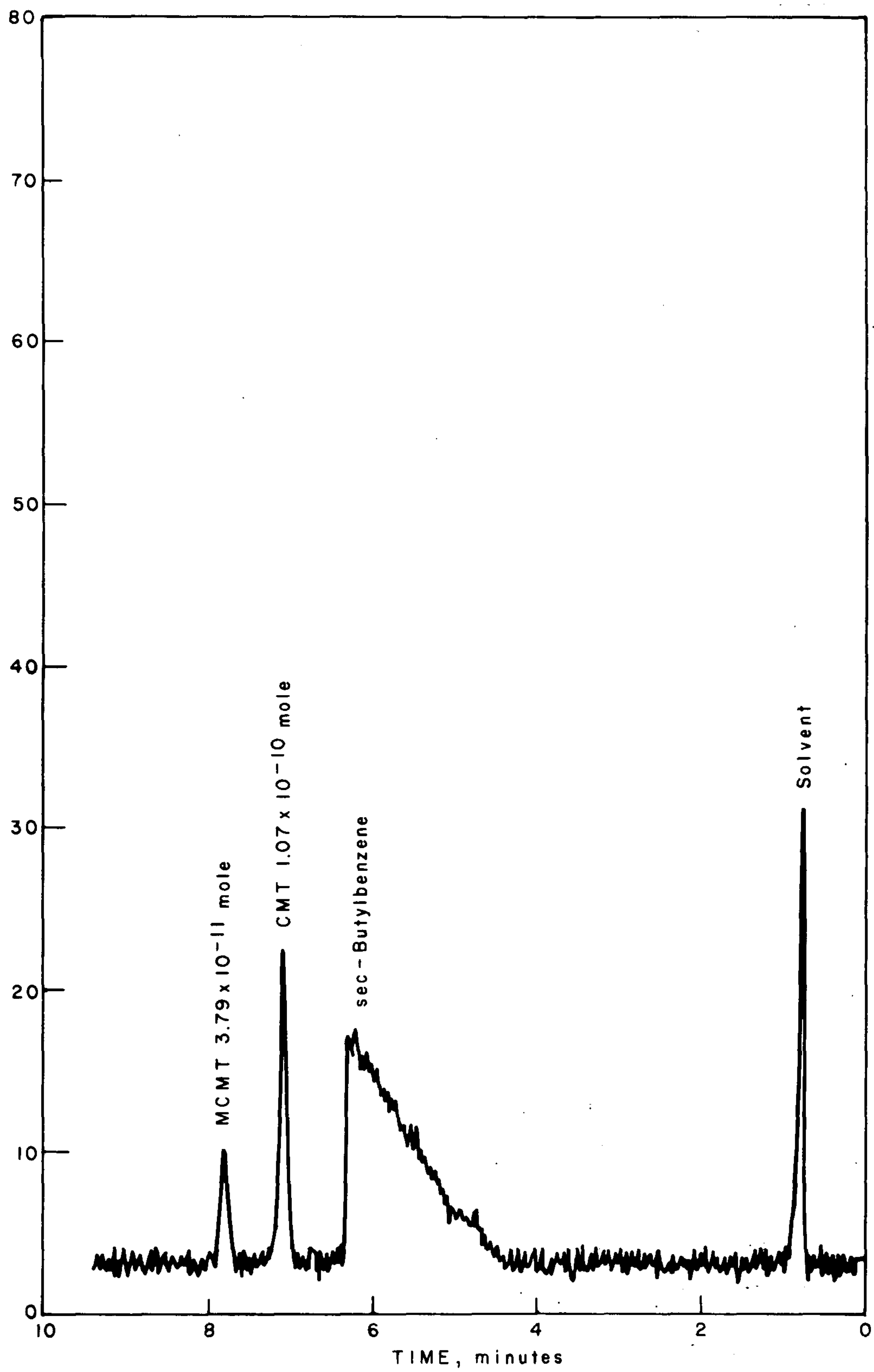


FIGURE 3.- Exhaust analysis for MCMT.

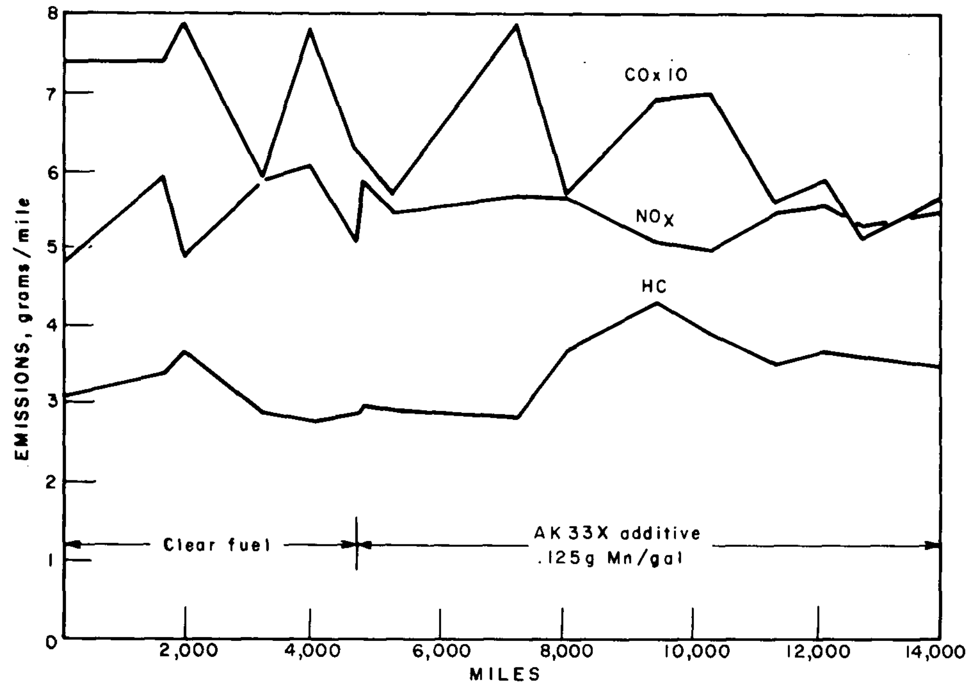


FIGURE 4.-Effect of mileage accumulation on exhaust emissions AK 33X vehicle.

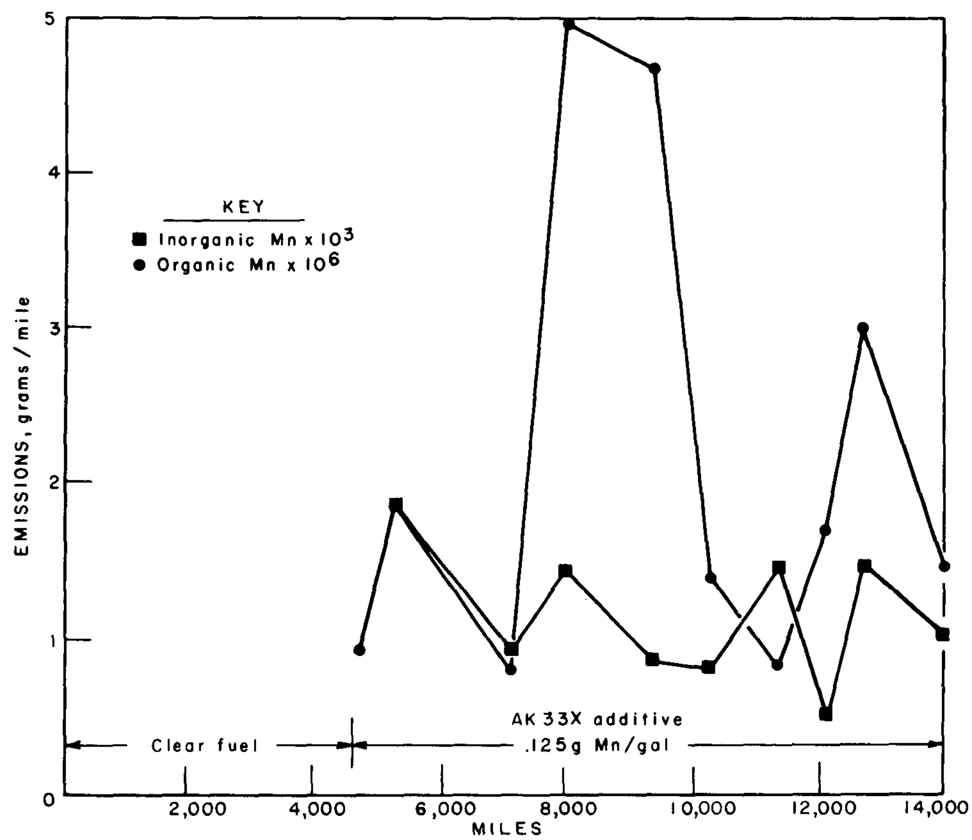


FIGURE 4A.-Effect of mileage accumulation on manganese emissions AK 33X vehicle.

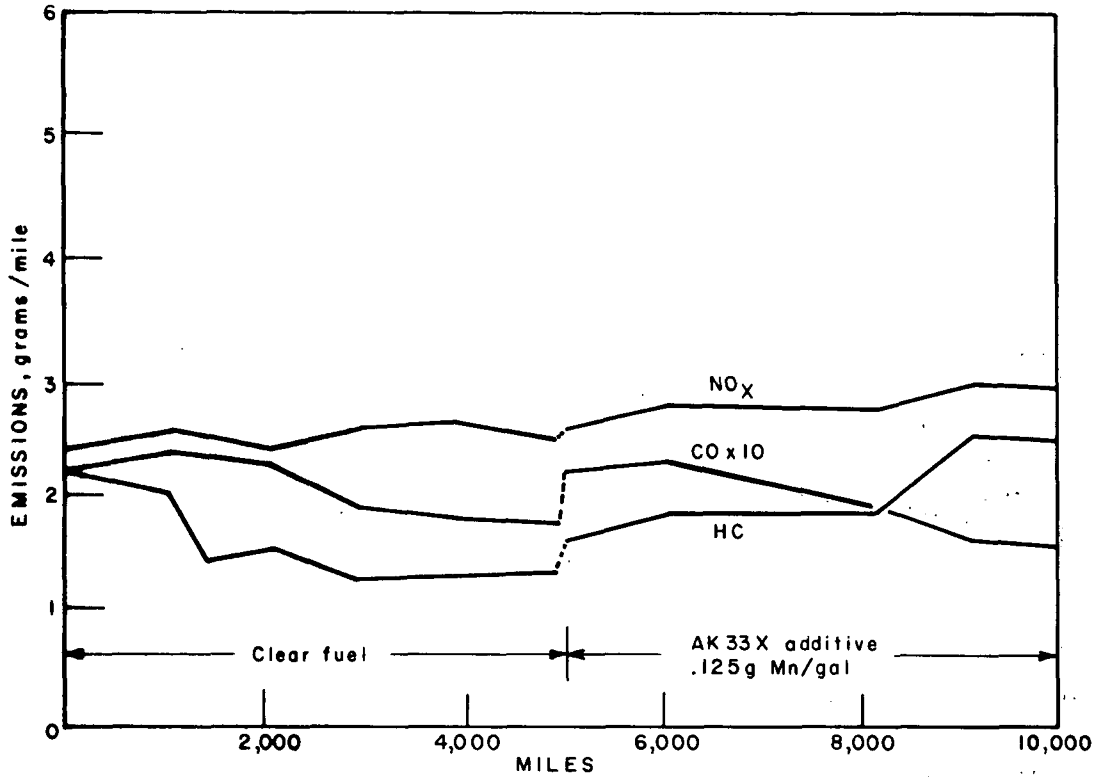


FIGURE 5.-Effect of mileage accumulation on exhaust emissions stationary engine A with AK33X.

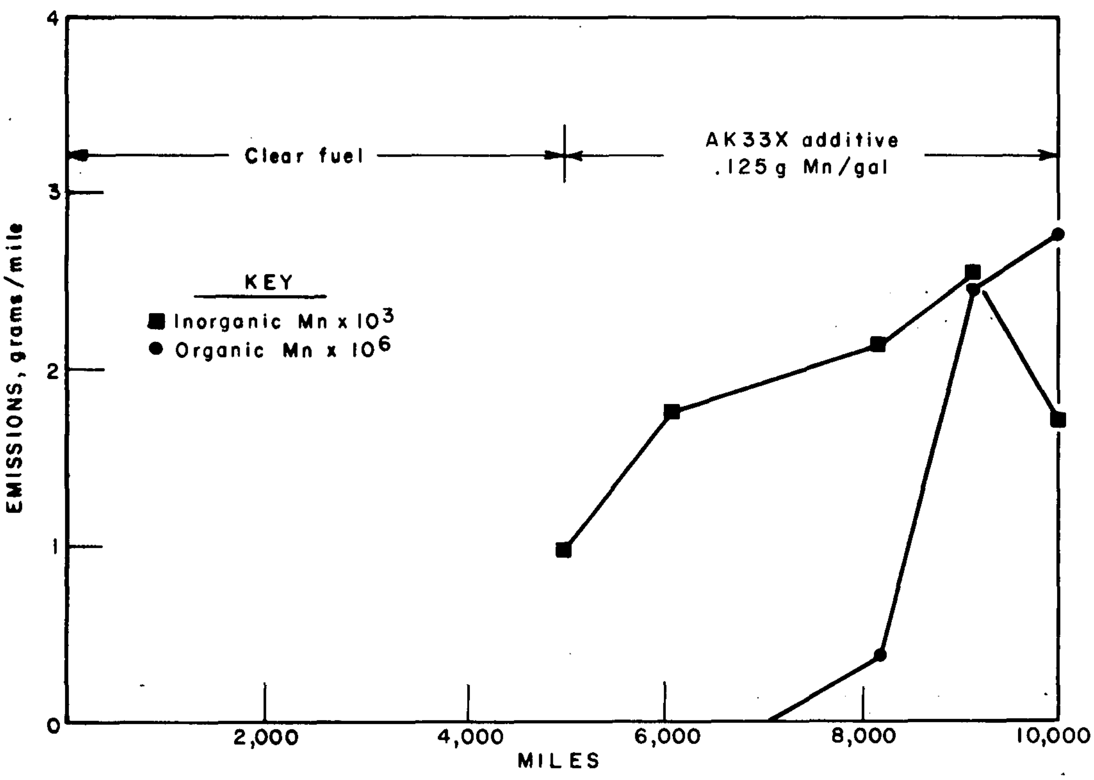


FIGURE 5A.-Effect of mileage accumulation on manganese emissions stationary engine A with AK33X.

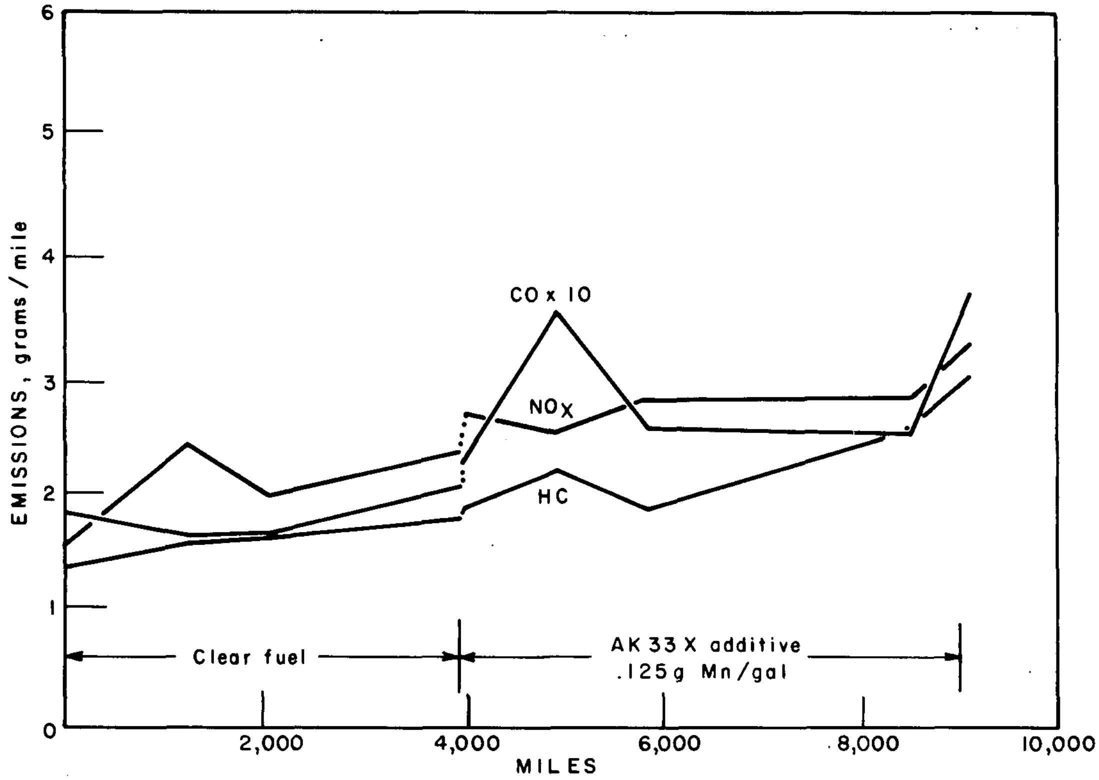


FIGURE 6.- Effect of mileage accumulation on exhaust emissions stationary engine B with AK33X.

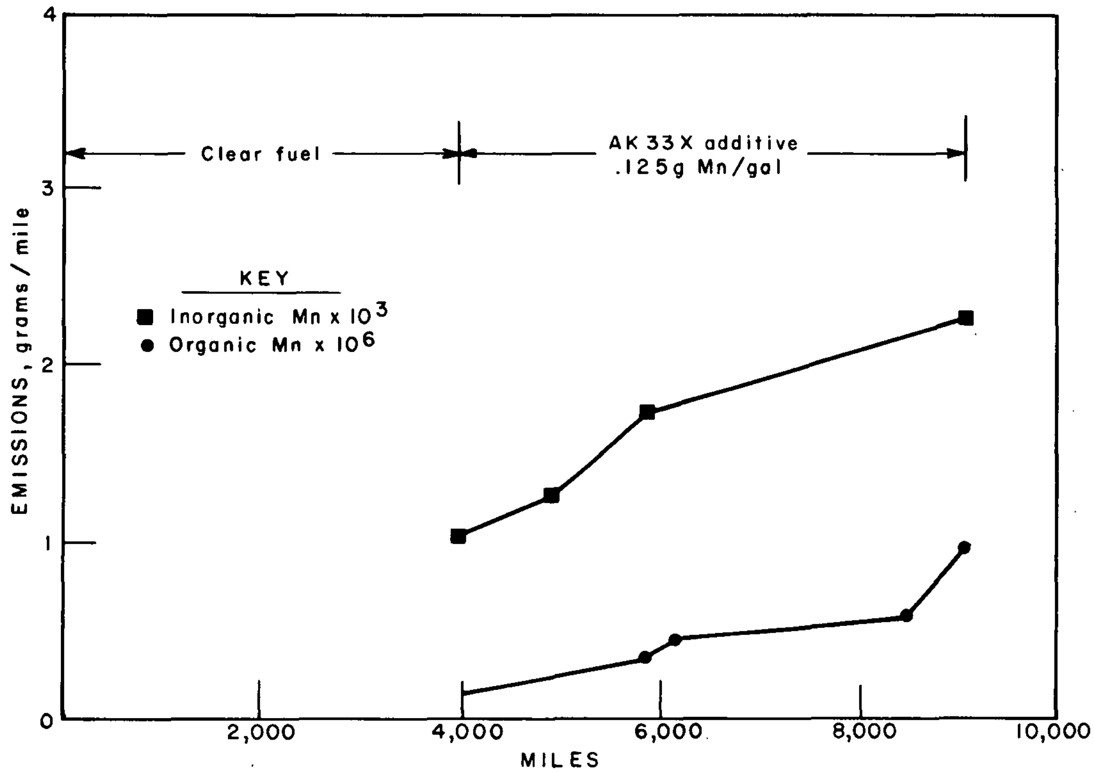


FIGURE 6A.-Effect of mileage accumulation on manganese emissions stationary engine B with AK33X.

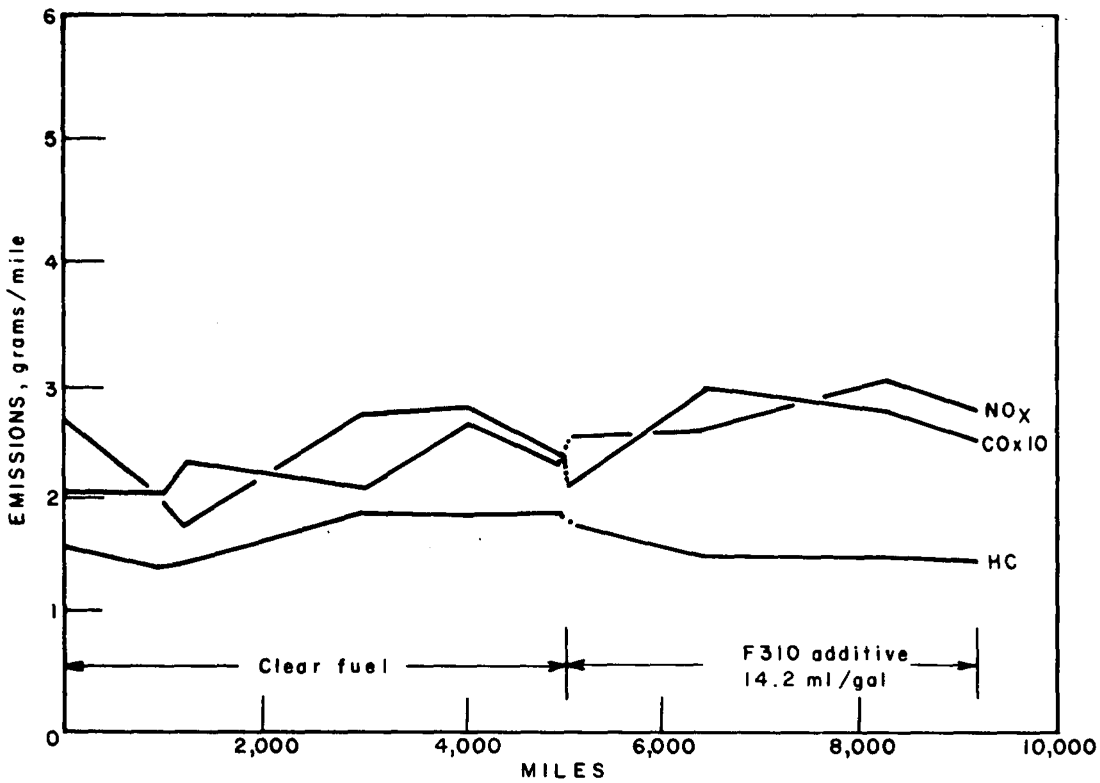


FIGURE 7.- Effect of mileage accumulation on exhaust emissions stationary engine A with F310.

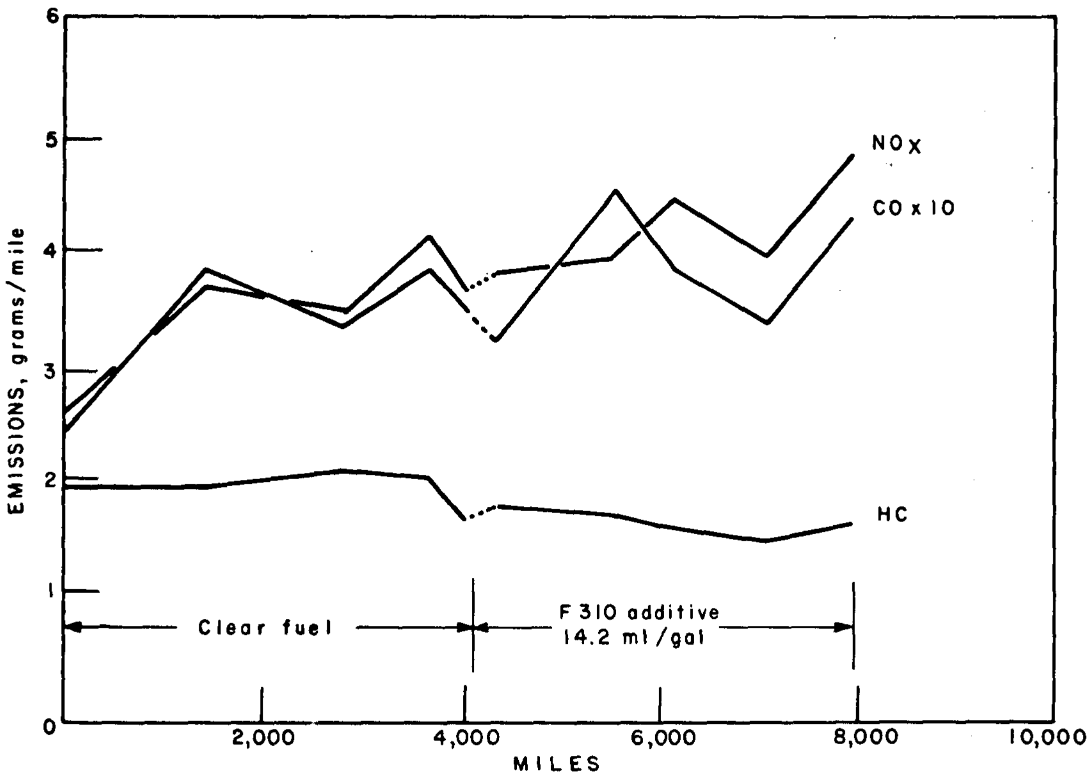


FIGURE 8.-Effect of mileage accumulation on exhaust emissions stationary engine B with F310.

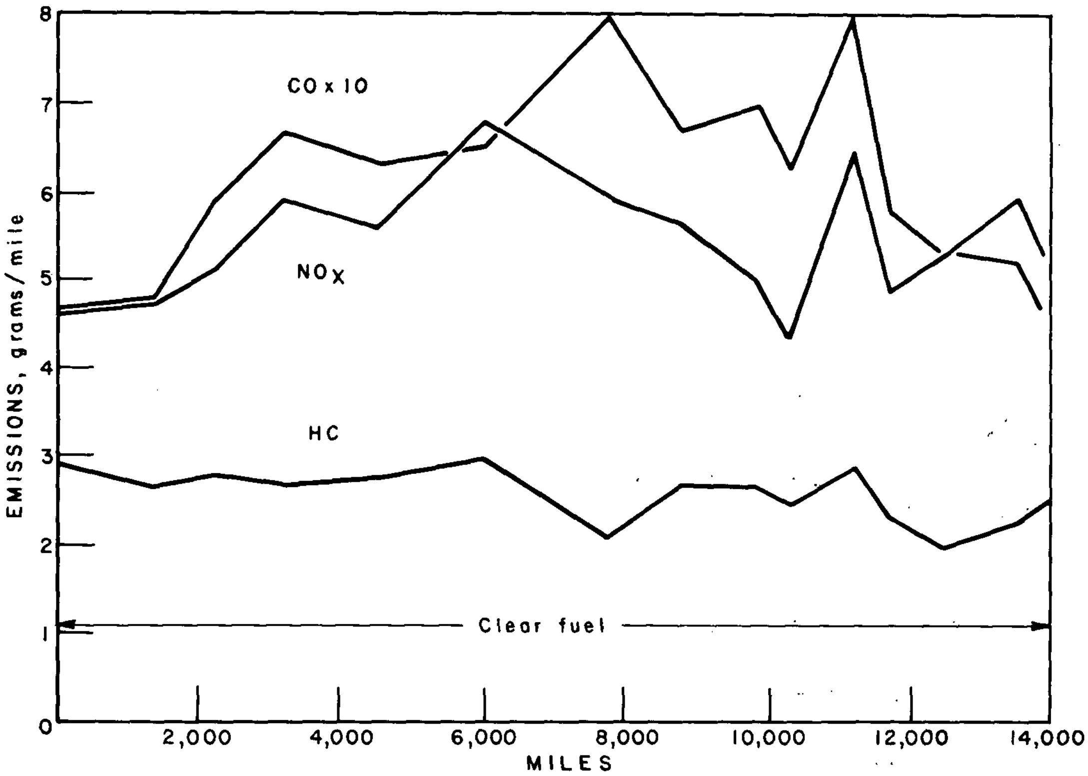


FIGURE 9.- Effect of mileage accumulation on exhaust emissions control vehicle.

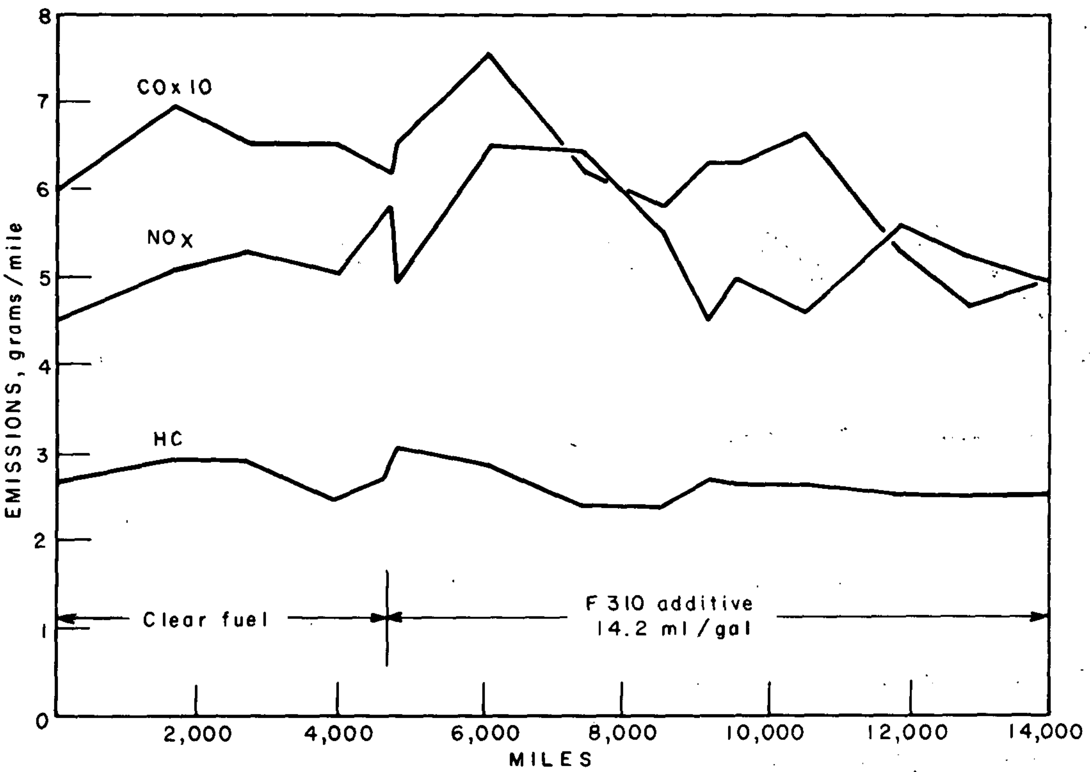


FIGURE 10.- Effect of mileage accumulation on exhaust emissions F 310 vehicle.

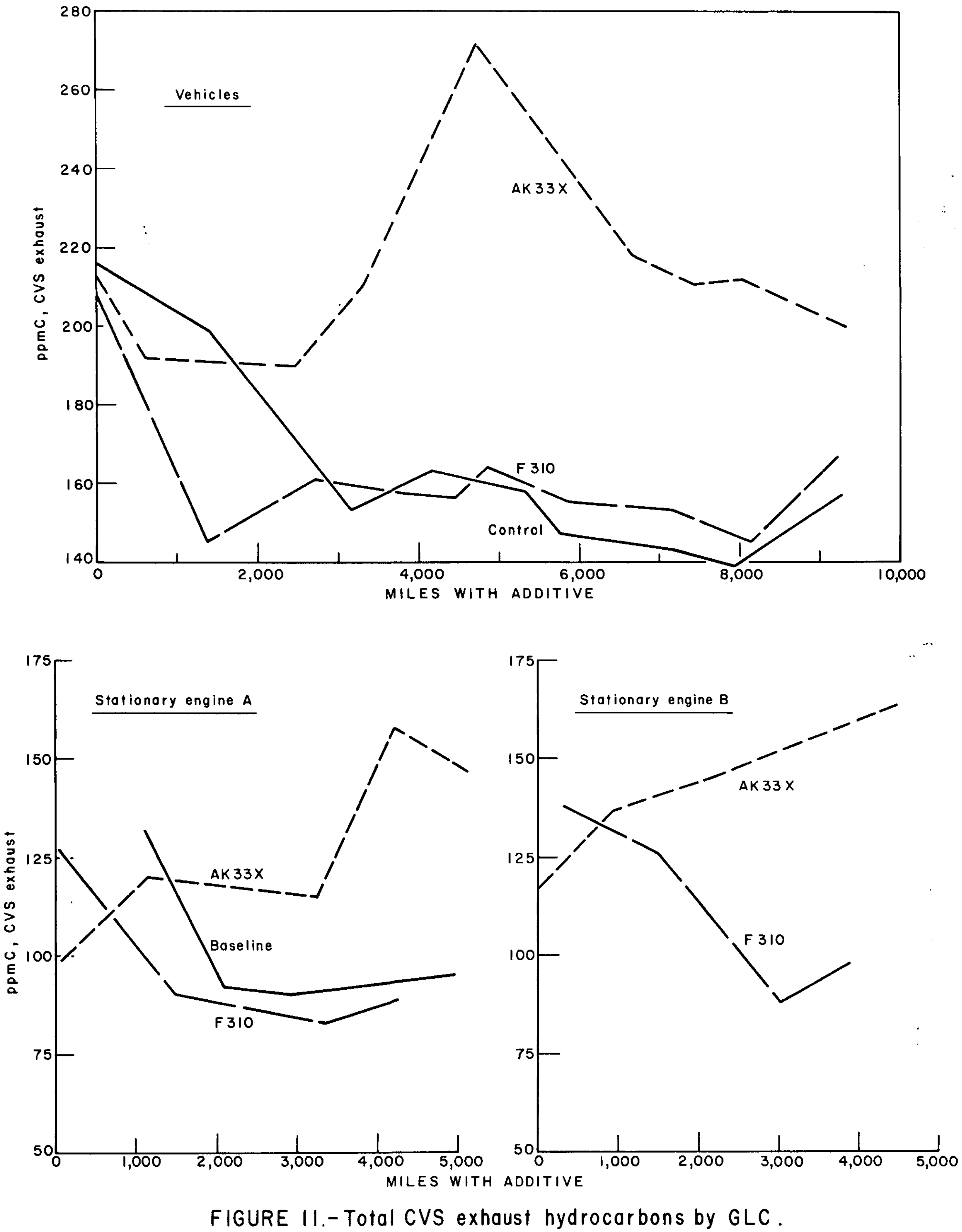


FIGURE 11.-Total CVS exhaust hydrocarbons by GLC.

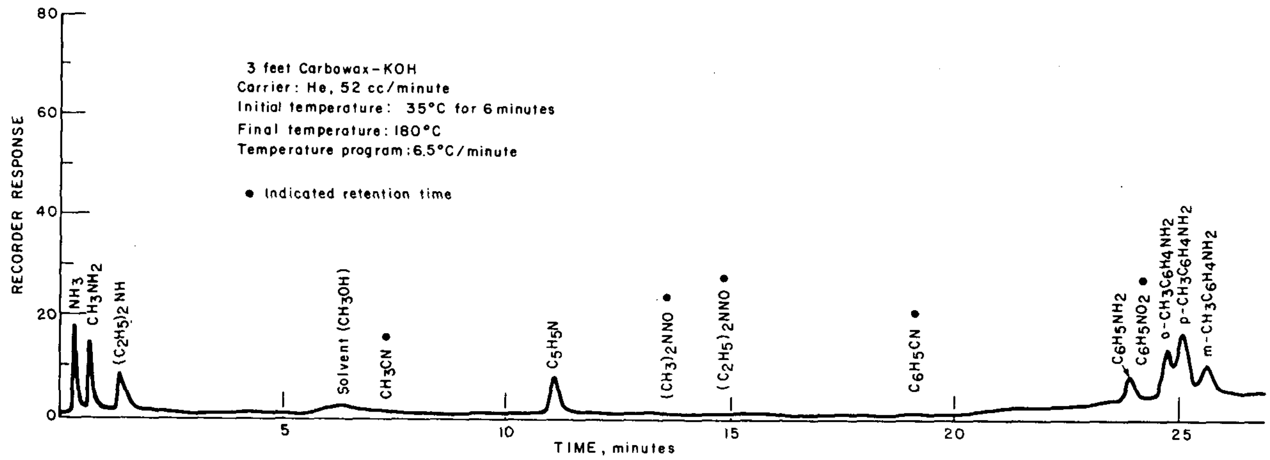


FIGURE 12.-Chromatogram of synthetic amines and pyridine, .08 mV/division.

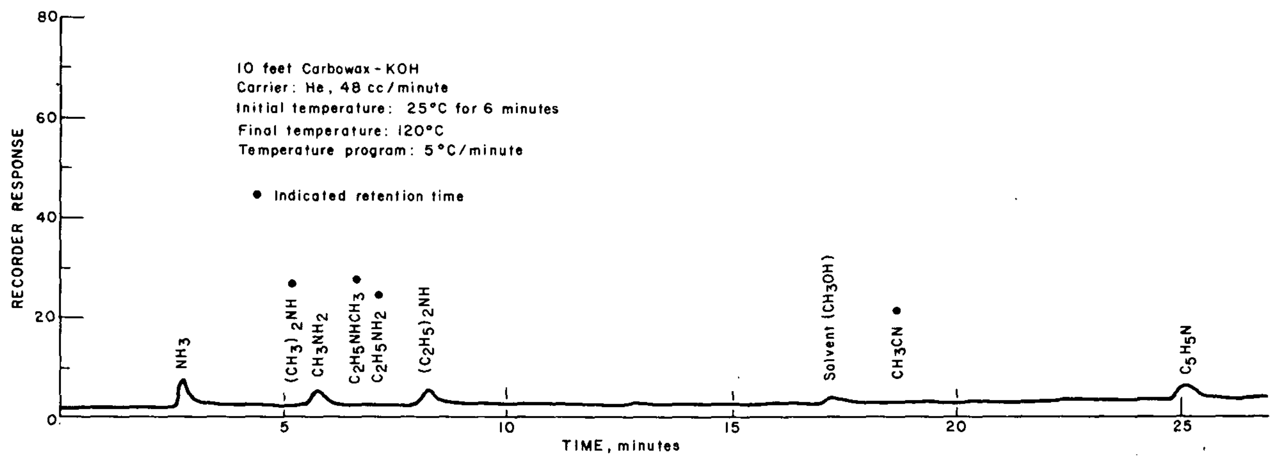


FIGURE 13.-Chromatogram of synthetic amines and pyridine, .08 mV/division.

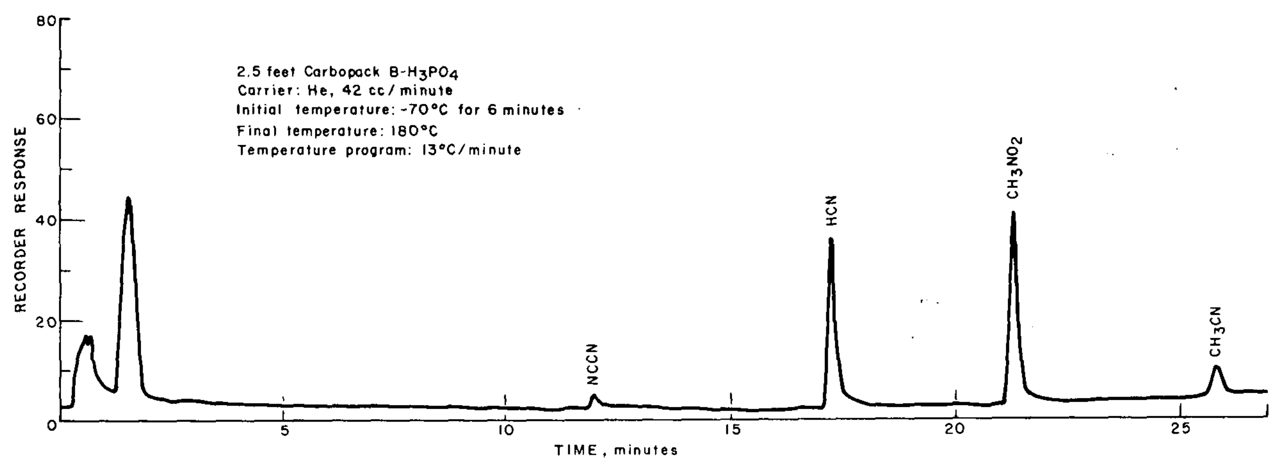


FIGURE 14.-Chromatogram of synthetic acidic and neutral nitrogen compounds, .04 mV/division.

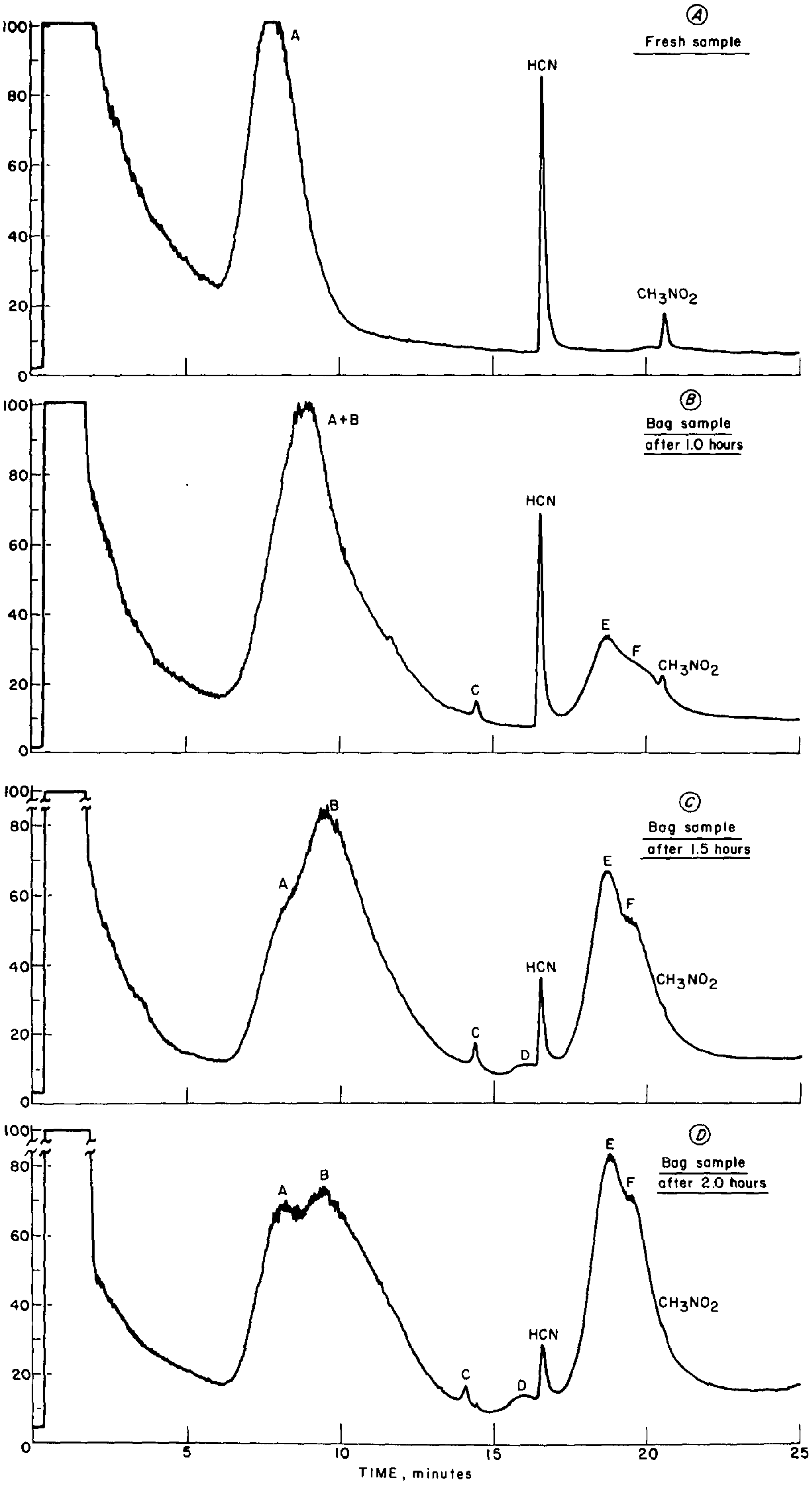


FIGURE 15.- Chromatogram for acidic and neutral nitrogen compounds, CVS exhaust, .04 mV/division.

APPENDIX A.--TABULATED DATA

TABLE A-1. - Detailed Hydrocarbon Analysis F-310 Vehicle, ppmC

Peak No.	Compound	CVS exhaust	CVS exhaust with scrubber	CVS exhaust	CVS exhaust with scrubber	CVS exhaust	CVS exhaust with scrubber	CVS exhaust	CVS exhaust with scrubber	CVS exhaust	CVS exhaust with scrubber
	Accumulated mileage..	4,750		6,070		7,420		8,550		9,150	
	Fuel..............	Indolene + F-310		Indolene + F-310		EPA + F-310		EPA + F-310		EPA + F-310	
1	Methane......................	17.39	17.39	16.56	16.56	12.81	12.81	12.95	12.95	12.76	12.76
2	Ethylene.....................	19.95	-	15.77	-	18.88	-	18.12	-	17.88	-
3	Ethane.......................	2.54	2.54	1.94	1.94	1.67	1.67	1.53	1.53	1.59	1.59
4	Acetylene....................	23.45	-	19.96	-	18.24	-	18.11	-	16.70	-
5	Propylene, propane...........	12.46	.11	8.63	.14	9.61	.15	9.20	.07	7.41	.32
6	Isobutane....................	.81	.21	.29	.10	-	.07	.97	.10	.32	.16
7	Butene-1, isobutylene........	6.64	-	4.94	-	4.85	-	4.63	-	4.37	-
8	n-Butane, 1,3-butadiene......	4.61	2.24	2.67	1.01	3.49	1.81	4.26	2.50	3.81	2.26
9	trans-2-Butene...............	.98	-	.61	-	.79	-	.77	-	.52	-
10	cis-2-Butene.................	1.20	-	.75	-	.96	-	.93	-	.42	-
11	3-Methyl-1-butene............	.28	-	.12	-	.38	-	.34	-	.05	-
12	Isopentane...................	3.46	3.46	1.77	1.77	2.99	2.99	3.92	3.92	3.54	3.54
13	Pentene-1....................	.16	-	.09	-	.25	-	.25	-	.10	-
14	n-Pentane, 2-methyl-1-butene.	1.59	1.08	.89	.53	2.39	2.25	3.12	3.01	2.90	2.78
15	trans-2-Pentene..............	.58	-	.34	-	.34	-	.36	-	.25	-
16	cis-2-Pentene................	.24	-	.14	-	.19	-	.20	-	.09	-
17	2-Methyl-2-butene............	1.16	-	.73	-	.52	-	.52	-	.36	-
18	Cyclopentane, 3-methyl-1-pentene....................	.13	.08	.07	.04	4.26	5.08	5.25	5.66	5.76	5,01
19	2,3-Dimethylbutane...........	1.23	1.23	.62	.62	.44	.44	.51	.51	.40	.40
20	2-Methylpentane, 2,3-dimethyl-1-butene......	1.33	1.22	.69	.63	.69	.43	.78	.53	.47	.43
21	3-Methylpentane..............	.72	.74	.38	.40	.38	.22	.40	.31	.20	.27
22	1-Hexene, 2-ethyl-1-butene...	.13	-	.06	-	.40	-	.40	-	.15	-
23	n-Hexane, cis-3-hexene.......	.69	.67	.35	.36	.26	.15	.26	.21	.16	.23
24	Methylcyclopentane, 3-methyltrans-2-pentene....	.70	.53	.39	.27	.37	.15	.39	.17	.26	.18
25	2,4-Dimethylpentane..........	1.44	1.40	.77	.68	.40	.17	.32	.14	.15	.18
26	Benzene, cyclohexane.........	9.84	.19	7.78	.15	6.37	.02	5.52	.04	5.38	.04
27	Cyclohexene, 2,3-dimethylpentane, 2-methylhexane............	2.94	2.10	1.40	1.06	2.62	2.07	3.15	2.71	3.63	3.23
28	3-Methylhexane...............	.99	.81	.47	.41	.57	.38	.60	.49	.67	.59
29	Isooctane....................	7.59	7.44	3.72	3.72	4.57	4.57	5.63	5.63	6.88	6.88
30	n-Heptane....................	.84	.67	.37	.32	.82	.53	.89	.67	1.31	.87
31	Methylcyclohexane............	.44	.34	.19	.17	.44	.25	.48	.34	.57	.44
32	2,4-Dimethylhexane, 2,5-dimethylhexane.........	2.32	2.38	1.27	1.22	.96	.80	.97	.92	1.23	1.21
33	2,3,4-Trimethylpentane.......	3.09	3.05	1.45	1.46	.50	.61	.48	.47	.63	.64
34	2,3,3-Trimethylpentane.......	3.48	3.48	1.63	1.63	.39	.39	.25	.25	.32	.32
35	Toluene, 2,3-dimethylhexane..	29.71	1.07	21.25	.51	18.81	.33	19.32	.30	21.40	.39
36	2-Methylheptane..............	2.28	.62	-	.31	2.16	.92	2.40	.97	2.95	1.20
37	3-Methylheptane..............	1.21	.52	.68	.26	1.44	.95	1.55	1.01	1.94	1.28
38	2,2,5-Trimethylhexane........	1.58	1.24	.85	.63	.36	.24	.20	.07	.23	.10
39	n-Octane.....................	.32	.27	.16	.13	.90	.68	.85	.68	1.10	.97
40	2,3,5-Trimethylhexane........	.18	.14	.07	.07	.12	.02	.06	.02	.07	.06
41	2,5-Dimethylheptane, 3,5-dimethylheptane........	.13	.12	.04	.08	.31	.16	.20	.19	.27	.30
42	Ethylbenzene.................	2.46	.06	1.65	.04	1.67	.06	1.46	.10	1.61	.17
43	p-Xylene, m-xylene...........	5.92	.13	4.29	.08	4.83	.32	4.72	.35	5.28	.49
44	o-Xylene.....................	3.56	.18	2.56	.12	2.72	-	2.35	-	2.56	-
45	n-Propylbenzene..............	.31	-	.22	-	.24	-	.16	-	.20	-
46	1-Methyl-3-ethylbenzene......	1.89	.02	1.40	.01	1.33	.04	1.11	.04	1.26	.06
47	1-Methyl-2-ethylbenzene......	.84	.15	.63	.03	.54	.07	.47	.06	.10	.08
48	Mesitylene...................	.75	.07	.54	.10	.53	-	.43	-	.52	-
49	1,2,4-Trimethylbenzene.......	3.82	.17	3.63	.11	2.45	-	1.69	-	1.91	.02
50	sec-Butylbenzene, n-decane...	.42	.14	-	.09	.68	.09	.49	.07	.53	.12
	*Total hydrocarbons by GC.....	205.70		144.90		160.65		157.19		156.35	

* Includes exhaust hydrocarbons not reported in detailed analysis.

TABLE A-1. - Detailed Hydrocarbon Analysis
F-310 Vehicle, ppmC--Continued

Peak No.	Accumulated mileage... / Fuel............... / Compound	9,550 EPA + F-310 CVS exhaust	9,550 EPA + F-310 CVS exhaust with scrubber	10,550 EPA + F-310 CVS exhaust	10,550 EPA + F-310 CVS exhaust with scrubber	11,880 EPA + F-310 CVS exhaust	11,880 EPA + F-310 CVS exhaust with scrubber	12,840 EPA + F-310 CVS exhaust	12,840 EPA + F-310 CVS exhaust with scrubber	13,940 EPA + F-310 CVS exhaust	13,940 EPA + F-310 CVS exhaust with scrubber
1	Methane.....................	12.91	12.91	13.65	13.65	11.85	11.85	9.84	9.84	10.15	10.15
2	Ethylene....................	18.40	-	18.64	-	16.81	-	15.00	-	17.69	-
3	Ethane......................	1.59	1.59	1.57	1.57	1.52	1.52	1.32	1.32	1.59	1.59
4	Acetylene...................	18.27	-	18.90	-	16.99	-	13.67	-	15.84	-
5	Propylene, propane..........	9.57	.20	8.08	.42	7.96	.13	7.73	.19	9.03	.09
6	Isobutane...................	-	.10	-	.40	.67	.10	-	.09	-	.09
7	Butene-1, isobutylene.......	4.86	-	4.87	-	4.20	-	4.06	-	4.76	-
8	n-Butane, 1,3-butadiene.....	3.93	1.88	3.84	1.93	4.29	2.61	3.37	1.93	4.07	2.20
9	trans-2-Butene..............	.75	-	.41	-	.60	-	.39	-	.67	-
10	cis-2-Butene................	1.05	-	.44	-	.73	-	.75	-	.98	-
11	3-Methyl-1-butene...........	.40	-	.04	-	.14	-	.07	-	.29	-
12	Isopentane..................	3.05	3.05	3.41	3.41	4.10	4.10	3.31	3.31	3.80	3.80
13	Pentene-1...................	.07	-	.10	-	.13	-	.14	-	.17	-
14	n-Pentane, 2-methyl-1-butene	2.71	2.43	2.93	2.89	3.29	3.19	2.92	2.67	3.27	3.06
15	trans-2-Pentene.............	.23	-	.21	-	.26	-	.27	-	.28	-
16	cis-2-Pentene...............	.09	-	.08	-	.12	-	.16	-	.16	-
17	2-Methyl-2-butene...........	.36	-	.35	-	.40	-	.41	-	.47	-
18	Cyclopentane, 3-methyl-1-pentene..................	5.51	4.53	5.58	5.07	6.24	5.57	5.61	5.24	6.33	5.50
19	2,3-Dimethylbutane..........	.36	.36	.32	.32	.43	.43	.37	.37	.47	.47
20	2-Methylpentane, 2,3-dimethyl-1-butene.....	.41	.37	.34	.28	.51	.42	.40	.39	.49	.51
21	3-Methylpentane.............	.17	.21	.15	.16	.23	.22	.26	.18	.34	.33
22	1-Hexene, 2-ethyl-1-butene..	.12	-	.12	-	.17	-	.20	-	.29	-
23	n-Hexane, cis-3-hexene......	.16	.16	.15	.15	.16	.14	.24	.16	.25	.28
24	Methylcyclopentane, 3-methyltrans-2-pentene...	.25	.14	.20	.11	.20	.14	.29	.17	.34	.22
25	2,4-Dimethylpentane.........	.09	.12	.10	.08	.09	.11	.19	.15	.22	.20
26	Benzene, cyclohexane........	6.06	.04	6.35	.45	5.15	.04	4.98	.05	5.31	.05
27	Cyclohexene, 2,3-dimethylpentane, 2-methylhexane...........	3.71	3.19	3.15	2.89	3.32	3.09	3.43	3.19	3.76	3.51
28	3-Methylhexane..............	.70	.59	.57	.52	.60	.55	.66	.59	.68	.66
29	Isooctane...................	6.73	6.73	5.96	5.96	6.37	6.37	6.72	6.72	7.18	7.18
30	n-Heptane...................	.98	.84	.82	.69	.87	.78	1.04	.86	1.07	.96
31	Methylcyclohexane...........	.53	.43	.43	.36	.47	.41	.53	.44	.56	.50
32	2,4-Dimethylhexane, 2,5-dimethylhexane........	1.16	1.16	.99	.95	1.08	1.03	1.19	1.00	1.21	1.17
33	2,3,4-Trimethylpentane......	.59	.59	.50	.50	.56	.57	.63	.61	.61	.63
34	2,3,3-Trimethylpentane......	.29	.29	.19	.19	.25	.25	.33	.33	.30	.30
35	Toluene, 2,3-dimethylhexane.	22.54	.36	21.75	.28	20.52	.30	20.73	.42	23.02	.36
36	2-Methylheptane.............	2.55	1.15	2.19	1.09	2.54	1.02	2.02	1.40	2.69	1.14
37	3-Methylheptane.............	1.69	1.20	1.43	1.09	1.67	1.07	1.58	1.37	1.78	1.12
38	2,2,5-Trimethylhexane.......	.19	.09	.31	.11	.16	.07	.15	.10	.19	.09
39	n-Octane....................	.98	.87	.81	.76	.96	.79	.96	.87	1.00	.82
40	2,3,5-Trimethylhexane.......	.06	.04	.01	.01	.04	.03	.07	.04	.06	.03
41	2,5-Dimethylheptane, 3,5-dimethylheptane.......	.23	.29	.15	.19	.21	.26	.29	.28	.25	.25
42	Ethylbenzene................	1.66	.14	1.60	.09	1.54	1.27	1.66	.13	1.78	.16
43	p-Xylene, m-xylene..........	5.47	.45	5.36	.41	5.51	.44	5.33	.44	5.68	.45
44	o-Xylene....................	2.65	.01	2.58	-	2.52	-	2.52	-	2.76	-
45	n-Propylbenzene.............	.18	-	.11	-	.15	-	.26	-	.23	.04
46	1-Methyl-3-ethylbenzene.....	1.33	.06	1.22	.15	1.46	.19	1.29	.17	1.44	.22
47	1-Methyl-2-ethylbenzene.....	.52	.08	.49	.08	.57	.11	.53	.10	.54	.13
48	Mesitylene..................	.45	-	.41	.07	.48	.11	.55	.11	.46	.15
49	1,2,4-Trimethylbenzene......	1.76	.02	1.86	-	1.89	-	1.65	-	1.91	-
50	sec-Butylbenzene, n-decane..	.47	.11	.39	.09	.44	.11	.26	.10	.55	.13
	*Total hydrocarbons by GC....	163.61		155.17		153.27		144.90		166.86	

* Includes exhaust hydrocarbons not reported in detailed analysis.

TABLE A-2. - Detailed Hydrocarbon Analysis
AK33X Vehicle, ppmC

Peak No.	Compound	Accumulated mileage.. 4,740		5,305		7,170		8,030		9,434	
	Fuel..............	Indolene + AK33X		Indolene + AK33X		EPA + AK33X		EPA + AK33X		EPA + AK33X	
		CVS exhaust	CVS exhaust with scrubber	CVS exhaust	CVS exhaust with scrubber	CVS exhaust	CVS exhaust with scrubber	CVS exhaust	CVS exhaust with scrubber	CVS exhaust	CVS exhaust with scrubber
1	Methane....................	17.49	17.49	17.10	17.10	14.61	14.61	16.01	16.01	18.07	18.07
2	Ethylene...................	19.75	-	19.02	-	23.32	-	24.35	-	28.45	-
3	Ethane.....................	2.50	2.50	2.55	2.55	2.27	2.27	2.40	2.40	2.76	2.76
4	Acetylene..................	24.75	-	23.31	-	21.47	-	23.95	-	27.36	-
5	Propylene, propane..........	12.77	.14	12.39	.15	12.32	.18	11.05	.15	14.82	.24
6	Isobutane..................	1.21	.29	1.20	.25	-	.13	-	.13	-	.21
7	Butene-1, isobutylene.......	6.25	-	6.27	-	6.40	-	6.36	-	7.74	-
8	n-Butane, 1,3-butadiene.....	5.26	2.93	4.40	2.10	5.03	2.65	4.78	2.32	7.08	4.19
9	trans-2-Butene.............	1.08	-	1.04	-	.88	-	.68	-	1.07	-
10	cis-2-Butene...............	1.45	-	1.51	-	1.44	-	.68	-	1.67	-
11	3-Methyl-1-butene...........	.36	-	.46	-	.43	-	.07	-	.50	-
12	Isopentane.................	3.98	3.98	2.91	2.91	4.15	4.15	4.50	4.50	6.88	6.88
13	Pentene-1..................	.22	-	.14	-	.32	-	.14	-	.40	-
14	n-Pentane, 2-methyl-1-butene	1.77	1.22	1.40	.95	3.28	2.99	3.69	3.43	5.73	5.50
15	trans-2-Pentene............	.61	-	.46	-	.45	-	.36	-	.59	-
16	cis-2-Pentene..............	.28	-	.21	-	.27	-	.15	-	.34	-
17	2-Methyl-2-butene...........	1.17	-	1.01	-	.70	-	.58	-	.83	-
18	Cyclopentane, 3-methyl-1-pentene...................	.19	.09	.13	.07	5.29	5.37	6.73	5.88	10.65	10.31
19	2,3-Dimethylbutane..........	1.31	1.31	.98	.98	.60	.60	.63	.63	.85	.85
20	2-Methylpentane, 2,3-dimethyl-1-butene.....	1.48	1.28	1.12	1.01	.60	.59	.69	.63	1.28	.94
21	3-Methylpentane............	.85	.82	.63	.66	.52	.28	.31	.37	.71	.54
22	1-Hexene, 2-ethyl-1-butene..	.21	-	.14	-	.47	-	.15	-	.59	-
23	n-Hexane, cis-3-hexene......	.75	.75	.57	.62	.36	.25	.28	.34	.51	.48
24	Methylcyclopentane, 3-methyltrans-2-pentene...	.73	.53	.55	.44	.50	.22	.36	.31	.71	.40
25	2,4-Dimethylpentane.........	1.40	1.32	1.06	1.11	.49	.30	.33	.38	.55	.34
26	Benzene, cyclohexane........	9.61	.19	8.78	.17	7.46	.05	8.08	.09	8.40	.12
27	Cyclohexene, 2,3-dimethylpentane, 2-methylhexane...........	2.59	1.99	2.00	1.52	3.15	2.43	4.17	3.78	5.92	5.40
28	3-Methylhexane.............	1.04	.78	.68	.60	.64	.50	.84	.77	1.23	1.06
29	Isooctane..................	7.09	7.09	5.56	5.56	5.59	5.59	8.47	8.47	11.08	11.08
30	n-Heptane..................	.76	.62	.56	.54	.74	.67	1.17	1.02	1.70	1.48
31	Methylcyclohexane...........	.38	.30	.28	.27	.37	.31	.60	.50	.90	.74
32	2,4-Dimethylhexane, 2,5-dimethylhexane........	2.11	2.20	1.66	1.74	1.06	1.03	1.60	1.60	1.94	1.92
33	2,3,4-Trimethylpentane......	2.87	2.89	2.24	2.16	.67	.64	1.07	1.06	.96	.96
34	2,3,3-Trimethylpentane......	3.22	3.22	2.48	2.48	.48	.48	.79	.79	.48	.48
35	Toluene, 2,3-dimethylhexane.	28.32	.95	25.18	.78	24.09	.36	29.85	.52	35.69	.59
36	2-Methylheptane............	2.12	.55	1.63	.46	2.11	.80	3.21	1.24	4.09	1.93
37	3-Methylheptane............	1.15	.40	.84	.38	1.33	.81	2.03	1.29	2.74	2.06
38	2,2,5-Trimethylhexane.......	1.46	1.04	1.15	.90	.36	.27	.54	.41	.30	.16
39	n-Octane...................	.28	.21	.24	.21	.76	.59	1.12	.93	1.60	1.53
40	2,3,5-Trimethylhexane.......	.14	.13	.13	.11	.06	.02	.07	.05	.10	.09
41	2,5-Dimethylheptane, 3,5-dimethylheptane.......	.08	.11	.10	.09	.19	.15	.25	.25	.40	.49
42	Ethylbenzene...............	2.39	.06	2.30	.05	2.02	.01	2.40	.10	2.93	.39
43	p-Xylene, m-xylene..........	6.06	.13	5.43	.11	5.87	.30	7.42	.46	9.22	.82
44	o-Xylene...................	3.68	.20	3.31	.16	3.20	-	3.77	.01	4.41	.12
45	n-Propylbenzene............	.37	-	.38	.01	.17	-	.24	-	.33	.10
46	1-Methyl-3-ethylbenzene.....	2.13	.09	2.00	.03	1.48	.04	2.16	.06	2.31	.19
47	1-Methyl-2-ethylbenzene.....	.98	.24	.90	.13	.63	.08	.80	.13	.94	.28
48	Mesitylene.................	.87	.12	.82	.06	.53	-	.76	.01	.84	-
49	1,2,4-Trimethylbenzene......	4.40	.28	4.18	.13	2.54	.03	2.95	.03	3.21	-
50	sec-Butylbenzene, n-decane..	.50	.22	.57	.11	.60	.12	.64	.13	.80	.26
	*Total hydrocarbons by GC....	212.42		191.64		190.29		210.72		271.80	

* Includes exhaust hydrocarbons not reported in detailed analysis.

TABLE A-2. - Detailed Hydrocarbon Analysis
AK33X Vehicle, ppmC--Continued

Peak No.	Compound	10,353		11,390		12,140		12,740		14,050	
	Accumulated mileage...	10,353		11,390		12,140		12,740		14,050	
	Fuel...............	EPA + AK33X		EPA + AK33X		EPA + AK33X		EPA + AK33X		EPA + AK33X	
		CVS exhaust	CVS Exhaust with scrubber	CVS exhaust	CVS Exhaust with scrubber	CVS exhaust	CVS Exhaust with scrubber	CVS exhaust	CVS Exhaust with scrubber	CVS exhaust	CVS Exhaust with scrubber
1	Methane....................	15.90	15.90	17.01	17.01	15.85	15.85	14.15	14.15	12.27	12.27
2	Ethylene....................	31.22	-	26.91	-	27.62	-	26.73	-	25.94	-
3	Ethane......................	3.09	3.09	3.02	3.02	2.81	2.81	2.78	2.78	2.65	2.65
4	Acetylene..................	26.87	-	22.25	-	22.31	-	22.12	-	18.80	-
5	Propylene, propane..........	16.05	.53	14.17	.36	14.10	.21	13.98	.13	14.16	.13
6	Isobutane..................	1.46	.48	-	.13	-	.12	-	.12	-	.13
7	Butene-1, isobutylene.......	8.40	-	7.38	-	7.44	-	7.09	-	7.39	-
8	n-Butane, 1,3-butadiene.....	6.70	3.54	5.32	2.13	5.40	2.45	5.82	2.89	5.67	2.62
9	trans-2-Butene.............	1.15	-	.95	-	.77	-	.84	-	1.22	-
10	cis-2-Butene...............	1.66	-	1.47	-	1.87	-	1.05	-	1.60	-
11	3-Methyl-1-butene...........	.30	-	.33	-	.21	-	.09	-	.47	-
12	Isopentane.................	5.45	5.45	3.90	3.90	3.99	3.99	4.76	4.76	4.25	4.25
13	Pentene-1..................	.28	-	.15	-	.18	-	.13	-	.16	-
14	n-Pentane, 2-methyl-1-butene	4.57	4.29	3.70	3.17	3.53	3.15	4.13	3.75	3.62	3.31
15	trans-2-Pentene............	.47	-	.31	-	.37	-	.30	-	.30	-
16	cis-2-Pentene..............	.23	-	.13	-	.18	-	.11	-	.13	-
17	2-Methyl-2-butene...........	.65	-	.49	-	.51	-	.46	-	.50	-
18	Cyclopentane, 3-methyl-1-pentene..................	8.24	7.72	6.91	6.22	6.30	4.87	7.75	6.23	6.59	5.26
19	2,3-Dimethylbutane..........	.59	.59	.45	.45	.35	.35	.47	.47	.45	.45
20	2-Methylpentane, 2,3-dimethyl-1-butene.....	.78	.64	.56	.51	.41	.37	.48	.47	.51	.47
21	3-Methylpentane............	.37	.34	.24	.26	.21	.17	.20	.21	.22	.28
22	1-Hexene, 2-ethyl-1-butene..	.27	-	.15	-	.16	-	.14	-	.20	-
23	n-Hexane, cis-3-hexene......	.29	.30	.25	.24	.23	.15	.21	.17	.18	.20
24	Methylcyclopentane, 3-methyltrans-2-pentene...	.35	.26	.32	.21	.27	.15	.29	.18	.23	.15
25	2,4-Dimethylpentane.........	.17	.21	.14	.14	.14	.11	.13	.14	.10	.12
26	Benzene, cyclohexane........	9.00	.07	7.92	.08	8.39	.05	7.31	.05	6.52	.03
27	Cyclohexene, 2,3-dimethylpentane, 2-methylhexane...........	4.38	3.96	4.09	3.61	3.21	2.93	4.37	3.85	3.64	3.10
28	3-Methylhexane.............	.87	.78	.85	.72	.64	.57	.83	.72	.69	.59
29	Isooctane..................	8.18	8.18	7.43	7.43	6.20	6.20	8.08	8.08	6.65	6.65
30	n-Heptane..................	1.26	1.11	1.13	1.00	.93	.86	1.29	1.04	.94	.82
31	Methylcyclohexane...........	.65	.58	.59	.51	.48	.43	.67	.51	.54	.42
32	2,4-Dimethylhexane, 2,5-dimethylhexane........	1.26	1.23	1.17	1.16	1.01	1.02	1.42	1.35	1.14	1.12
33	2,3,4-Trimethylpentane......	.64	.64	.59	.60	.49	.51	.68	.67	.52	.52
34	2,3,3-Trimethylpentane......	.30	.30	.28	.28	.20	.20	.32	.32	.22	.22
35	Toluene, 2,3-dimethylhexane.	32.29	.39	29.44	.35	28.57	.31	30.16	.43	26.23	.27
36	2-Methylheptane............	3.54	1.27	3.12	1.19	2.44	1.08	3.57	1.58	3.38	1.04
37	3-Methylheptane............	2.25	1.35	2.02	1.28	1.62	1.13	2.32	1.63	2.12	1.09
38	2,2,5-Trimethylhexane.......	.65	.25	.21	.10	.15	.08	.25	.09	.23	.07
39	n-Octane...................	1.27	.94	1.14	.97	.95	.89	1.25	1.15	1.06	.78
40	2,3,5-Trimethylhexane.......	.08	.03	.07	.06	.05	.04	.06	.02	.05	.03
41	2,5-Dimethylheptane, 3,5-dimethylheptane.......	.31	.25	.27	.34	.26	.31	.27	.26	.21	.21
42	Ethylbenzene...............	2.80	.16	2.56	.11	2.55	.20	2.60	.16	2.33	.07
43	p-Xylene, m-xylene..........	8.31	.47	7.55	.53	7.44	.50	7.94	.65	6.65	.37
44	o-Xylene...................	4.25	-	3.87	-	3.76	-	3.89	-	3.39	-
45	n-Propylbenzene............	.31	-	.25	.01	.29	-	.22	-	.20	-
46	1-Methyl-3-ethylbenzene.....	2.29	.18	2.09	.19	2.07	.20	.22	.24	1.82	.12
47	1-Methyl-2-ethylbenzene.....	.86	.09	.76	.11	.77	.11	.78	.15	.66	.07
48	Mesitylene.................	.77	.10	.65	.11	.68	.11	.71	.15	.60	.06
49	1,2,4-Trimethylbenzene......	3.52	-	2.79	-	2.64	-	2.73	-	2.96	-
50	sec-Butylbenzene, n-decane..	.81	.10	.67	.12	.64	.11	.56	.14	.83	.07
	*Total hydrocarbons by GC....	247.22		217.74		211.23		212.18		200.46	

* Includes exhaust hydrocarbons not reported in detailed analysis.

TABLE A-3. - Detailed Hydrocarbon Analysis
Control Vehicle, ppmC

	Accumulated mileage..	4,550		5,950		7,700		8,725		9,865	
	Fuel...............	Indolene		Indolene		EPA		EPA		EPA	
Peak No.	Compound	CVS exhaust	CVS exhaust with scrubber	CVS exhaust	CVS exhaust with scrubber	CVS exhaust	CVS exhaust with scrubber	CVS exhaust	CVS exhaust with scrubber	CVS exhaust	CVS exhaust with scrubber
1	Methane.....................	16.86	16.86	17.40	17.40	12.04	12.04	13.77	13.77	13.45	13.45
2	Ethylene....................	17.79	-	17.07	-	17.02	-	18.34	-	17.92	-
3	Ethane......................	2.22	2.22	2.20	2.20	1.48	1.48	1.52	1.52	1.48	1.48
4	Acetylene...................	23.96	-	24.65	-	17.05	-	19.40	-	18.36	-
5	Propylene, propane..........	11.01	.10	10.62	.13	8.48	.13	9.35	.10	7.42	.24
6	Isobutane...................	.98	.27	.70	.16	-	.08	.99	.09	.26	.13
7	Butene-1, isobutylene.......	5.82	-	5.72	-	4.41	-	4.77	-	4.30	-
8	n-Butane, 1,3-butadiene.....	4.93	2.98	3.77	1.92	3.28	1.81	4.20	2.39	4.13	2.56
9	trans-2-Butene..............	.95	-	.83	-	.61	-	.73	-	.50	-
10	cis-2-Butene................	1.06	-	1.11	-	.95	-	.97	-	.51	-
11	3-Methyl-1-butene...........	.31	-	.32	-	.34	-	.42	-	.07	-
12	Isopentane..................	4.46	4.46	3.43	3.43	2.93	2.93	3.90	3.90	3.77	3.77
13	Pentene-1...................	.24	-	.19	-	.26	-	.08	-	.12	-
14	n-Pentane, 2-methyl-1-butene	1.95	1.35	1.59	1.07	2.36	2.18	3.30	3.01	3.03	2.90
15	trans-2-Pentene.............	.69	-	.56	-	.35	-	.16	-	.25	-
16	cis-2-Pentene...............	.32	-	.28	-	.23	-	.06	-	.11	-
17	2-Methyl-2-butene...........	1.35	-	1.15	-	.54	-	.34	-	.39	-
18	Cyclopentane, 3-methyl-1-pentene..................	.22	.10	.14	.09	4.04	4.16	6.42	5.22	5.78	4.76
19	2,3-Dimethylbutane..........	1.63	1.63	1.23	1.23	.43	.43	.41	.41	.39	.39
20	2-Methylpentane, 2,3-dimethyl-1-butene.....	1.83	1.62	1.24	1.23	.43	.39	.42	.40	.47	.41
21	3-Methylpentane.............	1.03	.98	.75	.79	.42	.17	.17	.19	.22	.26
22	1-Hexene, 2-ethyl-1-butene..	.26	-	.16	-	.43	-	.10	-	.16	-
23	n-Hexane, cis-3-hexene......	.92	.91	.68	.72	.26	.16	.16	.15	.16	.23
24	Methylcyclopentane, 3-methyltrans-2-pentene...	.92	.67	.65	.54	.38	.17	.22	.15	.26	.18
25	2,4-Dimethylpentane.........	1.91	1.77	1.35	1.39	.36	.19	.13	.14	.17	.20
26	Benzene, cyclohexane........	8.70	.24	8.69	.27	5.99	.02	6.04	.07	5.80	.09
27	Cyclohexene, 2,3-dimethylpentane, 2-methylhexane...........	3.33	2.75	2.42	2.01	2.46	2.06	3.72	3.44	3.56	3.12
28	3-Methylhexane..............	1.17	1.04	.83	.76	.55	.39	.71	.62	.66	.57
29	Isooctane...................	9.90	9.57	7.08	7.08	4.53	4.53	7.10	7.10	6.72	6.72
30	n-Heptane...................	1.12	.82	.73	.59	.76	.54	.99	.83	.96	.87
31	Methylcyclohexane...........	.52	.41	.38	.31	.41	.26	.51	.41	.53	.43
32	2,4-Dimethylhexane, 2,5-dimethylhexane........	2.91	2.93	2.22	2.28	.93	.81	1.20	1.17	1.21	1.21
33	2,3,4-Trimethylpentane......	3.95	3.99	3.06	3.05	.50	.63	.64	.72	.63	.65
34	2,3,3-Trimethylpentane......	4.49	4.48	3.46	3.46	.40	.40	.36	.36	.31	.31
35	Toluene, 2,3-dimethylhexane.	29.56	1.29	26.36	1.04	16.77	.38	21.37	.37	21.26	.40
36	2-Methylheptane.............	2.62	.73	1.91	.60	1.71	.94	2.39	1.16	2.53	1.20
37	3-Methylheptane.............	1.42	.57	.96	.49	1.22	.97	1.58	1.20	1.74	1.30
38	2,2,5-Trimethylhexane.......	1.92	1.45	1.50	1.25	.29	.26	.22	.12	.19	.10
39	n-Octane....................	.39	.31	.32	.26	.88	.59	.95	.80	1.15	1.01
40	2,3,5-Trimethylhexane.......	.24	.18	.18	.16	.13	.01	.06	.02	.09	.07
41	2,5-Dimethylheptane, 3,5-dimethylheptane.......	.19	.15	.13	.15	.34	.15	.25	.20	.32	.34
42	Ethylbenzene................	2.39	.08	2.29	.08	1.62	.01	1.57	.09	1.67	.18
43	p-Xylene, m-xylene..........	5.73	.16	5.62	.16	4.27	.33	5.09	.39	5.57	.51
44	o-Xylene....................	3.35	.22	3.26	.23	2.47	-	2.38	-	2.60	-
45	n-Propylbenzene.............	.42	-	.49	-	.26	-	.13	-	.14	-
46	1-Methyl-3-ethylbenzene.....	2.00	.07	2.15	.05	1.04	.05	1.25	.05	1.30	.06
47	1-Methyl-2-ethylbenzene.....	.92	.26	.99	.21	.50	.09	.48	.09	.49	.10
48	Mesitylene..................	.88	.12	.94	.10	.46	-	.42	-	.42	-
49	1,2,4-Trimethylbenzene......	3.91	.31	4.12	.24	1.72	.02	1.58	-	1.59	-
50	sec-Butylbenzene, n-decane..	.72	.14	.77	.15	.58	.11	.42	.08	.39	.09
	*Total hydrocarbons by GC....	216.16		198.66		153.15		163.42		157.81	

* Includes exhaust hydrocarbons not reported in detailed analysis.

TABLE A-3. - Detailed Hydrocarbon Analysis Control Vehicle, ppmC--Continued

Peak No.	Accumulated mileage... / Fuel... / Compound	10,320 EPA CVS exhaust	10,320 EPA CVS exhaust with scrubber	11,725 EPA CVS exhaust	11,725 EPA CVS exhaust with scrubber	12,490 EPA CVS exhaust	12,490 EPA CVS exhaust with scrubber	13,840 EPA CVS exhaust	13,840 EPA CVS exhaust with scrubber
1	Methane......................	14.85	14.85	12.51	12.51	10.76	10.76	10.44	10.44
2	Ethylene.....................	16.92	-	16.09	-	15.96	-	14.82	-
3	Ethane.......................	1.35	1.35	1.37	1.37	1.40	1.40	1.25	1.25
4	Acetylene....................	21.98	-	17.75	-	15.60	-	16.21	-
5	Propylene, propane...........	7.90	.11	7.88	.19	7.26	.11	7.61	.12
6	Isobutane....................	.52	.08	.71	.11	-	.09	.80	.09
7	Butene-1, isobutylene........	3.95	-	3.88	-	3.95	-	3.76	-
8	n-Butane, 1,3-butadiene......	3.88	2.28	4.07	2.51	3.69	2.21	3.80	2.30
9	trans-2-Butene...............	.57	-	.64	-	.40	-	.65	-
10	cis-2-Butene.................	.71	-	.83	-	.54	-	.86	-
11	3-Methyl-1-butene............	.19	-	.27	-	.06	-	.34	-
12	Isopentane...................	3.60	3.60	4.38	4.38	3.43	3.43	4.26	4.26
13	Pentene-1....................	.19	-	.23	-	.15	-	.30	-
14	n-Pentane, 2-methyl-1-butene.	2.90	2.76	3.18	2.14	2.93	2.63	3.52	3.43
15	trans-2-Pentene..............	.30	-	.13	-	.25	-	.41	-
16	cis-2-Pentene................	.14	-	.04	-	.15	-	.24	-
17	2-Methyl-2-butene............	.39	-	.25	-	.40	-	.55	-
18	Cyclopentane, 3-methyl-1-pentene....................	5.30	5.12	6.31	4.04	5.27	5.02	6.77	6.39
19	2,3-Dimethylbutane...........	.38	.38	.32	.32	.35	.35	.63	.62
20	2-Methylpentane, 2,3-dimethyl-1-butene......	.43	.37	.31	.32	.37	.35	.96	.63
21	3-Methylpentane..............	.19	.18	.11	.16	.23	.14	.52	.34
22	1-Hexene, 2-ethyl-1-butene...	.15	-	.07	-	.19	-	.55	-
23	n-Hexane, cis-3-hexene.......	.13	.21	.17	.10	.18	.14	.35	.26
24	Methylcyclopentane, 3-methyltrans-2-pentene....	.20	.16	.24	.17	.21	.15	.50	.21
25	2,4-Dimethylpentane..........	.12	.13	.15	.13	.12	.12	.47	.19
26	Benzene, cyclohexane.........	5.43	.14	5.03	.04	5.00	.05	4.95	.04
27	Cyclohexene, 2,3-dimethylpentane, 2-methylhexane............	2.78	2.51	3.18	2.88	3.03	2.72	4.31	3.83
28	3-Methylhexane...............	.52	.47	.57	.52	.57	.50	.87	.70
29	Isooctane....................	5.17	5.17	5.85	5.85	5.71	5.71	8.12	8.12
30	n-Heptane....................	.74	.68	.79	.71	.84	.71	1.38	1.00
31	Methylcyclohexane............	.39	.35	.41	.36	.44	.36	.77	.51
32	2,4-Dimethylhexane, 2,5-dimethylhexane.........	.89	.87	.93	.93	.96	.84	1.26	1.21
33	2,3,4-Trimethylpentane.......	.43	.43	.47	.48	.52	.51	.68	.69
34	2,3,3-Trimethylpentane.......	.19	.18	.19	.19	.23	.23	.31	.31
35	Toluene, 2,3-dimethylhexane..	17.38	.23	17.59	.25	18.45	.32	20.30	.34
36	2-Methylheptane..............	1.89	.79	1.96	.86	2.00	1.09	2.84	1.21
37	3-Methylheptane..............	1.25	.83	1.29	.89	1.36	1.14	1.87	1.29
38	2,2,5-Trimethylhexane........	.11	.04	.12	.05	.12	.07	.18	.09
39	n-Octane.....................	.72	.59	.75	.63	.85	.81	1.05	.86
40	2,3,5-Trimethylhexane........	.03	.01	.03	.02	.04	.02	.03	.02
41	2,5-Dimethylheptane, 3,5-dimethylheptane........	.14	.18	.15	.16	.19	.22	.22	.22
42	Ethylbenzene.................	1.29	.10	1.27	.08	1.41	.11	1.48	.15
43	p-Xylene, m-xylene...........	4.36	.36	4.28	.33	4.77	.44	5.32	.43
44	o-Xylene.....................	2.08	.04	2.02	-	2.19	-	2.30	-
45	n-Propylbenzene..............	.11	-	.14	-	.17	-	.14	-
46	1-Methyl-3-ethylbenzene......	1.03	.24	1.10	.14	1.15	.17	1.23	.14
47	1-Methyl-2-ethylbenzene......	.41	.14	.42	.08	.45	.10	.47	.08
48	Mesitylene...................	.34	.14	.37	.09	.39	.11	.40	.09
49	1,2,4-Trimethylbenzene.......	1.43	-	1.45	-	1.55	-	1.45	-
50	sec-Butylbenzene, n-decane...	.28	.16	.34	.10	.39	.09	.33	.08
	*Total hydrocarbons by GC.....	147.32		143.09		138.63		157.41	

* Includes exhaust hydrocarbons not reported in detailed analysis.

TABLE A-4. - Detailed Hydrocarbon Analysis
Stationary Engine A, ppmC

Peak No.	Compound	1,080		2,080		2,930		4,950		5,000	
	Fuel	Indolene		Indolene		Indolene		Indolene		Indolene + AK33X	
		CVS exhaust	CVS exhaust with scrubber	CVS exhaust	CVS exhaust with scrubber	CVS exhaust	CVS exhaust with scrubber	CVS exhaust	CVS exhaust with scrubber	CVS exhaust	CVS exhaust with scrubber
1	Methane	9.28	9.28	7.68	7.68	6.83	6.83	7.53	7.53	6.58	6.58
2	Ethylene	10.56	-	11.07	-	10.20	-	11.07	-	10.44	-
3	Ethane	1.10	1.10	1.32	1.32	1.24	1.24	1.28	1.28	1.24	1.24
4	Acetylene	11.67	-	11.34	-	10.47	-	10.42	-	10.42	-
5	Propylene, propane	6.57	-	6.47	-	5.49	-	6.48	.07	6.97	.02
6	Isobutane	.93	.34	.43	.20	.31	.13	.76	.13	.33	.17
7	Butene-1, isobutylene	3.20	-	3.48	-	2.90	-	3.39	-	3.30	-
8	n-Butane, 1,3-butadiene	4.77	3.49	2.57	1.33	1.91	.92	2.43	1.18	3.21	1.99
9	trans-2-Butene	.71	-	.51	-	.40	-	.62	-	.47	-
10	cis-2-Butene	.72	-	1.01	-	.36	-	.68	-	.63	-
11	3-Methyl-1-butene	.18	-	.19	-	.10	-	.27	-	.14	-
12	Isopentane	4.15	4.24	1.63	1.63	1.10	1.10	1.53	1.53	2.45	2.45
13	Pentene-1	.17	-	.13	-	.06	-	.13	-	.12	-
14	n-Pentane, 2-methyl-1-butene	1.64	1.22	.85	.50	.56	.33	.74	.43	1.08	.67
15	trans-2-Pentene	.54	-	.48	-	.30	-	.32	-	.41	-
16	cis-2-Pentene	.24	-	.27	-	.09	-	.14	-	.20	-
17	2-Methyl-2-butene	.96	-	.69	-	.46	-	.64	-	.75	-
18	Cyclopentane, 3-methyl-1-pentene	.17	.08	.10	.05	.08	.02	.13	.03	.12	.05
19	2,3-Dimethylbutane	1.26	1.29	.51	.51	.39	.39	.53	.53	.77	.77
20	2-Methylpentane, 2,3-dimethyl-1-butene	1.35	1.26	.53	.53	.46	.40	.67	.53	.76	.75
21	3-Methylpentane	.75	.80	.37	.37	.25	.25	.40	.36	.49	.49
22	1-Hexene, 2-ethyl-1-butene	.16	-	.16	-	.09	-	.23	-	.12	-
23	n-Hexane, cis-3-hexene	.65	.72	.30	.29	.21	.20	.31	.26	.40	.36
24	Methylcyclopentane, 3-methyltrans-2-pentene	.62	.45	.26	.20	.23	.14	.34	.20	.43	.27
25	2,4-Dimethylpentane	1.21	1.14	.52	.53	.47	.38	.64	.51	.80	.69
26	Benzene, cyclohexane	4.70	.14	4.46	.09	3.97	.05	4.23	.06	4.32	.08
27	Cyclohexene, 2,3-dimethylpentane, 2-methylhexane	2.18	1.65	.87	.68	.83	.55	1.10	.76	1.28	1.06
28	3-Methylhexane	.82	.61	.29	.24	.27	.21	.36	.28	.45	.39
29	Isooctane	5.92	5.70	2.50	2.39	2.55	2.02	2.66	2.67	3.64	3.64
30	n-Heptane	.62	.47	.19	.16	.24	.16	.37	.21	.39	.34
31	Methylcyclohexane	.30	.23	.09	.08	.10	.07	.20	.11	.20	.17
32	2,4-Dimethylhexane, 2,5-dimethylhexane	1.67	1.67	.66	.67	.65	.64	.95	.95	1.03	1.01
33	2,3,4-Trimethylpentane	2.39	2.33	.95	.93	.76	.75	1.01	1.00	1.40	1.42
34	2,3,3-Trimethylpentane	2.70	2.68	1.07	1.05	.88	.88	1.21	1.21	1.61	1.61
35	Toluene, 2,3-dimethylhexane	16.96	.74	11.47	.28	10.46	.26	12.05	.32	13.00	.46
36	2-Methylheptane	1.47	.41	.67	.15	-	.15	-	.18	.95	.25
37	3-Methylheptane	.75	.28	.31	.07	.42	.12	.57	.12	.51	.18
38	2,2,5-Trimethylhexane	1.05	.87	.42	.34	.58	.31	.65	.37	.68	.50
39	n-Octane	.19	.15	.05	.06	.07	.05	.14	.06	.14	.10
40	2,3,5-Trimethylhexane	.11	.08	.03	.04	.03	.03	.11	.04	.09	.06
41	2,5-Dimethylheptane, 3,5-dimethylheptane	.07	.05	.02	.02	.02	.02	.12	.03	.07	.04
42	Ethylbenzene	1.31	.02	.96	-	.86	.01	1.08	.01	1.08	.01
43	p-Xylene, m-xylene	2.97	.06	2.07	.04	1.79	.03	2.16	.03	2.26	.05
44	o-Xylene	1.75	.07	1.48	.09	1.33	.02	1.56	.03	1.53	.04
45	n-Propylbenzene	.18	-	.12	-	.09	-	.18	-	.14	-
46	1-Methyl-3-ethylbenzene	.98	-	.70	-	.57	-	1.00	.02	1.04	.01
47	1-Methyl-2-ethylbenzene	.39	-	.27	.02	.24	.02	.35	.05	.31	.04
48	Mesitylene	.39	.07	.30	-	.28	.01	.50	.02	.31	.02
49	1,2,4-Trimethylbenzene	2.19	.13	1.48	.02	1.80	.03	2.17	.01	1.70	.04
50	sec-Butylbenzene, n-decane	-	-	.18	.03	-	.06	-	.02	.34	.03
	*Total hydrocarbons by GC	131.75		92.13		89.77		95.01		98.78	

* Includes exhaust hydrocarbons not reported in detailed analysis.

TABLE A-4. - Detailed Hydrocarbon Analysis
Stationary Engine A, ppmC--
Continued

	Accumulated mileage..	963		5,000		6,400		8,250		9,130	
	Fuel...............	EPA		EPA + F-310		EPA + F-310		EPA + F-310		EPA + F-310	
Peak No.	Compound	CVS exhaust	CVS exhaust with scrubber	CVS exhaust	CVS exhaust with scrubber	CVS exhaust	CVS exhaust with scrubber	CVS exhaust	CVS exhaust with scrubber	CVS exhaust	CVS exhaust with scrubber
1	Methane....................	7.23	7.23	7.85	7.85	7.49	7.49	7.77	7.77	7.09	7.09
2	Ethylene...................	11.46	-	14.57	-	10.99	-	11.47	-	11.84	-
3	Ethane.....................	.87	.87	1.18	1.18	.87	.87	.92	.92	.90	.90
4	Acetylene..................	10.65	-	12.07	-	9.95	-	10.97	-	10.48	-
5	Propylene, propane..........	5.00	.06	5.77	.26	4.36	.18	3.84	.04	5.22	.06
6	Isobutane..................	.64	.11	.33	.16	.22	.06	-	.04	-	.05
7	Butene-1, isobutylene.......	2.29	-	3.15	-	2.49	-	2.46	-	2.64	-
8	n-Butane, 1,3-butadiene.....	2.95	1.96	3.64	2.26	2.51	1.49	2.18	1.21	2.54	1.42
9	trans-2-Butene.............	.48	-	.43	-	.31	-	.22	-	.33	-
10	cis-2-Butene...............	.57	-	.51	-	.39	-	.36	-	.46	-
11	3-Methyl-1-butene..........	.19	-	.09	-	.07	-	.03	-	.07	-
12	Isopentane.................	3.02	3.02	3.43	3.43	2.44	2.44	1.99	1.99	2.29	2.29
13	Pentene-1..................	.14	-	.11	-	.08	-	.07	-	.08	-
14	n-Pentane, 2-methyl-1-butene	2.32	2.35	2.74	2.62	2.00	1.86	1.70	1.51	1.88	1.72
15	trans-2-Pentene............	.25	-	.24	-	.16	-	.14	-	.16	-
16	cis-2-Pentene..............	.11	-	.11	-	.07	-	.08	-	.07	-
17	2-Methyl-2-butene..........	.31	-	.34	-	.25	-	.23	-	.26	-
18	Cyclopentane, 3-methyl-1-pentene..................	4.14	4.16	5.10	4.30	3.63	3.36	3.08	2.70	3.35	2.95
19	2,3-Dimethylbutane..........	.34	.34	.35	.35	.25	.25	.20	.20	.24	.24
20	2-Methylpentane, 2,3-dimethyl-1-butene.....	.47	.33	.44	.37	.24	.24	.20	.19	.23	.23
21	3-Methylpentane............	.25	.17	.20	.24	.14	.09	.11	.08	.15	.10
22	1-Hexene, 2-ethyl-1-butene..	.25	-	.17	-	.12	-	.08	-	.12	-
23	n-Hexane, cis-3-hexene......	.16	.11	.15	.19	.09	.08	.10	.07	.10	.07
24	Methylcyclopentane, 3-methyltrans-2-pentene...	.23	.10	.24	.14	.15	.08	.11	.07	.12	.07
25	2,4-Dimethylpentane.........	.17	.08	.12	.11	.07	.07	.05	.05	.05	.06
26	Benzene, cyclohexane........	3.05	.01	4.29	.02	3.31	.04	3.31	.02	3.29	.02
27	Cyclohexene, 2,3-dimethylpentane, 2-methylhexane...........	2.01	1.89	2.55	2.23	1.87	1.80	1.53	1.33	1.71	1.48
28	3-Methylhexane.............	.36	.33	.47	.40	.39	.29	.28	.24	.34	.26
29	Isooctane..................	3.89	3.89	4.61	4.61	3.42	3.42	2.68	2.68	3.01	3.01
30	n-Heptane..................	.55	.49	.66	.59	.47	.39	.40	.34	.44	.38
31	Methylcyclohexane...........	.28	.22	.36	.29	.24	.20	.20	.17	.22	.19
32	2,4-Dimethylhexane, 2,5-dimethylhexane........	.59	.56	.79	.77	.53	.49	.39	.33	.45	.46
33	2,3,4-Trimethylpentane......	.29	.29	.40	.39	.26	.26	.21	.18	.22	.23
34	2,3,3-Trimethylpentane......	.15	.15	.22	.22	.11	.11	.08	.08	.09	.09
35	Toluene, 2,3-dimethylhexane.	10.11	.19	14.82	.26	11.11	.15	10.02	.11	10.61	.15
36	2-Methylheptane............	1.29	.51	1.70	.76	1.21	.45	1.00	.32	1.09	.41
37	3-Methylheptane............	.83	.54	1.14	.81	.76	.46	.62	.33	.68	.41
38	2,2,5-Trimethylhexane.......	.08	.04	.13	.07	.07	.03	.06	.02	.06	.04
39	n-Octane...................	.43	.45	.70	.67	.40	.31	.30	.25	.35	.29
40	2,3 5-Trimethylhexane.......	.04	.02	.05	.07	-	-	.01	.01	.01	.01
41	2,5-Dimethylheptane, 3,5-dimethylheptane.......	.12	.07	.21	.26	.08	.09	.06	.09	.06	.09
42	Ethylbenzene...............	.74	.04	1.20	.40	.82	.03	.72	.03	.78	.07
43	p-Xylene, m-xylene..........	2.27	.16	3.65	.32	2.67	.17	2.26	.11	2.39	.17
44	o-Xylene...................	1.24	-	2.00	-	1.34	-	1.20	-	1.33	-
45	n-Propylbenzene............	.10	-	.18	-	.07	-	.12	-	.17	-
46	1-Methyl-3-ethylbenzene.....	.56	.02	.95	.05	.67	.07	.57	.04	.67	.06
47	1-Methyl-2-ethylbenzene.....	.22	.03	.41	.07	.26	.04	.25	.02	.30	.03
48	Mesitylene.................	.19	-	.39	-	.22	.04	.21	.02	.26	.03
49	1,2,4-Trimethylbenzene......	1.12	-	1.77	-	1.03	.01	.96	-	1.09	-
50	sec-Butylbenzene, n-decane..	.32	.06	.51	.09	.32	.06	.39	.03	.42	.04
	*Total hydrocarbons by GC....	92.51		126.82		89.54		82.53		89.43	

* Includes exhaust hydrocarbons not reported in detailed analysis.

TABLE A-4. - Detailed Hydrocarbon Analysis Stationary Engine A, ppmC-- Continued

Peak No.	Accumulated mileage... / Fuel... / Compound	6,090 Indolene + AK33X CVS exhaust	6,090 Indolene + AK33X CVS exhaust with scrubber	8,180 Indolene + AK33X CVS exhaust	8,180 Indolene + AK33X CVS exhaust with scrubber	9,140 Indolene + AK33X CVS exhaust	9,140 Indolene + AK33X CVS exhaust with scrubber	10,040 Indolene + AK33X CVS exhaust	10,040 Indolene + AK33X CVS exhaust with scrubber	10,060 Indolene + AK33X CVS exhaust	10,060 Indolene + AK33X CVS exhaust with scrubber
1	Methane	9.50	9.50	9.00	9.00	8.61	8.61	8.66	8.66	7.37	7.37
2	Ethylene	14.82	-	13.85	-	12.25	-	12.88	-	14.44	-
3	Ethane	1.85	1.85	1.87	1.87	1.46	1.38	1.43	1.43	1.76	1.76
4	Acetylene	15.70	-	14.24	-	13.04	-	13.85	-	12.73	-
5	Propylene, propane	8.67	.05	8.18	.05	7.45	.19	6.72	.22	8.00	.18
6	Isobutane	1.10	.17	1.01	.18	1.14	.40	.63	.48	.80	.19
7	Butene-1, isobutylene	4.09	-	3.80	-	3.68	-	3.74	-	4.25	-
8	n-Butane, 1,3-butadiene	3.34	1.79	3.48	1.58	5.63	4.06	5.12	3.47	3.58	1.86
9	trans-2-Butene	.78	-	.79	-	.85	-	.70	-	.74	-
10	cis-2-Butene	1.04	-	1.00	-	.99	-	.94	-	.90	-
11	3-Methyl-1-butene	.30	-	.30	-	.37	-	.29	-	.34	-
12	Isopentane	2.18	2.18	2.06	2.06	5.36	5.36	4.75	4.75	2.50	2.50
13	Pentene-1	.19	-	.08	-	.29	-	.22	-	.15	-
14	n-Pentane, 2-methyl-1-butene	1.02	.59	.93	.61	2.20	1.67	1.98	1.56	1.15	.68
15	trans-2-Pentene	.42	-	.36	-	.76	-	.74	-	.47	-
16	cis-2-Pentene	.21	-	.14	-	.35	-	.39	-	.20	-
17	2-Methyl-2-butene	.75	-	.68	-	1.27	-	1.26	-	.83	-
18	Cyclopentane, 3-methyl-1-pentene	.18	.05	.08	.05	.22	.14	.22	.16	.17	.05
19	2,3-Dimethylbutane	.69	.69	.66	.66	1.71	1.71	1.53	1.53	.85	.85
20	2-Methylpentane, 2,3-dimethyl-1-butene	.82	.70	.68	.65	1.83	1.69	1.66	1.55	.81	.82
21	3-Methylpentane	.46	.45	.39	.40	1.03	1.15	.92	1.09	.56	.53
22	1-Hexene, 2-ethyl-1-butene	.15	-	.08	-	.27	-	.22	-	.23	-
23	n-Hexane, cis-3-hexene	.35	.34	.34	.32	.88	1.04	.75	.92	.44	.41
24	Methylcyclopentane, 3-methyltrans-2-pentene	.35	.24	.34	.23	.86	.72	.74	.60	.34	.29
25	2,4-Dimethylpentane	.68	.63	.71	.62	1.71	1.79	1.50	1.46	.91	.78
26	Benzene, cyclohexane	5.49	.08	5.38	.09	5.07	.29	5.30	.22	5.01	.10
27	Cyclohexene, 2,3-dimethylpentane, 2-methylhexane	1.28	.98	1.22	1.00	2.79	2.48	2.48	2.10	1.54	1.17
28	3-Methylhexane	.44	.37	.51	.37	.95	.94	.83	.77	.50	.43
29	Isooctane	3.53	3.53	3.56	3.44	8.09	8.09	7.09	7.09	4.20	4.20
30	n-Heptane	.40	.31	.34	.30	.97	.82	.71	.57	.58	.35
31	Methylcyclohexane	.20	.15	.19	.15	.50	.43	.35	.29	.28	.18
32	2,4-Dimethylhexane, 2,5-dimethylhexane	.95	.91	.93	.99	2.42	2.53	2.07	2.14	1.25	1.22
33	2,3,4-Trimethylpentane	1.20	1.28	1.28	1.27	3.39	3.31	2.96	2.94	1.62	1.64
34	2,3,3-Trimethylpentane	1.37	1.37	1.49	1.49	3.92	3.92	3.37	3.37	1.91	1.91
35	Toluene, 2,3-dimethylhexane	15.22	.44	14.78	.45	21.44	1.15	20.57	.95	16.67	.56
36	2-Methylheptane	-	.23	.92	.25	2.09	.67	1.56	.52	-	.30
37	3-Methylheptane	.60	.18	.41	.21	1.09	.64	.74	.40	.64	.24
38	2,2,5-Trimethylhexane	.86	.48	.69	.52	1.56	1.30	1.21	1.04	.97	.63
39	n-Octane	.14	.11	.10	.11	.32	.32	.23	.21	.17	.10
40	2,3,5-Trimethylhexane	.09	.05	.04	.06	.20	.18	.12	.12	.12	.07
41	2,5-Dimethylheptane, 3,5-dimethylheptane	.07	.04	.04	.05	.11	.19	.08	.08	.10	.05
42	Ethylbenzene	1.24	.01	1.31	.03	1.65	.11	1.60	.04	1.46	.02
43	p-Xylene, m-xylene	2.59	.05	2.69	.07	3.80	.17	3.58	.09	2.78	.06
44	o-Xylene	1.84	.06	1.95	.12	2.28	.26	2.23	.10	2.05	.06
45	n-Propylbenzene	.14	-	.17	-	.31	-	.28	-	.28	-
46	1-Methyl-3-ethylbenzene	1.09	.01	.89	.01	1.35	.03	1.91	.02	1.47	.01
47	1-Methyl-2-ethylbenzene	.36	.04	.34	.05	.59	.18	.55	.13	.48	.06
48	Mesitylene	.36	.01	.36	.02	.61	.09	.58	.05	.49	.01
49	1,2,4-Trimethylbenzene	2.18	.03	2.00	.08	2.92	.21	2.67	.10	3.31	.05
50	sec-Butylbenzene, n-decane	-	.03	-	.04	.61	.15	.49	.06	-	.03
	*Total hydrocarbons by GC	120.24		115.23		158.19		147.40		125.67	

* Includes exhaust hydrocarbons not reported in detailed analysis.

TABLE A-5. - Detailed Hydrocarbon Analysis
Stationary Engine B, ppmC

Peak No.	Compound	CVS exhaust	CVS exhaust with scrubber	CVS exhaust	CVS exhaust with scrubber	CVS exhaust	CVS exhaust with scrubber	CVS exhaust	CVS exhaust with scrubber	CVS exhaust	CVS exhaust with scrubber
	Accumulated mileage..	4,000		4,930		6,164		8,515		4,350	
	Fuel..............	Indolene + AK33X		Indolene + AK33X		Indolene + AK33X		EPA + AK33X		EPA + F-310	
1	Methane....................	7.11	7.11	9.70	9.70	11.24	-	8.03	8.03	10.36	10.36
2	Ethylene...................	11.28	-	13.03	-	15.47	-	20.34	-	15.08	-
3	Ethane.....................	1.18	1.18	1.46	1.46	1.81	-	1.60	1.60	1.05	1.05
4	Acetylene..................	10.39	-	12.28	-	15.42	-	11.97	-	15.14	-
5	Propylene, propane..........	6.70	.07	9.06	.10	10.38	-	9.03	.71	7.18	.07
6	Isobutane..................	.40	.18	.92	.17	1.03	-	.66	.45	.65	.10
7	Butene-1, isobutylene.......	3.76	-	4.71	-	4.97	-	5.32	-	3.86	-
8	n-Butane, 1,3-butadiene.....	3.26	1.85	3.54	1.80	3.46	-	5.59	3.43	4.05	2.52
9	trans-2-Butene.............	.59	-	.89	-	.74	-	.75	-	.56	-
10	cis-2-Butene...............	.72	-	1.23	-	-	-	.97	-	.67	-
11	3-Methyl-1-butene..........	.22	-	.37	-	.23	-	.26	-	.19	-
12	Isopentane.................	2.52	2.52	2.71	2.71	2.43	-	5.23	5.23	3.90	3.90
13	Pentene-1..................	.13	-	.25	-	.09	-	.20	-	.18	-
14	n-Pentane, 2-methyl-1-butene	1.17	.73	1.33	.88	1.15	-	4.24	4.08	3.14	2.92
15	trans-2-Pentene............	.46	-	.57	-	.44	-	.42	-	.29	-
16	cis-2-Pentene..............	.20	-	.28	-	.16	-	.22	-	.15	-
17	2-Methyl-2-butene..........	.86	-	1.02	-	.89	-	.65	-	.47	-
18	Cyclopentane, 3-methyl-1-pentene..................	.15	.06	.22	.10	.12	-	7.50	6.06	5.63	5.45
19	2,3-Dimethylbutane..........	.85	.85	.94	.94	.86	-	.57	.57	.45	.45
20	2-Methylpentane, 2,3-dimethyl-1-butene.....	.82	.81	1.17	.97	.91	-	.56	.65	.43	.42
21	3-Methylpentane............	.53	.47	.66	.68	.51	-	.43	.49	.31	.20
22	1-Hexene, 2-ethyl-1-butene..	.15	-	.25	-	.09	-	.39	-	.29	-
23	n-Hexane, cis-3-hexene......	.43	.42	.51	.61	.45	-	.29	.43	.20	.14
24	Methylcyclopentane, 3-methyltrans-2-pentene...	.44	.30	.54	.40	.46	-	.38	.18	.27	.16
25	2,4-Dimethylpentane.........	.88	.79	1.06	1.04	.91	-	.27	.15	.17	.12
26	Benzene, cyclohexane........	4.89	.10	5.80	.24	6.41	-	4.96	.05	4.49	.03
27	Cyclohexene, 2,3-dimethylpentane, 2-methylhexane...........	1.59	1.21	1.68	1.40	1.70	-	3.88	3.31	2.87	2.40
28	3-Methylhexane.............	.54	.45	.58	.53	.66	-	.73	.63	.54	.44
29	Isooctane..................	4.34	4.34	4.86	4.86	5.09	-	7.26	7.26	4.90	4.90
30	n-Heptane..................	.46	.37	.45	.50	.47	-	1.03	.89	.89	.63
31	Methylcyclohexane...........	.24	.17	.21	.25	.22	-	.53	.44	.46	.32
32	2,4-Dimethylhexane, 2,5-dimethylhexane........	1.40	1.44	1.62	1.65	1.57	-	1.22	1.16	.89	.75
33	2,3,4-Trimethylpentane......	1.70	1.67	1.98	1.95	2.01	-	.62	.60	.43	.41
34	2,3,3-Trimethylpentane......	1.96	1.96	2.23	2.23	2.24	-	.31	.31	.23	.23
35	Toluene, 2,3-dimethylhexane.	15.70	.56	19.16	.65	22.42	-	22.29	.36	16.50	.31
36	2-Methylheptane............	1.11	.32	1.32	.37	-	-	2.46	1.20	2.06	.94
37	3-Methylheptane............	.55	.26	.64	.30	.78	-	1.65	1.24	1.34	.92
38	2,2,5-Trimethylhexane.......	.78	.65	.93	.76	1.06	-	.16	.08	.16	.07
39	n-Octane...................	.16	.14	.16	.21	.17	-	.93	.81	.75	.69
40	2,3,5-Trimethylhexane.......	.09	.11	.08	.10	.08	-	.05	.02	.06	.03
41	2,5-Dimethylheptane, 3,5-dimethylheptane.......	.05	.11	.06	.07	.05	-	.23	.23	.19	.19
42	Ethylbenzene...............	1.25	.02	1.59	.03	1.75	-	1.72	.11	1.32	.18
43	p-Xylene, m-xylene..........	2.83	.06	3.75	.08	4.08	-	5.28	.44	4.24	.40
44	o-Xylene...................	1.85	.05	2.30	.07	2.64	-	2.68	-	2.18	-
45	n-Propylbenzene............	1.18	-	.29	-	.24	-	.16	-	.22	-
46	1-Methyl-3-ethylbenzene.....	1.33	.01	1.87	.02	1.47	-	1.36	.17	1.23	.26
47	1-Methyl-2-ethylbenzene.....	.40	.05	.60	.12	.59	-	.49	.10	.48	.15
48	Mesitylene.................	.40	.01	.57	.05	.56	-	.41	.11	.42	.11
49	1,2,4-Trimethylbenzene......	2.21	.04	2.85	.13	3.26	-	1.93	-	1.75	-
50	sec-Butylbenzene, n-decane..	.39	.03	.50	.10	.48	-	.42	.11	.56	.18
	*Total hydrocarbons by GC....	116.98		137.23		144.58		163.93		138.36	

* Includes exhaust hydrocarbons not reported in detailed analysis.

TABLE A-5. - Detailed Hydrocarbon Analysis
Stationary Engine B, ppmC--
Continued

Peak No.	Compound	5,540		6,125		7,070		7,930	
	Accumulated mileage..	5,540		6,125		7,070		7,930	
	Fuel...............	EPA + F-310		EPA + F-310		EPA + F-310		EPA + F-310	
		CVS exhaust	CVS exhaust with scrubber	CVS exhaust	CVS exhaust with scrubber	CVS exhaust	CVS exhaust with scrubber	CVS exhaust	CVS exhaust with scrubber
1	Methane.......................	11.36	11.36	8.31	8.31	7.25	7.25	7.39	7.39
2	Ethylene......................	14.14	-	11.85	-	11.87	-	11.75	-
3	Ethane........................	.99	.99	.77	.77	.75	.75	.64	.64
4	Acetylene.....................	15.77	-	11.41	-	9.94	-	9.89	-
5	Propylene, propane...........	6.91	.07	5.68	.06	4.39	.06	5.85	.07
6	Isobutane.....................	.78	.09	.89	.21	.16	.06	.66	.07
7	Butene-1, isobutylene.........	3.63	-	3.00	-	2.80	-	3.15	-
8	n-Butane, 1,3-butadiene.......	3.47	1.92	5.67	4.37	2.12	1.13	2.65	1.38
9	trans-2-Butene................	.63	-	.56	-	.33	-	.52	-
10	cis-2-Butene..................	.81	-	.69	-	.21	-	.68	-
11	3-Methyl-1-butene............	.33	-	.22	-	.04	-	.21	-
12	Isopentane....................	3.27	3.27	4.31	4.31	1.95	1.95	2.48	2.48
13	Pentene-1.....................	.12	-	.11	-	.10	-	.11	-
14	n-Pentane, 2-methyl-1-butene..	2.67	2.53	3.14	3.00	1.62	1.52	2.08	1.92
15	trans-2-Pentene..............	.25	-	.25	-	.18	-	.19	-
16	cis-2-Pentene................	.12	-	.12	-	.08	-	.09	-
17	2-Methyl-2-butene............	.36	-	.36	-	.25	-	.32	-
18	Cyclopentane, 3-methyl-1-pentene.....................	5.01	4.61	5.22	4.41	3.16	3.10	3.81	3.38
19	2,3-Dimethylbutane............	.38	.38	.37	.37	.26	.26	.31	.31
20	2-Methylpentane, 2,3-dimethyl-1-butene.......	.49	.39	.45	.37	.37	.25	.31	.32
21	3-Methylpentane..............	.22	.18	.21	.18	.18	.10	.25	.18
22	1-Hexene, 2-ethyl-1-butene....	.19	-	.15	-	.17	-	.23	-
23	n-Hexane, cis-3-hexene........	.16	.12	.14	.12	.12	.08	.17	.17
24	Methylcyclopentane, 3-methyltrans-2-pentene.....	.23	.12	.20	.10	.16	.09	.21	.14
25	2,4-Dimethylpentane..........	.14	.10	.11	.09	.09	.07	.13	.15
26	Benzene, cyclohexane.........	4.25	.04	3.43	.02	2.87	.02	3.10	.05
27	Cyclohexene, 2-3-dimethylpentane, 2-methylhexane.............	2.59	2.39	2.37	2.20	1.84	1.59	2.06	1.88
28	3-Methylhexane...............	.47	.43	.43	.39	.33	.28	.37	.35
29	Isooctane....................	4.82	4.82	4.43	4.43	3.25	3.25	3.82	3.82
30	n-Heptane....................	.74	.59	.65	.54	.57	.39	.58	.45
31	Methylcyclohexane............	.39	.30	.35	.30	.32	.21	.29	.23
32	2,4-Dimethylhexane, 2,5-dimethylhexane.........	.76	.76	.71	.68	.53	.49	.61	.56
33	2,3,4-Trimethylpentane.......	.38	.38	.36	.35	.26	.26	.31	.31
34	2,3,3-Trimethylpentane.......	.19	.19	.18	.18	.12	.12	.15	.15
35	Toluene, 2,3-dimethylhexane...	15.00	.22	13.36	.20	10.74	.14	11.68	.18
36	2-Methylheptane..............	1.88	.77	1.64	.69	1.49	.54	1.51	.65
37	3-Methylheptane..............	1.19	.81	1.06	.69	.89	.53	.95	.63
38	2,2,5-Trimethylhexane........	.13	.05	.12	.03	.10	.03	.11	.05
39	n-Octane.....................	.64	.57	.53	.48	.35	.32	.49	.43
40	2,3,5-Trimethylhexane........	.03	.02	-	-	-	-	.02	-
41	2,5-Dimethylheptane, 3,5-dimethylheptane.........	.13	.17	.10	.10	.07	.07	.10	.10
42	Ethylbenzene.................	1.14	.10	1.00	.06	.80	.03	.85	.05
43	p-Xylene, m-xylene...........	3.86	.34	3.45	.23	2.65	.15	2.85	.21
44	o-Xylene.....................	1.92	-	1.67	-	1.40	-	1.43	-
45	n-Propylbenzene..............	.14	-	.10	-	.07	-	.12	-
46	1-Methyl-3-ethylbenzene.......	1.04	.27	.93	.09	.67	.06	.77	.12
47	1-Methyl-2-ethylbenzene.......	.40	.08	.35	.05	.26	.03	.30	.07
48	Mesitylene...................	.35	.12	.32	.06	.23	.03	.29	.09
49	1,2,4-Trimethylbenzene........	1.42	.06	1.34	-	1.15	-	1.64	-
50	sec-Butylbenzene, n-decane....	.39	.13	.36	.05	.18	.05	.52	.10
	*Total hydrocarbons by GC......	126.48		112.15		88.10		97.76	

* Includes exhaust hydrocarbons not reported in detailed analysis.

TABLE A-6. - Effect of mileage accumulation on exhaust emissions
Stationary Engine A

Miles	Test temp., °F	Barometric pressure, mmHg	Fuel consumed, lbs/test	Emissions, grams/mile							MCMT percent emitted
				CO	HC	NO_x, uncorrected	NO_x, FTP corrected	Total aldehydes	MCMT x 10^6	Inorganic Mn x 10^6	
CLEAR FUEL											
0	100	750.5	4.30	22.0	2.18	2.34	3.42	-	-	-	-
1,080	76	755.6	4.23	23.5	1.97	2.53	2.83	-	-	-	-
1,400	85	741.5	4.05	23.4	1.39	2.47	3.12	-	-	-	-
2,080	91	749.7	4.17	22.5	1.51	2.35	3.18	-	-	-	-
2,930	83	745.5	4.21	18.6	1.24	2.53	3.38	-	-	-	-
3,900	90	742.5	4.29	17.9	-	2.59	3.66	-	-	-	-
4,950	86	743.3	4.11	17.5	1.29	2.45	2.86	-	0.00	-	0.000
CHANGE TO FUEL CONTAINING AK33X ADDITIVE - 0.125 gMn/GAL											
5,000	85	744.3	4.23	21.6	1.62	2.51	2.73	0.074	0.00	992	0.000
6,090	95	740.0	4.34	22.6	1.85	2.72	4.02	.074	.00	1,747	.000
8,180	83	745.0	4.80	18.9	1.80	2.70	3.14	.103	.37	2,127	.003
9,140	77	747.8	4.30	16.1	2.50	2.93	3.07	.125	2.46	2,527	.021
10,040	84	742.7	4.14	15.9	2.72	2.78	3.79	.148	2.99	1,691	.027
NEW SPARK PLUGS INSTALLED											
1,006	84	747.6	4.16	15.0	2.11	3.00	3.74	0.146	1.02	1,111	0.009
NEW TEST CYCLE											
0	88	741.1	4.61	26.3	1.64	2.05	2.48	-	-	-	-
963	84	744.0	4.25	19.8	1.39	2.01	2.79	-	-	-	-
1,120	85	743.1	4.47	17.7	1.41	2.28	2.32	-	-	-	-
2,930	80	743.2	3.85	27.2	1.86	2.09	2.76	-	-	-	-
4,012	76	751.9	4.07	27.6	1.84	2.66	2.65	-	-	-	-
4,940	94	746.4	3.73	23.6	1.86	2.27	2.97	-	-	-	-
CHANGE TO FUEL CONTAINING F-310 ADDITIVE - 14.2 ML/GAL											
5,000	82	748.2	4.02	21.0	1.79	2.52	3.12	0.108	-	-	-
6,400	60	740.0	4.23	29.3	1.50	2.56	2.18	.052	-	-	-
8,250	68	744.2	4.20	27.4	1.50	3.00	2.61	.071	-	-	-
9,130	75	757.0	4.07	24.9	1.44	2.76	2.56	.101	-	-	-

TABLE A-7. - Effect of mileage accumulation on exhaust emissions
Stationary Engine B

Miles	Test temp., °F	Barometric pressure mmHg	Fuel consumed, lbs/test	Emissions, grams/mile							MCMT percent emitted
				CO	HC	NO_x, uncorrected	NO_x, FTP corrected	Total aldehydes	MCMT x 10^6	Inorganic Mn x 10^6	
					CLEAR FUEL						
0	80	747.1	2.96	18.2	1.37	1.56	1.79	-	-	-	-
1,240	90	749.6	4.65	16.1	1.59	2.42	2.75	-	-	-	-
2,030	93	749.9	4.04	16.5	1.62	1.97	2.45	-	-	-	-
3,990	78	746.4	4.44	20.5	1.79	2.33	2.86	-	-	-	-
				CHANGE TO FUEL CONTAINING AK33X ADDITIVE - 0.125 gMn/GAL							
4,000	85	755.0	4.56	23.0	1.82	2.67	3.57	0.109	Trace	1,031	Trace
4,930	75	754.0	4.07	35.0	2.17	2.50	2.59	.164	<0.50	1,267	<0.005
5,870	74	747.8	4.29	25.5	1.85	2.79	2.77	.130	.35	1,746	.003
8,515	80	746.0	4.96	24.9	2.52	2.80	2.89	.130	.58	608	.004
9,085	71	745.3	4.79	36.7	2.98	3.29	3.09	-	.87	2,266	.008
					NEW TEST CYCLE						
0	76	740.0	4.89	25.1	1.68	2.64	2.61	-	-	-	-
1,420	66	744.2	4.88	38.4	1.98	3.72	3.27	-	-	-	-
2,840	71	740.5	4.92	33.8	2.15	3.49	3.59	-	-	-	-
3,650	74	748.7	5.08	38.9	2.09	4.15	3.84	-	-	-	-
4,050	78	739.0	5.04	34.8	1.73	3.64	4.27	-	-	-	-
				CHANGE TO FUEL CONTAINING F-310 ADDITIVE - 14.2 ML/GAL							
4,350	78	739.1	4.89	32.8	1.81	3.82	4.36	0.091	-	-	-
5,540	70	743.3	4.91	45.3	1.77	3.96	3.87	.089	-	-	-
6,125	76	749.3	4.98	38.6	1.66	4.45	4.08	.094	-	-	-
7,070	71	741.4	5.24	34.1	1.55	3.99	4.00	.103	-	-	-
7,930	80	755.7	5.39	43.0	1.66	4.82	4.10	.092	-	-	-

TABLE A-8. - Effect of mileage accumulation on exhaust emissions
F-310 Vehicle

Miles	Test temp., °F	Barometric pressure mmHg	Fuel consumed, lbs/test	Emissions, grams/mile								MCMT percent emitted
				CO	HC	NO_x, uncorrected	NO_x, FTP corrected	Total aldehydes	MCMT x 10^6	Inorganic Mn x 10^6		
					CLEAR FUEL							
0	72	748.2	4.60	59.5	2.76	4.78	4.55	-	-	-		-
1,710	67	745.0	3.46	69.6	2.96	5.46	5.08	-	-	-		-
2,743	83	745.9	4.61	65.5	2.62	4.40	5.33	-	-	-		-
4,030	82	748.8	4.92	65.6	2.51	3.86	5.06	-	-	-		-
4,700	93	741.6	4.62	62.1	2.77	4.44	5.81	-	-	-		-
					CHANGE TO FUEL CONTAINING F-310 ADDITIVE - 14.2 ML/GAL							
4,750	81	745.9	4.77	64.7	3.11	4.00	4.91	0.086	-	-		-
6,070	86	742.5	4.92	75.8	2.85	4.02	6.51	.093	-	-		-
7,420	94	749.6	4.98	62.2	2.41	4.40	6.45	.065	-	-		-
8,550	79	743.2	4.77	58.0	2.39	4.43	5.58	.089	-	-		-
9,150	80	742.2	4.43	63.4	2.73	3.60	4.57	.072	-	-		-
9,550	84	740.0	4.62	63.2	2.66	3.59	4.99	.077	-	-		-
10,550	76	744.0	4.66	66.5	2.66	3.81	4.60	.090	-	-		-
11,880	66	751.1	4.70	52.7	2.58	5.03	5.63	.105	-	-		-
12,840	66	737.9	4.70	45.7	2.53	5.63	5.25	.054	-	-		-
13,940	66	744.0	4.67	49.7	2.53	5.48	5.00	.086	-	-		-

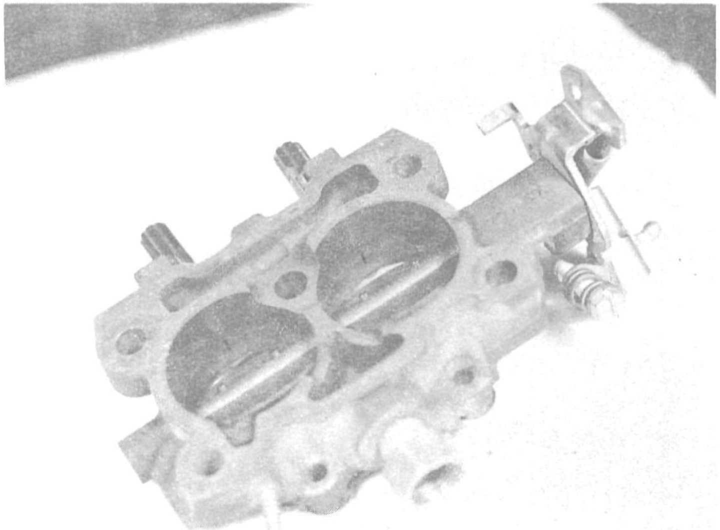
TABLE A-9. - Effect of mileage accumulation on exhaust emissions AK33X Vehicle

Miles	Test temp., °F	Barometric pressure mmHg	Fuel consumed, lbs/test	Emissions, grams/mile							MCMT percent emitted
				CO	HC	NO_x, uncorrected	NO_x, FTP corrected	Total aldehydes	MCMT x 10^6	Inorganic Mn x 10^6	
CLEAR FUEL											
0	86	741.1	5.07	74.4	3.09	4.34	4.85	-	-	-	-
1,600	80	744.5	4.94	74.4	3.43	5.65	5.96	-	-	-	-
1,910	77	739.0	4.74	79.5	3.72	4.68	4.93	-	-	-	-
3,190	83	745.9	4.58	59.3	2.89	4.89	5.93	-	-	-	-
4,010	80	747.7	5.24	78.3	2.80	4.51	6.09	-	-	-	-
4,700	90	748.0	4.16	63.5	2.92	3.97	5.16	-	-	-	-
CHANGE TO FUEL CONTAINING AK33X ADDITIVE - 0.125 gMn/GAL											
4,740	90	750.0	4.86	61.9	3.02	4.03	5.88	0.088	-	915	-
5,305	80	746.6	4.35	57.4	2.98	4.57	5.48	-	1.86	1,857	0.016
7,170	87	744.4	4.89	79.2	2.87	4.54	5.77	.089	0.80	905	.006
8,030	81	744.1	4.89	57.8	3.69	4.43	5.68	.109	4.97	1,440	.037
9,434	60	752.0	5.02	69.7	4.29	5.53	5.04	.105	4.63	846	.042
10,353	70	744.0	4.96	70.3	3.97	4.70	5.00	.126	1.29	800	.010
11,390	62	750.4	4.66	56.3	3.52	5.45	5.45	.096	.82	1,452	.007
12,140	55	740.3	4.72	58.8	3.47	5.59	5.59	.096	1.70	500	.013
12,740	76	742.5	4.56	51.8	3.63	4.84	5.31	.085	2.98	1,471	.024
14,050	63	755.5	5.00	56.4	3.52	6.22	5.53	.093	1.44	1,095	.011

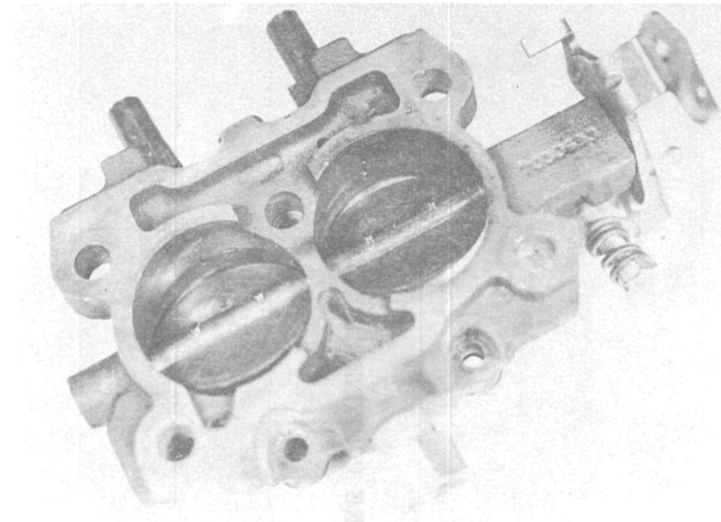
TABLE A-10.- Effect of mileage accumulation on exhaust emissions
Control Vehicle

Miles	Test temp., °F	Barometric pressure mmHg	Fuel consumed, lbs/test	Emissions, grams/mile							MCMT percent emitted
				CO	HC	NO_x, uncorrected	NO_x, FTP corrected	Total aldehydes	MCMT x 10^6	Inorganic Mn x 10^6	
CLEAR FUEL											
0	65	748.6	4.76	46.7	2.92	5.18	4.62	-	-	-	-
1,400	67	745.0	4.59	48.3	2.65	5.28	4.78	-	-	-	-
2,250	83	745.9	4.68	59.2	2.81	4.27	5.18	-	-	-	-
3,200	85	748.8	5.03	66.6	2.69	4.51	5.97	-	-	-	-
4,550	95	748.4	4.89	63.6	2.78	3.70	5.60	-	-	-	-
5,950	85	747.8	4.73	65.7	2.99	4.52	6.80	0.103	-	-	-
7,700	92	746.0	5.00	82.7	2.07	4.28	5.97	.093	-	-	-
8,725	84	744.1	4.77	67.3	2.64	3.91	5.65	.083	-	-	-
9,865	80	742.5	4.34	70.2	2.65	4.23	5.01	.069	-	-	-
10,320	70	744.6	4.27	63.3	2.43	4.08	4.39	.086	-	-	-
11,200	89	740.2	5.03	80.2	2.96	4.17	6.47	.092	-	-	-
11,725	74	748.0	4.41	57.8	2.30	4.78	4.86	.096	-	-	-
12,490	60	740.3	4.63	52.9	2.00	5.12	5.29	-	-	-	-
13,490	82	737.5	4.57	59.8	2.28	4.28	5.03	-	-	-	-
13,840	65	740.0	4.50	53.0	2.47	5.32	4.85	.066	-	-	-

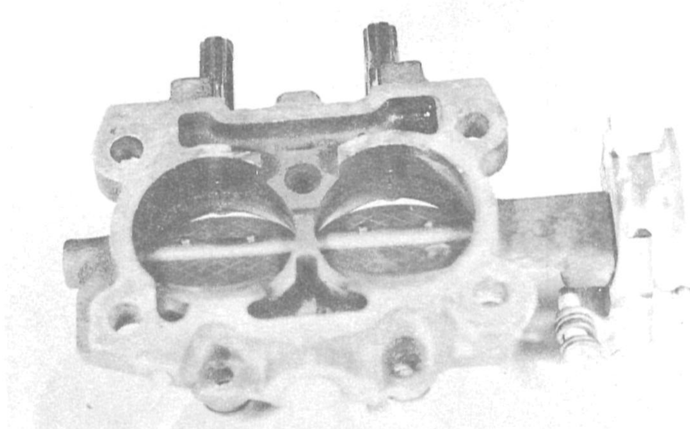
APPENDIX B.--PHOTOGRAPHS OF ENGINE COMPONENTS



AK33X vehicle

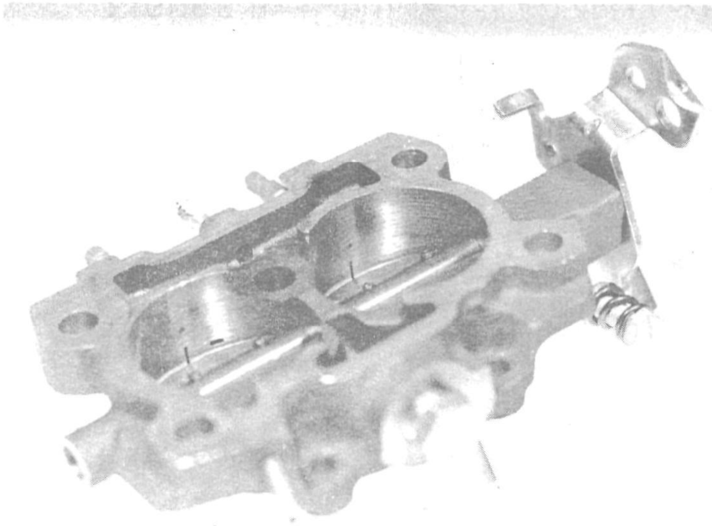


F310 vehicle

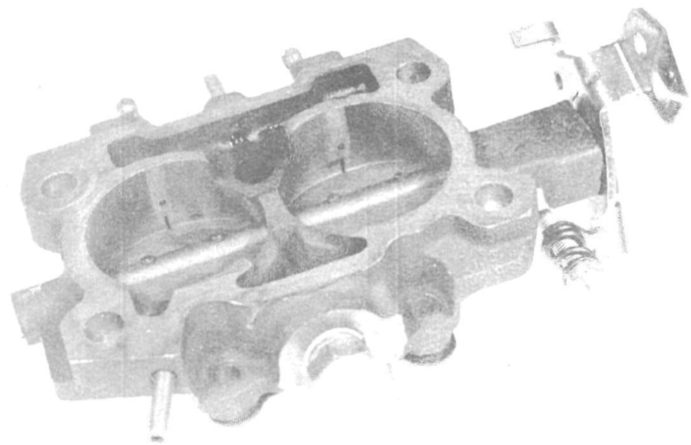


Control vehicle

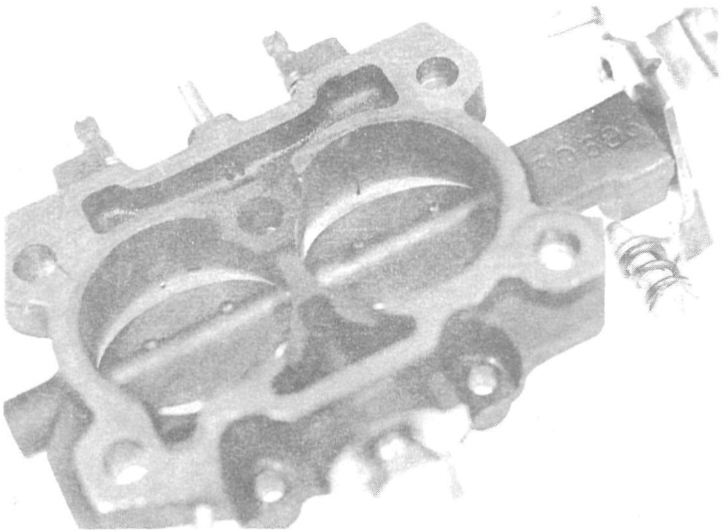
FIGURE B-1.-Carburetor bases for the AK33X, F310, and control vehicles.



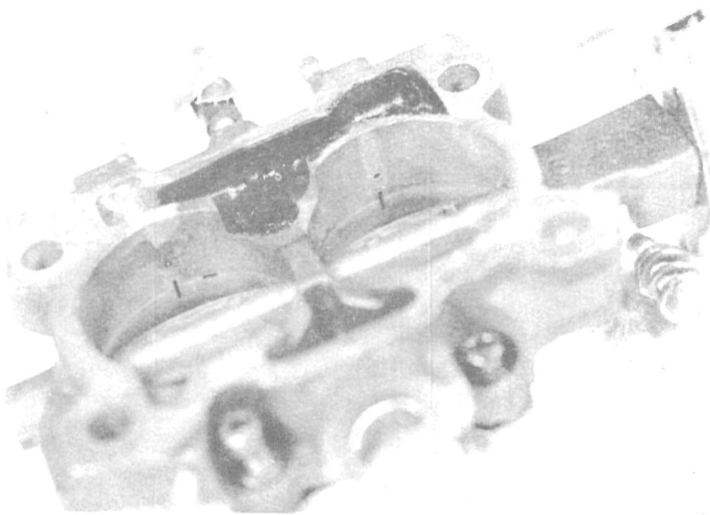
AK33X engine A



AK33X engine B

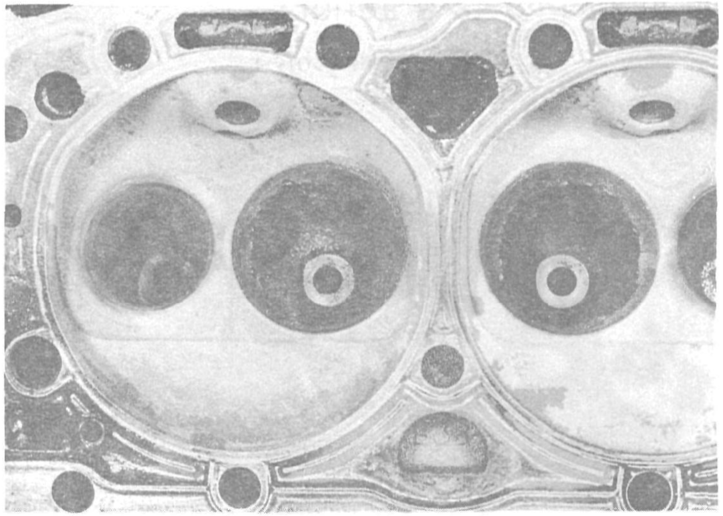


F310 engine A

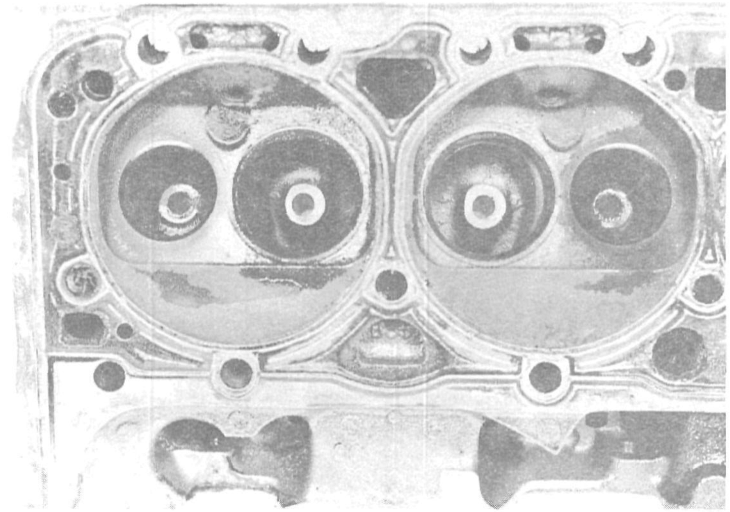


F310 engine B

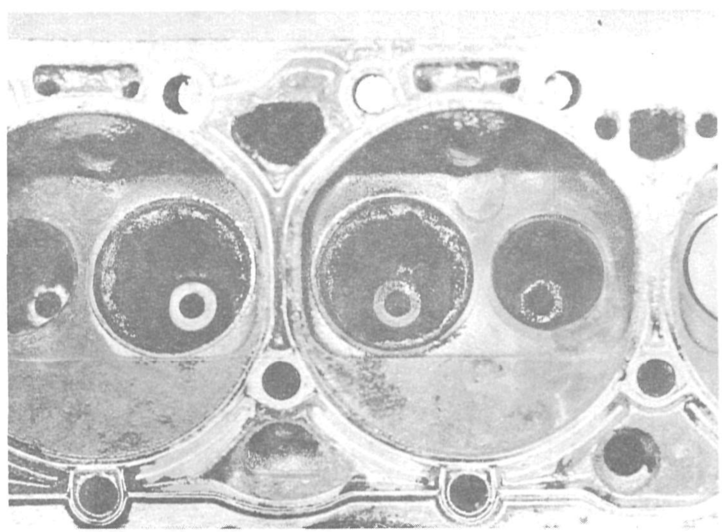
FIGURE B-2.- Carburetor bases for the stationary engines.



AK33X vehicle

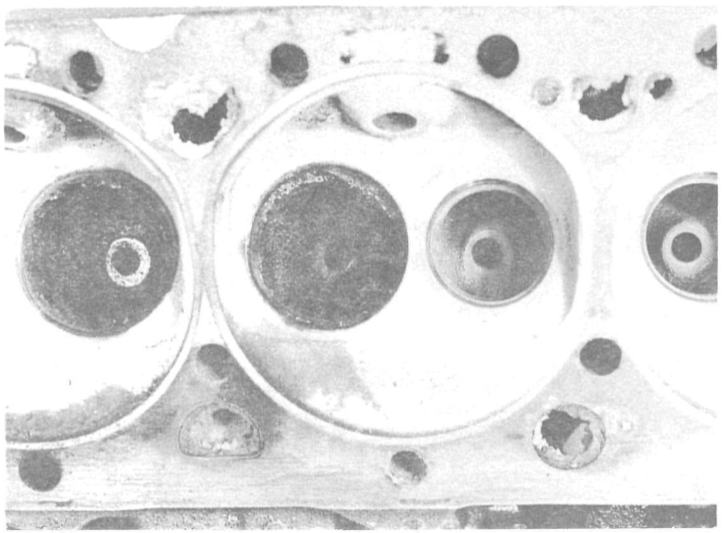


F310 vehicle

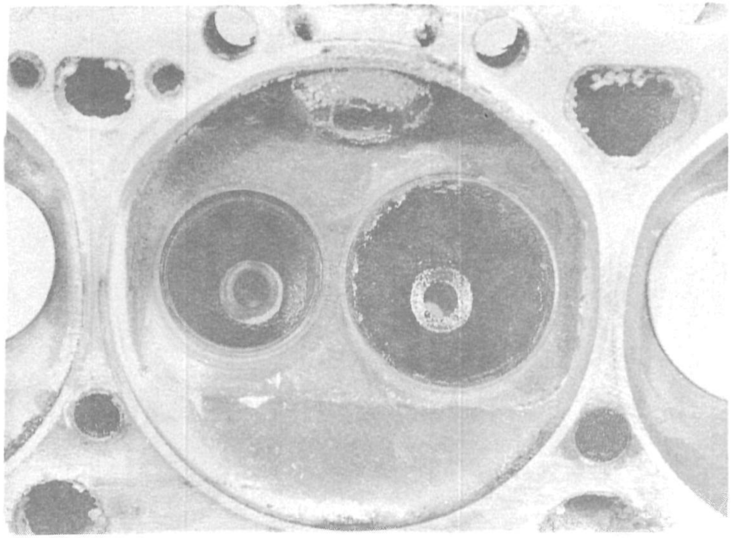


Control vehicle

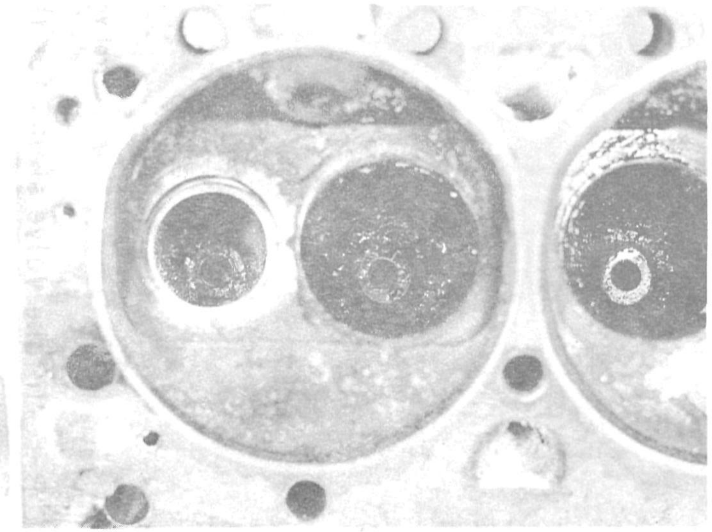
FIGURE B-3.- Intake and exhaust ports for the AK33X, F310, and control vehicles.



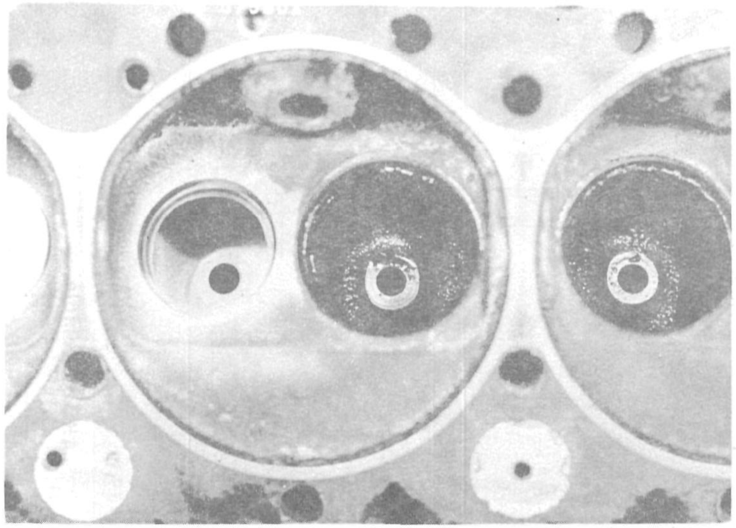
AK33X engine A



AK33X engine B

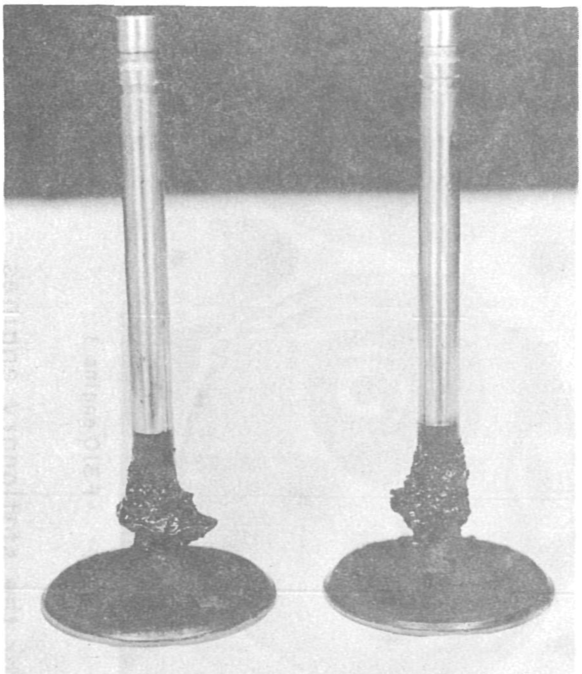


F310 engine A

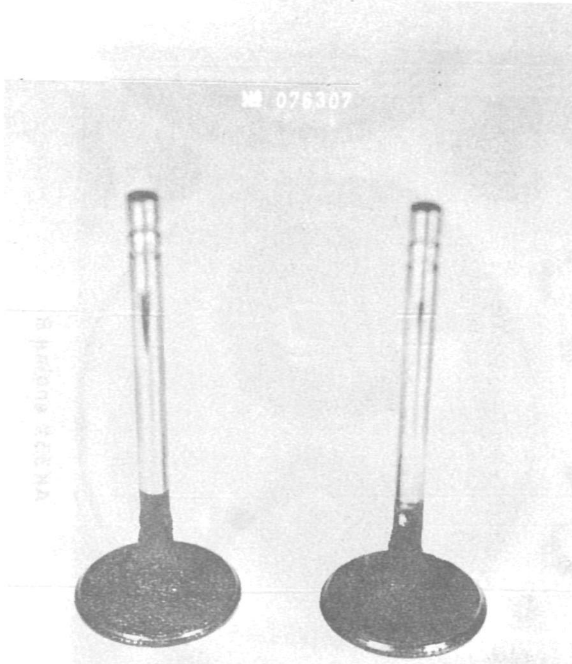


F310 engine B

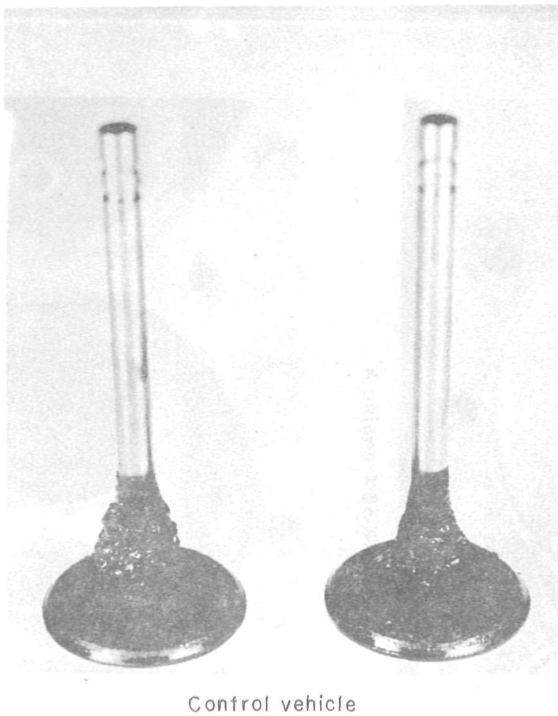
FIGURE B-4. - Intake and exhaust ports for the stationary engines.



AK33X vehicle

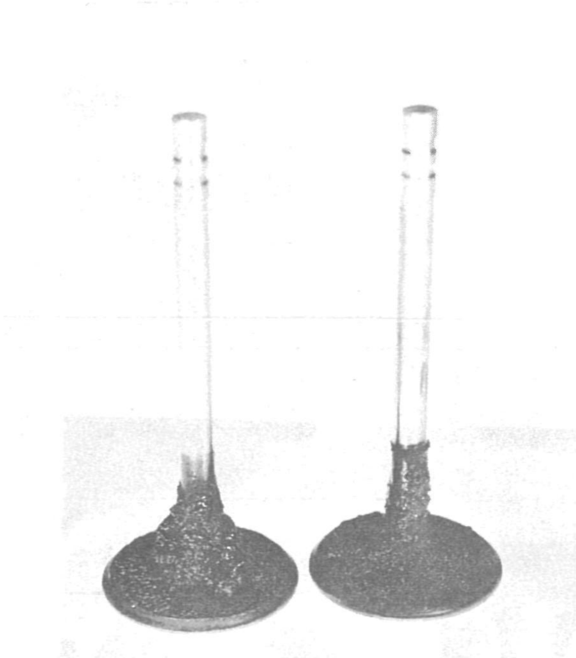


F310 vehicle

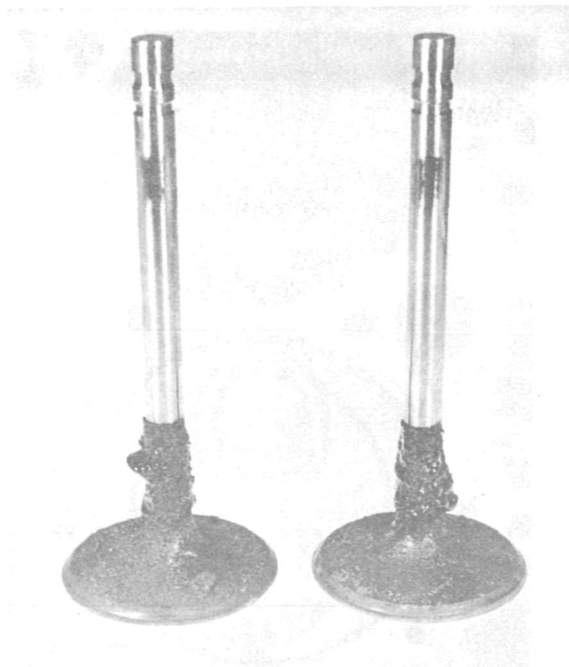


Control vehicle

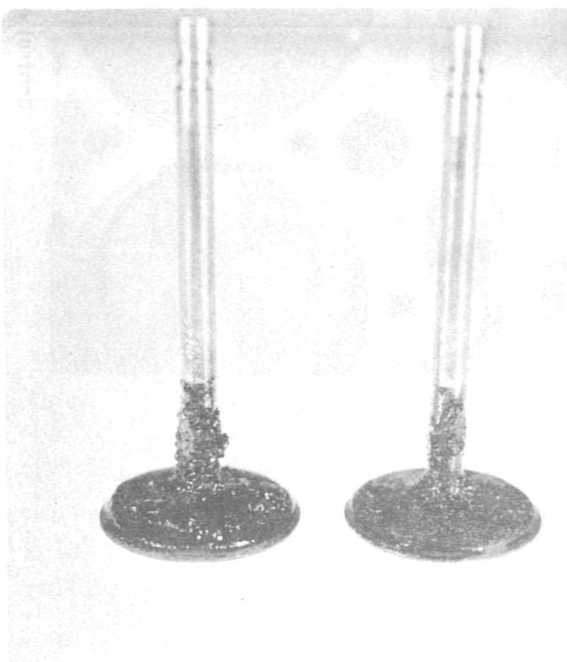
FIGURE B-5.-Intake valve stems for the AK33X, F310, and control vehicles.



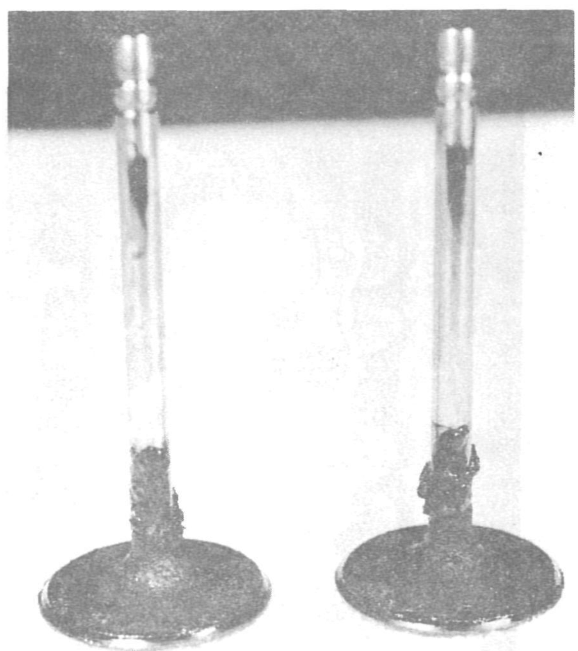
AK33X engine A



AK33X engine B

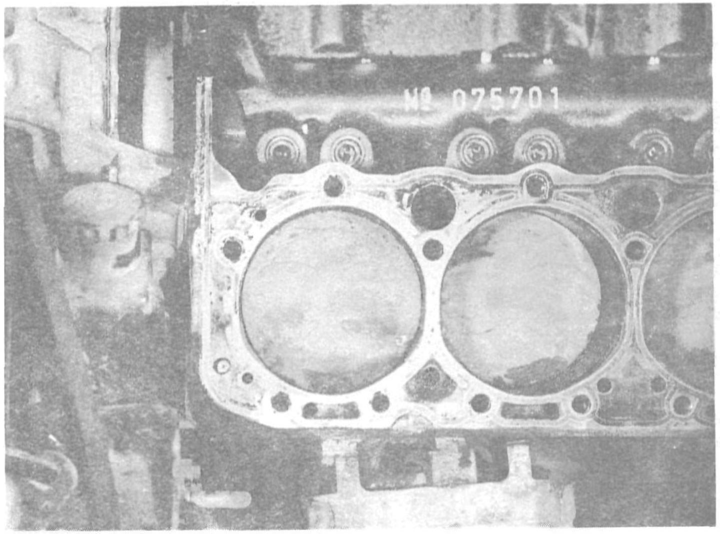


F310 engine A

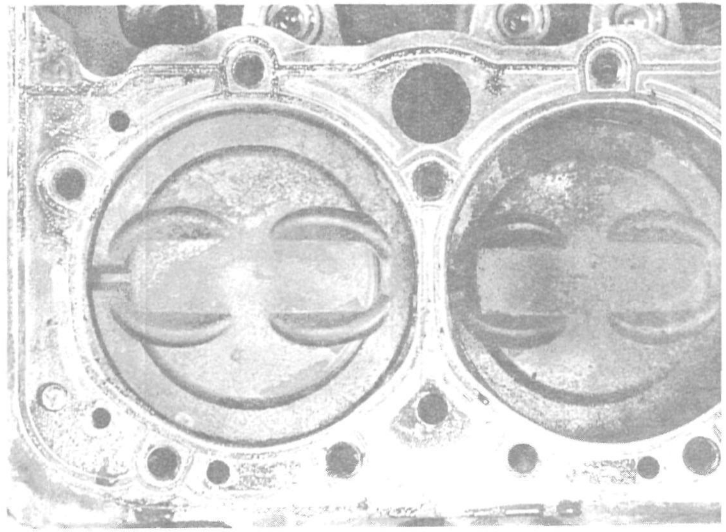


F310 engine B

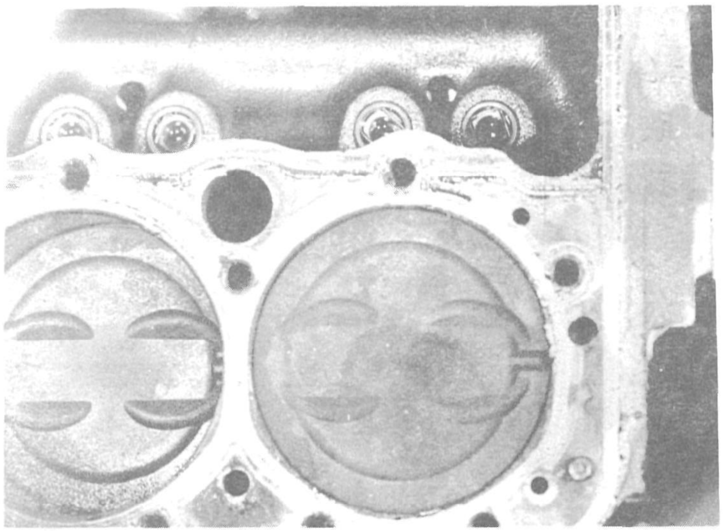
FIGURE B-6.-Intake valve stems for the stationary engines.



AK33X vehicle

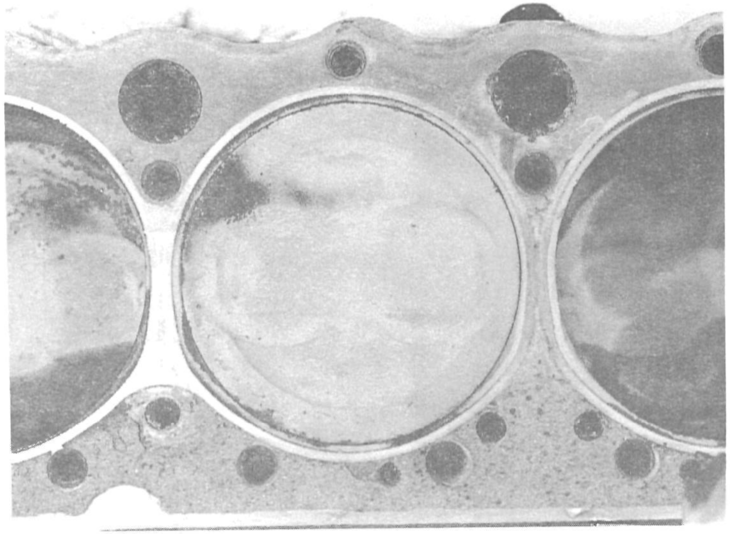


F310 vehicle

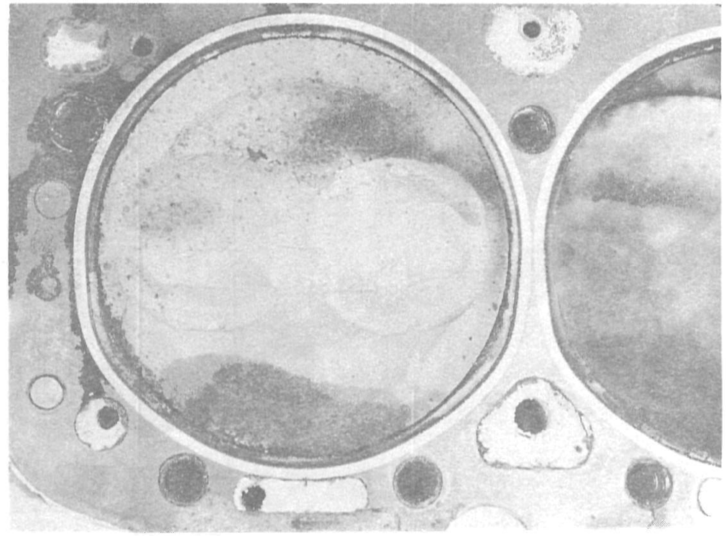


Control vehicle

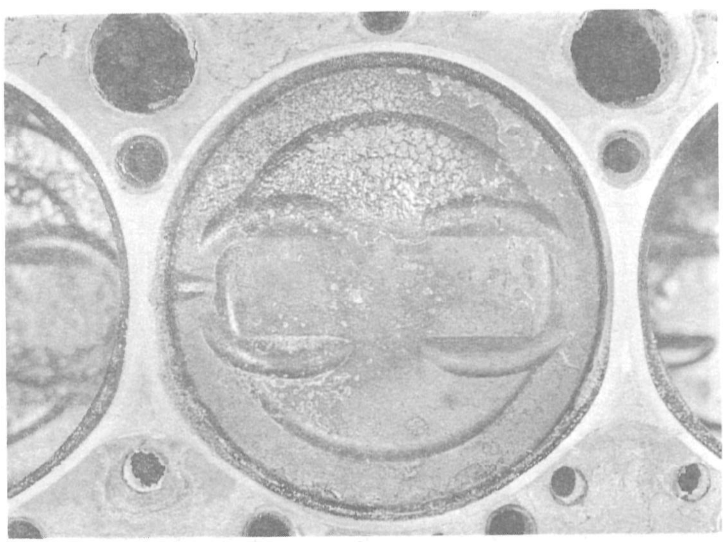
FIGURE B-7.-Piston head for the AK33X, F310, and control vehicles.



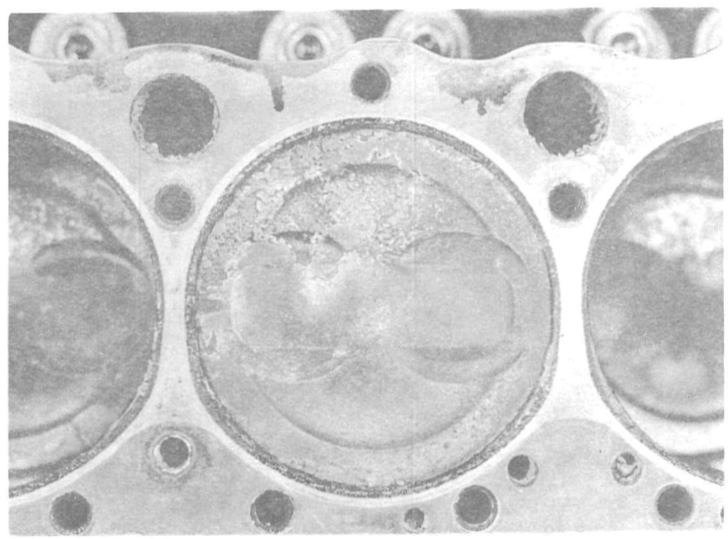
AK33X engine A



AK33X engine B

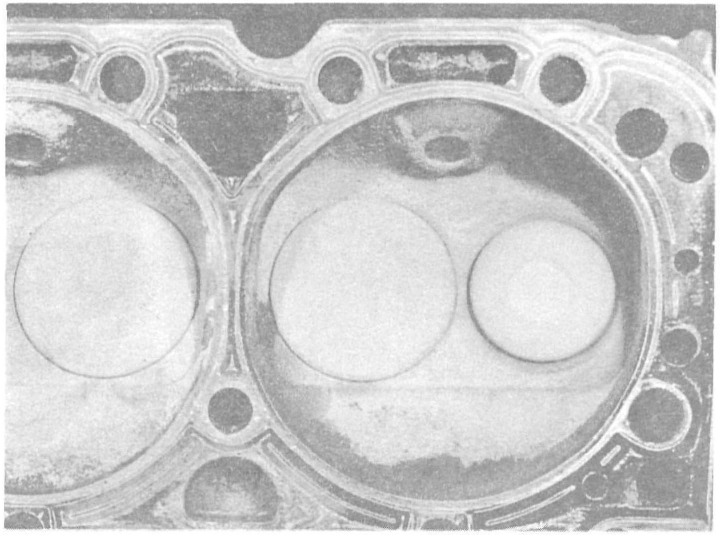


F310 engine A

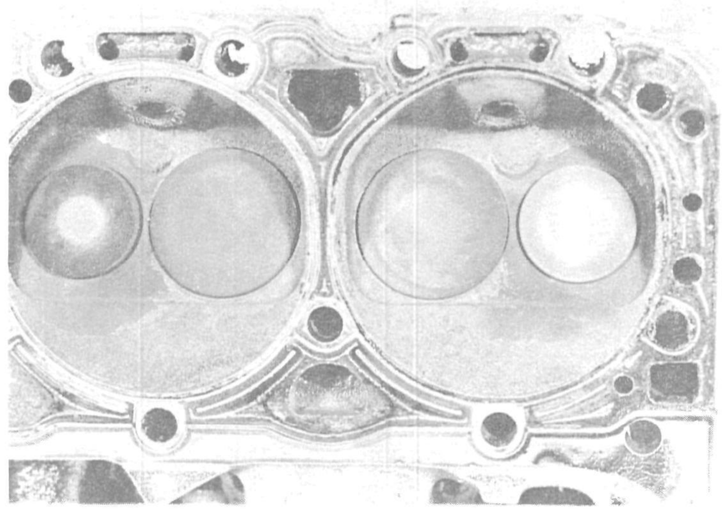


F310 engine B

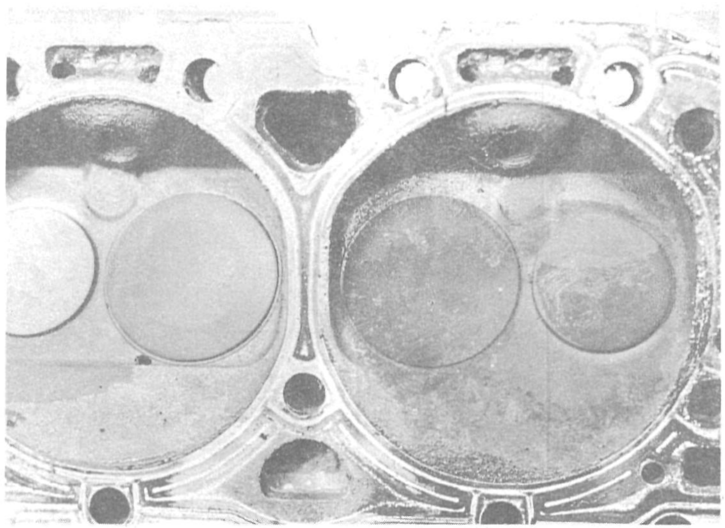
FIGURE B-8.-Piston head for the stationary engines.



AK33X vehicle

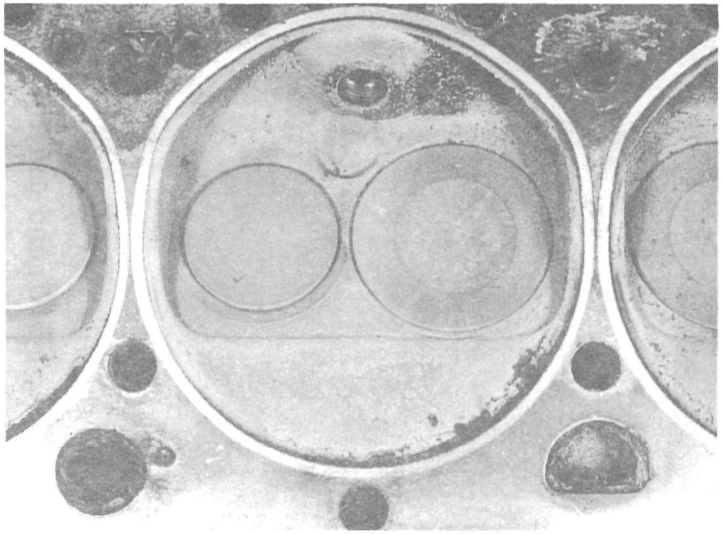


F310 vehicle

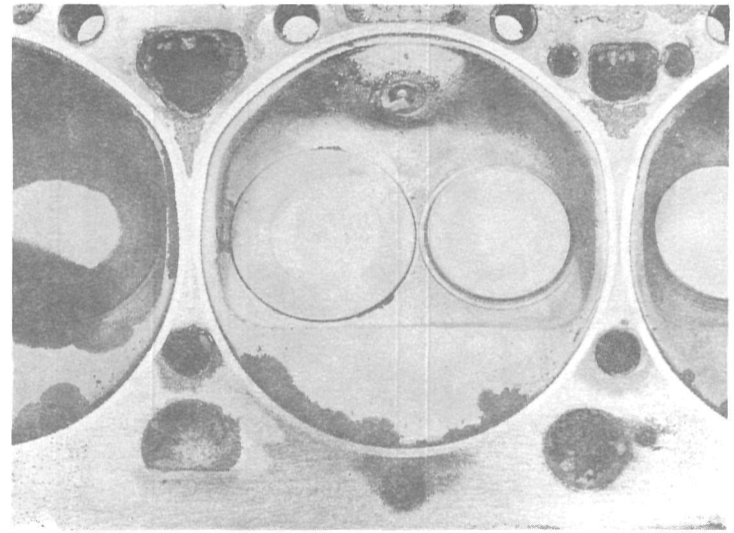


Control vehicle

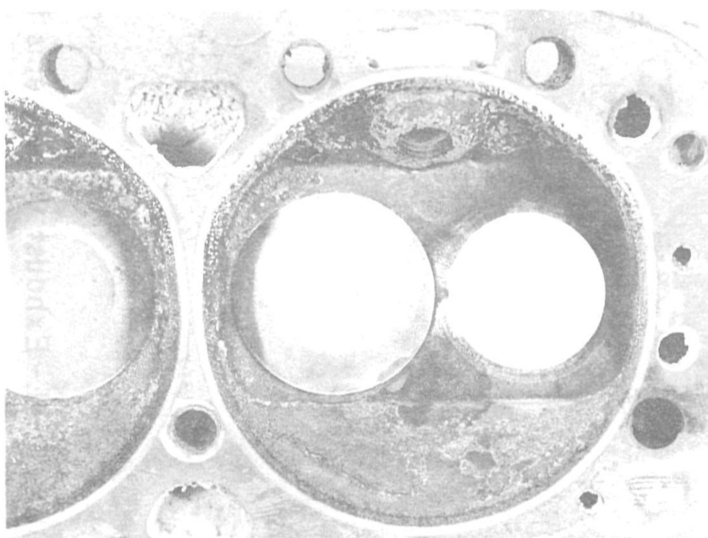
FIGURE B-9.-Cylinder heads for the AK33X, F310, and control vehicles.



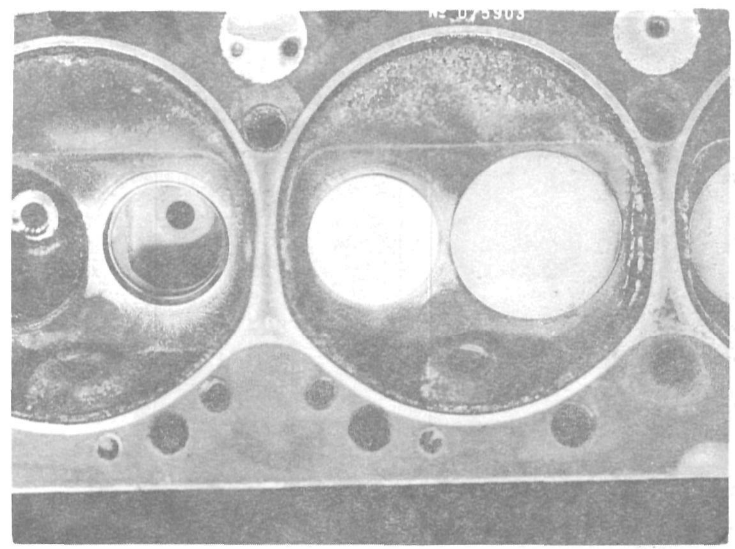
AK33X engine A



AK33X engine B

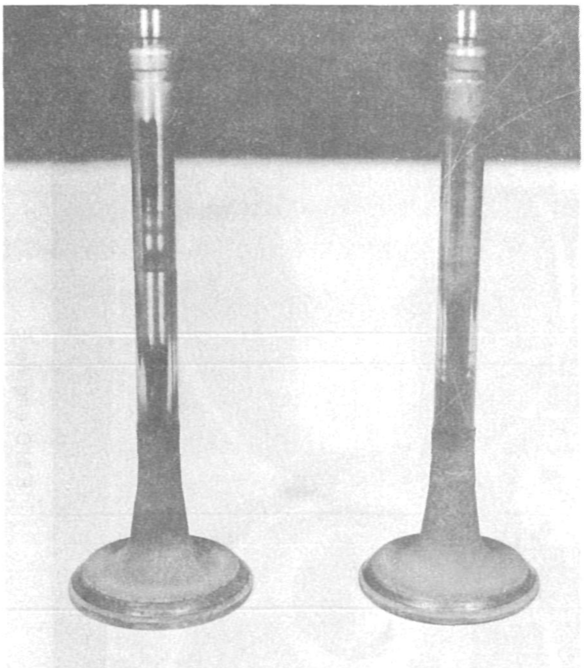


F310 engine A

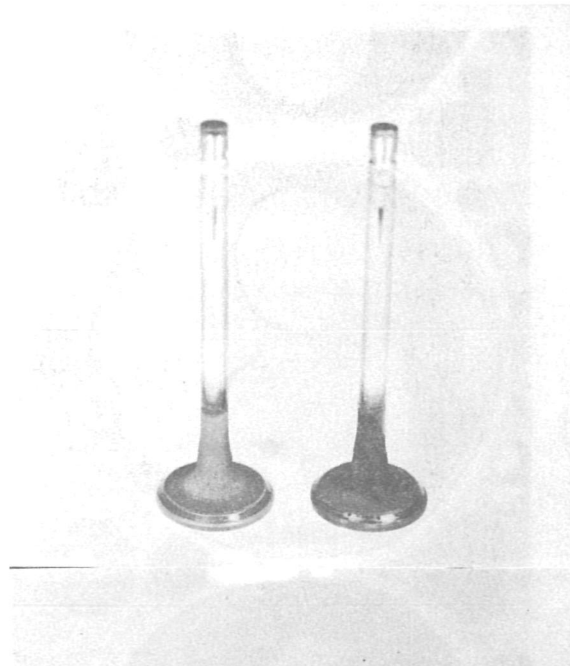


F310 engine B

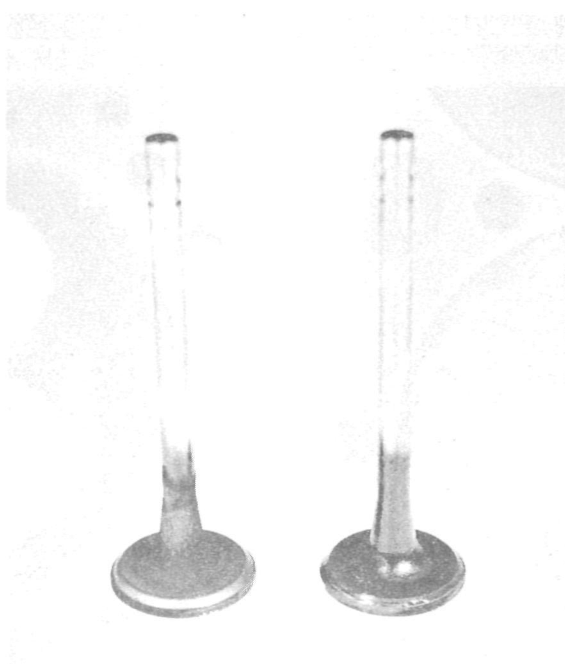
FIGURE B-10.-Cylinder heads for the stationary engines.



AK33X vehicle

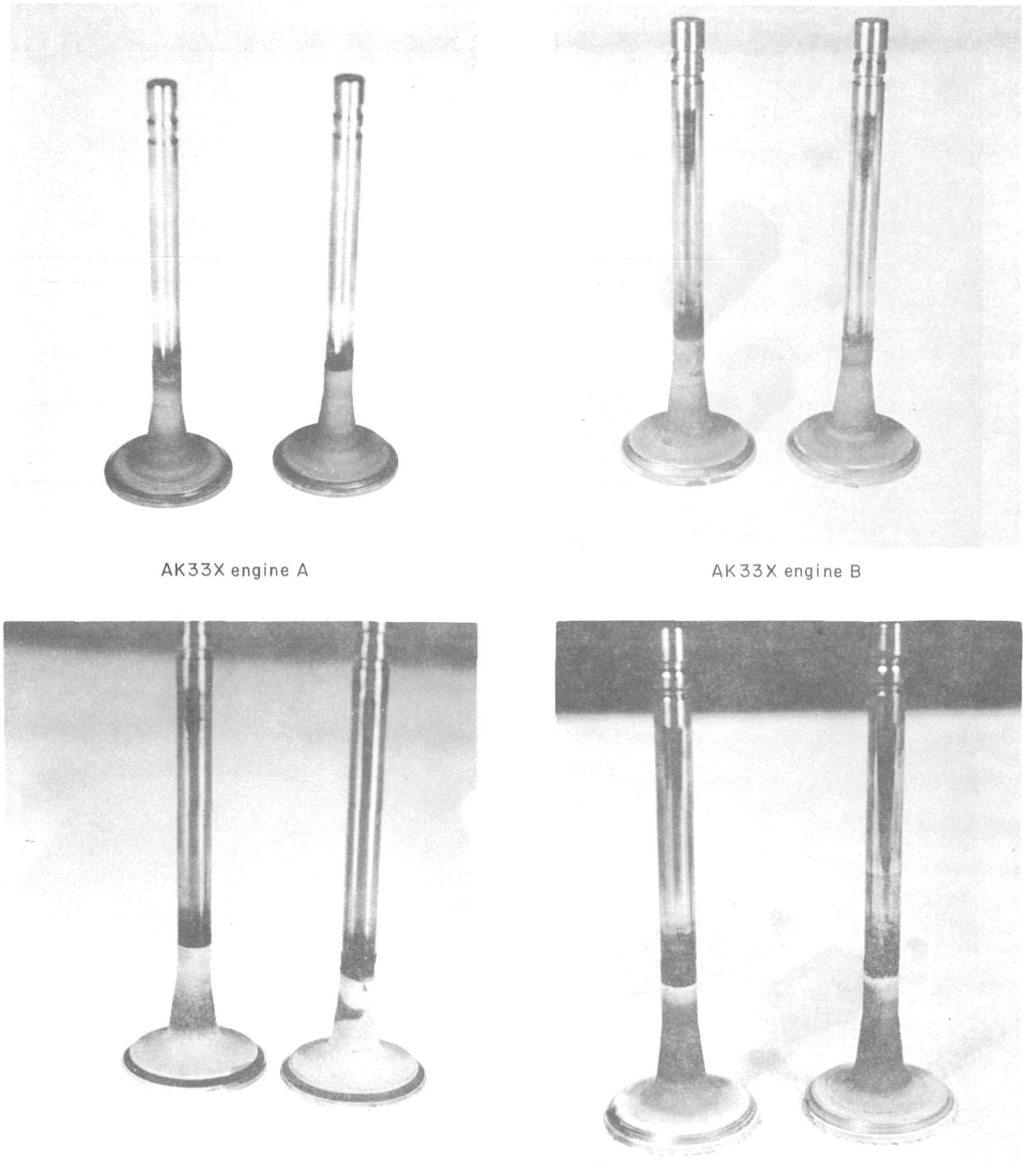


F310 vehicle



Control vehicle

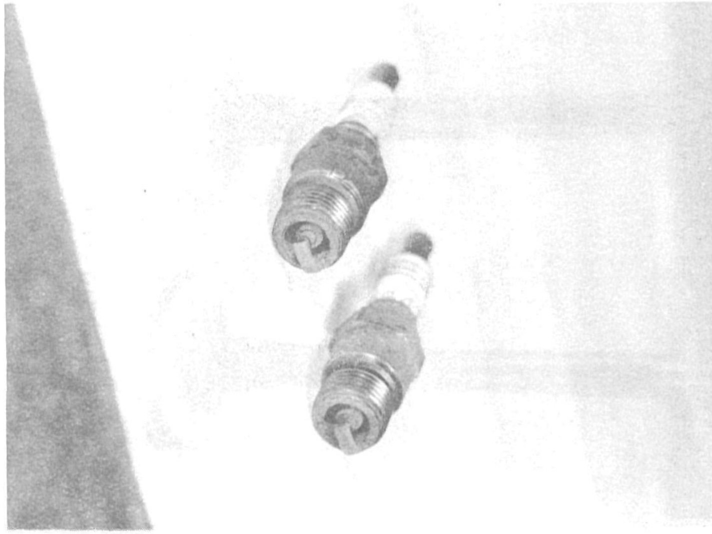
FIGURE B-11.- Exhaust valve stems for the AK33X, F310, and control vehicles.



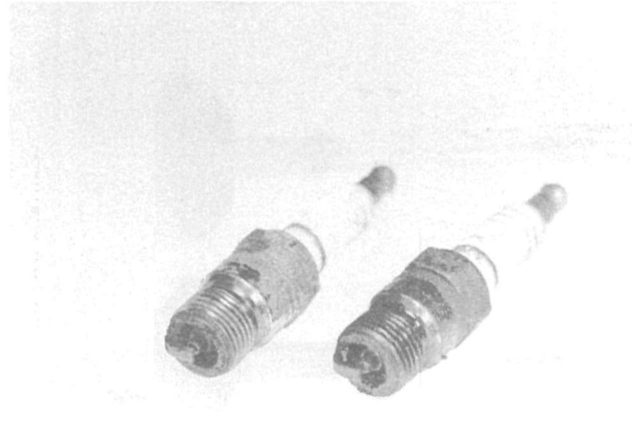
AK33X engine A — AK33X engine B

F.310 engine A — F310 engine B

FIGURE B-12.-Exhaust valve stems for the stationary engines.



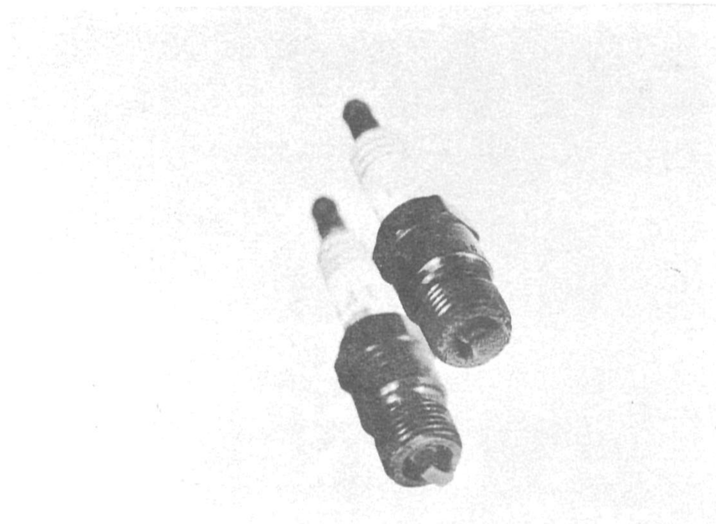
AK33X vehicle



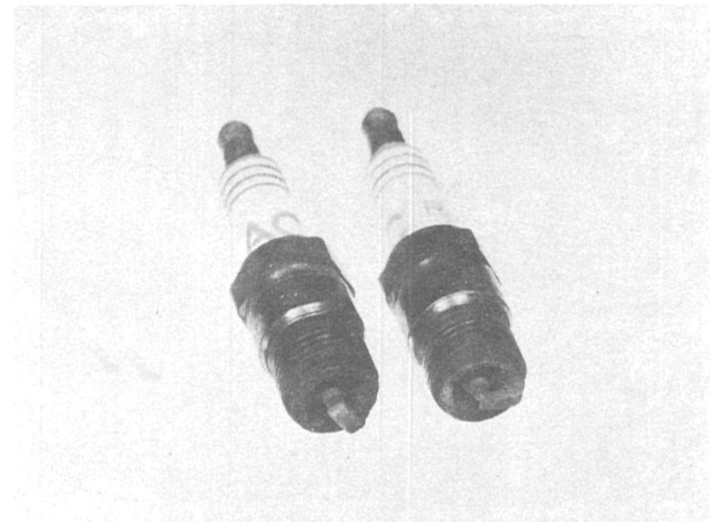
F310 vehicle

Control vehicle

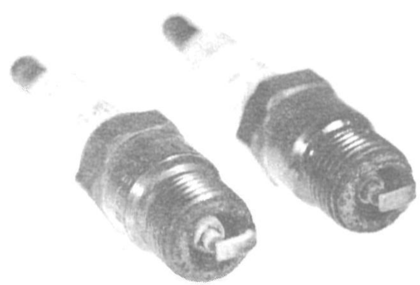
FIGURE B-13.-Spark plugs for the AK33X, F310, and control vehicles.



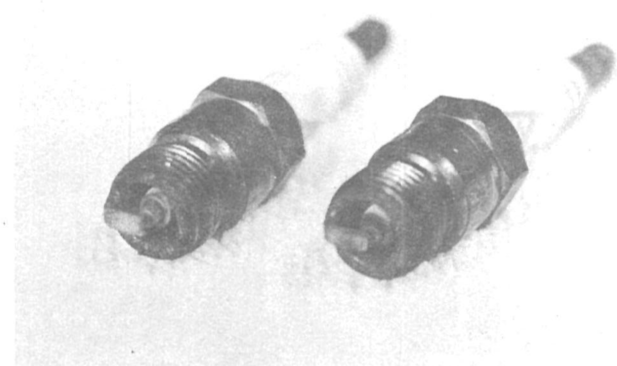
AK33X engine A



AK33X engine B

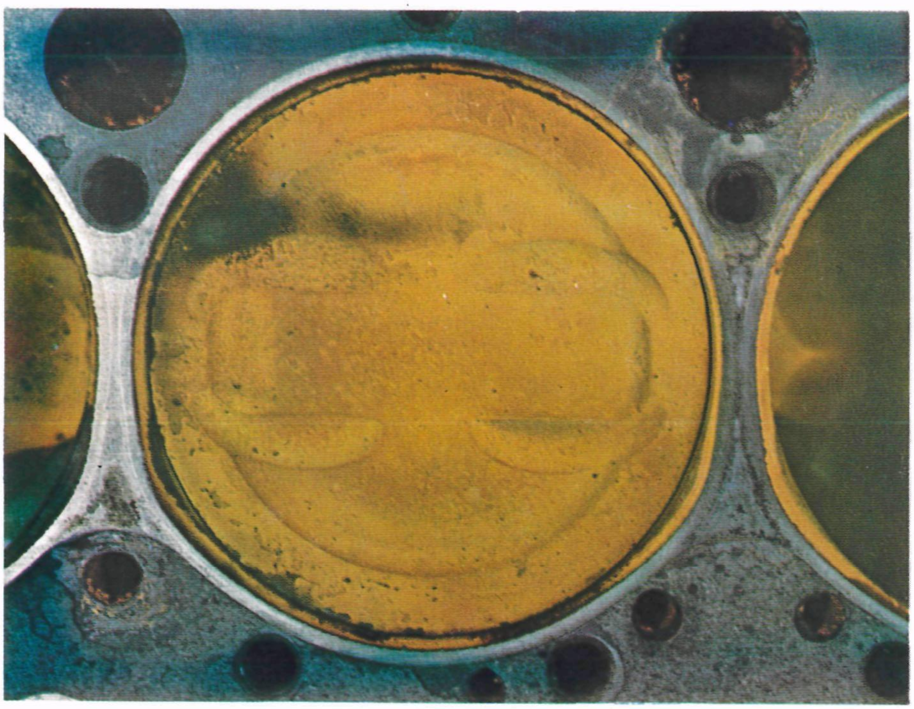


F310 engine A

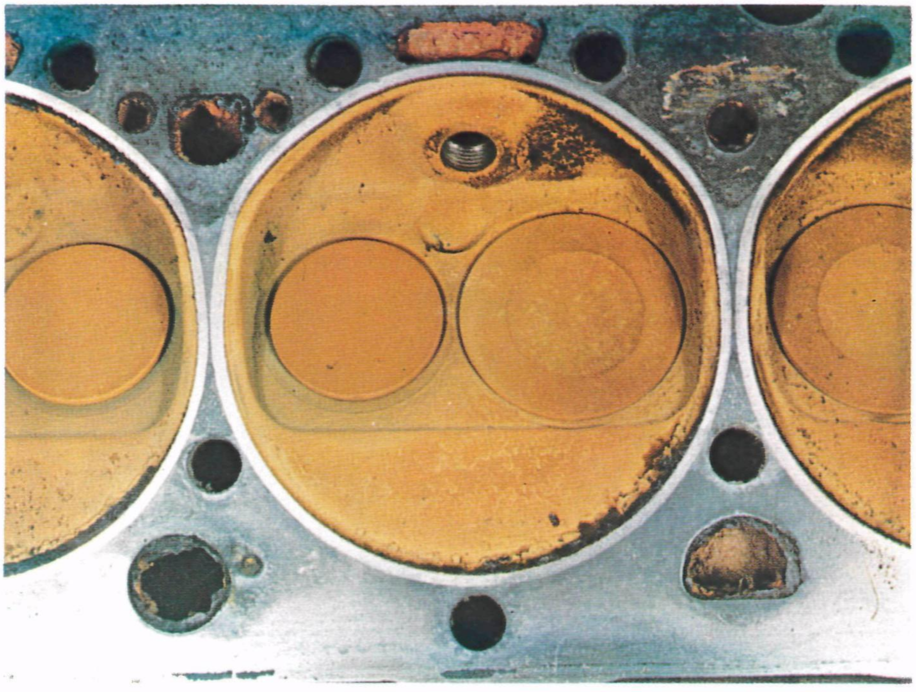


F310 engine B

FIGURE B-14.-Spark plugs for the stationary engines.



Piston head -- AK33X engine A



Cylinder head -- AK33X engine A

FIGURE B-15.- Piston and engine head for AK33X engine A.