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Emission Characterization of a 2-Stroke Heavy-Duty Diesel Coach Engine and Vehicle With and Without a Particulate Trap

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Emission Characterization of a 2-Stroke Heavy-Duty Diesel Coach Engine and Vehicle With and Without a Particulate Trap

by

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Work Assignment 7

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Prepared for

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FOREWORD

The project on which this report is based was initiated by Work Assignment No. 7 of EPA Contract 68-03-3073, received by SwRI on April 20, 1982. The contract was for "Pollutant Assessment Support for the Emission Control Technology Division." Work Assignment No. 7 of that contract was specifically for "Preliminary Investigation of Trap/Oxidizer in a Heavy-Duty Bus Engine." The work was identified within SwRI as Project No. 05-6619-007.

The Project Officer and the Technical Project Monitor for EPA's Technology Assessment Branch during the Work Assignment were Mr. Robert J. Garbe and Mr. Thomas M. Baines, respectively. SwRI Project Director was Mr. Karl J. Springer, and SwRI Project Manager was Mr. Charles T. Hare. The SwRI Task Leader and principal investigator for the Work Assignment No. 7 effort was Mr. Terry L. Ullman. Lead technical personnel were Mr. Patrick Medola and Mr. Raul R. Martinez.

We would like to express our appreciation to Detroit Diesel Allison Division for supplying the engine; the VIA Metropolitan Transit Company of San Antonio for supplying the Coach used in this program, at nominal cost; and Corning Glass Works for supplying the uncatalyzed trap substrates and technical information.

ABSTRACT

Diesel soot or smoke has been regarded as a nuisance pollutant and potential health hazard, especially in congested urban areas where diesel buses operate. A non-catalyzed particulate trap was studied as an exhaust aftertreatment device on a heavy-duty DDAD 6V71 diesel coach engine, and later, on a similarly-powered in-service GMC RTS-II bus. The emphasis of the program was on gathering exhaust emissions information during particulate accumulation by the trap. The work also included trap shell and hardware fabrication, installation, and devising a workable regeneration scheme. Regeneration was accomplished using an in-exhaust-pipe burner to raise the engine's idle exhaust gas temperature from 120 to 700°C.

Emissions characterization included regulated emissions (HC, CO, and NO_x) along with particulate, selected hydrocarbons, aldehydes, phenols, and odor. The particulate matter was characterized in terms of sulfate content, C, H, N, S, metal content, and soluble organic fraction. The soluble organic fraction was further analyzed for benzo(a)pyrene (BaP), C, H, N, S, and boiling point distribution.

Exhaust emissions from the DDAD 6V71 coach engine were characterized over the 1979 13-mode Federal Test Procedure (FTP), or shorter versions of this modal test, over the 1984 Transient FTP, and over an experimental bus cycle. Emissions from the GMC RTS-II coach were characterized over an experimental heavy-duty vehicle chassis driving cycle and over an experimental chassis driving cycle developed for testing buses.

Particulate emissions were reduced by an average of 79 percent over both steady-state and transient operation using the trap. Smoke emissions with the trap in place were essentially zero during all modes of operation, including full-rack acceleration. Although the trap was quite effective in reducing carbonaceous particulate emissions, it had a variable effect in reducing the soluble organic fraction (SOF) of the total particulate. Some reduction in sulfate emissions were also noted. The effect of the trap on regulated and other unregulated emissions was generally minimal. Differences in brake specific fuel consumption (BSFC) with the trap were also minimal.

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I. INTRODUCTION

Over the years, diesel soot and smoke have been regarded as a nuisance pollutant and a potential health hazard, especially in congested urban areas where diesel buses operate. Among the limited technologies currently available to reduce diesel particulate emissions, the particulate trap appears to be one method which may be adaptable under some conditions. Although some experiments with particulate traps and associated regeneration schemes have been conducted with light-duty diesel engines and vehicles, relatively little information has been published on the application of particulate trap technology to heavy-duty diesel engines and vehicles.

The objectives of this work were to: 1) evaluate the effectiveness of a-low-mileage trap installed on a heavy-duty diesel bus engine, 2) develop a method of regeneration, and 3) characterize the emission levels during trap use compared to baseline. The trap used in this work was a ceramic substrate manufactured by Corning. The basic substrate was of the same type used in the manufacture of monolithic catalytic converters. The substrate was not coated with any catalytic material, and alternate channels of the substrate were blocked in order to cause the exhaust gases to "filter" through the walls of the substrate. The project was to be carried out on a two-stroke DDAD 6V71 coach engine tested on an engine dynamometer (for which baseline data had already been accumulated), and then repeated on a similarly-powered bus vehicle tested on a chassis dynamometer.

Emissions from the engine with trap, mounted on a engine dynamometer, were characterized over steady-state operation of the 13-mode FTP,(1)* as well as over the 1984 Heavy-Duty Transient FTP.(2) Emissions were also measured over an experimental transient bus cycle. In addition, exhaust emissions from a bus vehicle with a similar engine were characterized over an experimental driving cycle for testing heavy-duty vehicles under transient conditions on the chassis dynamometer, with and without the trap. Emissions were also measured over a chassis dynamometer version of the transient cycle meant to represent bus operation.

*Numbers in parentheses designate references at the end of this report.

II. SUMMARY

One of the current strategies to meet the EPA proposed particulate standard of 0.25 g/hp-hr (0.34 g/kW-hr) for heavy-duty diesel engines is to use a particulate trap. Changes made to diesel engines to reduce NO_x emissions generally result in greater particulate emissions. Utilizing a particulate trap, as an exhaust aftertreatment to reduce particulate emissions, would allow manufacturers to adjust the engines to meet more stringent NO_x emission standards. Although some work with particulate traps has been conducted on light-duty diesel applications, relatively little work has been published on trap application to heavy-duty diesel engines. This program was conducted as a preliminary investigation into the application of a non-catalyst particulate trap on a heavy-duty bus engine as well as on a coach vehicle. A bus engine and coach vehicle were chosen for this demonstration because buses contribute to much of the urban particulate levels,(3) to which many people are exposed. In addition, preliminary demonstration of a trap application would be helpful if retrofitting is considered. The emphasis of the program was to accumulate exhaust emissions information, but the program also included trap shell and hardware fabrication, installation, and devising a workable regeneration scheme.

The test engine used in this program was DDAD 6V71 coach engine, for which emissions had been characterized in another program conducted for EPA.(4) The test vehicle used in this program was a 1980 GMC RTS-II in-service coach. This bus was also powered by a DDAD 6V71 coach engine. This engine is a 2-stroke direct-injected diesel engine which uses a blower for scavenging. Hence, the temperatures of the exhaust gases are generally lower than from a similarly rated 4-stroke diesel engine. In order to regenerate the particulate trap, that is, to oxidize the trapped particles, temperatures near 600°C (1112°F) are generally required. At rated power conditions of 135 kW at 2100 rpm on No. 1 diesel fuel, the maximum exhaust temperature was 522°C measured near the exhaust manifold.

The non-catalyzed trap was made of Corning EX-47 material in the form of a cylinder measuring 12 inches long by 11.25 inches diameter. This substrate material had 100 cells/in^2 and had a mean pore size of 12-13 microns.(5) An in-exhaust-pipe fuel burner was developed for regeneration of the trap. Considering the potential bus vehicle application of the trap, it was thought that regeneration at idle would be most reasonable. For regeneration, idle exhaust gas temperature was raised from about 120°C to 700°C by the burner.

Exhaust emissions from the DDAD 6V71 coach engine were measured over the 1979 13-mode Federal Test Procedure (FTP), or shorter versions of this modal test, over the 1984 Transient FTP, and over an experimental bus cycle.(1,2,6) Exhaust emissions from the GMC RTS-II coach were characterized over chassis versions of truck and bus cycle operation.(7,8) Following trap accumulation of particulate, regeneration was successfully accomplished during engine idle operation using the burner. Several cycles of trap accumulation-regeneration were completed during emissions

test work on the engine dynamometer. The trap and exhaust system were then transferred to a coach vehicle. The bus was successfully operated over the road in a service-like manner during trap particulate accumulation. After regenerating the trap on the bus, regulated and unregulated emissions were determined over chassis versions of the heavy-duty transient cycles for trucks and buses during trap particulate accumulation. Upon completion of testing the bus with the trap, emissions without the trap were determine using the same chassis test procedures.

Table 1 summarizes the composite results obtained during this program and includes baseline data (without trap) and results from coach vehicle testing without the trap, determined under other programs. As expected, the trap reduced particulate emissions substantially. Over transient testing of the engine with the trap, the total particulate emission was reduced by about 65 percent. Transient testing of the coach vehicle with the trap indicated a 92 percent reduction in total particulate emissions. It should be noted that total particulate emission levels from the coach vehicle were very high. Over steady-state testing of the test engine with the trap, total particulate emission was reduced by 79 percent on the basis of 7-mode composite. During the steady-state test work, the trap efficiency ranged from 95 percent during the full load/intermediate speed condition to 38 percent during the 50 percent load/rated speed condition. The trap was quite effective in reducing the amount of observed "carbon black" typically found on the particulate filter, but it had a variable effect in reducing the soluble organic fraction (SOF) of the total particulate. Smoke emissions were essentially reduced to zero under all modes of operation including full-rack acceleration.

For the test engine, the trap reduced the brake specific SOF by 45 percent over the 7-mode composite, 38 percent over the transient composite, and 63 percent over the bus cycle. SOF over transient chassis testing with the trap was reduced by about 88 percent. Of the SOF submitted for analysis of benzo(a)pyrene (BaP), the levels of BaP were found to be minimal and no dependence on the trap can be readily assessed.

The sulfate portion of the total particulate was also determined. The trap appeared to be responsible for a 79 percent reduction in 7-mode composite sulfate emissions from the engine alone. Transient composite sulfate emission was reduced by 67 percent. A trend to lower sulfate emission also appeared from transient cycle composite results obtained over chassis testing of the coach vehicle with the trap; but over the bus cycle with the trap, the sulfate increased. The potential of a non-catalyzed trap to store and purge sulfate aerosols over various operating conditions was not determined in this program.

The effects of the trap on regulated and other unregulated emissions were generally minimal. Emissions of hydrocarbons were generally reduced by a few percent for the engine alone and by almost 34 percent for the coach vehicle. Considering individual hydrocarbons (C_1 through C_3 along with benzene and toluene), some reduction in the overall total of individual hydrocarbons, mostly ethylene, was associated with use of

TABLE 1. SUMMARY OF COMPOSITE EMISSION RATES FROM A DDAD 6V71 COACH ENGINE AND A GMC RTS-II COACH VEHICLE WITH AND WITHOUT A PARTICULATE TRAP

Composite Emission Rates	Test Configuration									
	DDAD 6V71 Coach Engine (1)						GMC RTS-II Coach (2)			
	Without Trap (Baseline)			With Trap			Without Trap		With Trap	
Federal Test Procedure (FTP)	13-Mode	Transient	Bus Cycle	13-Mode	Transient	Bus Cycle	Transient	Bus Cycle	Transient	Bus Cycle
Hydrocarbons, HC[a] g/kW-hr (1), g/km (2), (g/kg fuel)	1.64[a,b] (5.69)	1.90[a] (6.46)	1.93[a] (6.39)	1.68[b] (5.87)	1.89 (6.39)	1.83 (6.16)	1.56 (3.85)	2.25 (4.46)	1.02 (2.56)	1.47 (3.09)
Carbon Monoxide, CO g/kW-hr (1), g/km (2), (g/kg fuel)	9.62[a,b] (33.4)	5.18[a] (17.6)	4.13[a] (13.7)	6.24[b] (21.8)	4.45 (15.0)	4.12 (13.9)	53.6 (132)	70.6 (140)	44.7 (112)	66.0 (139)
Oxides of Nitrogen, NO_x[b] g/kW-hr (1), g/km (2), (g/kg fuel)	9.79[a,b] (34.0)	8.17[a] (27.8)	9.02[a] (29.9)	10.00[b] (35.0)	7.77 (26.2)	8.59 (28.9)	10.2 (25.2)	12.9 (25.6)	10.8 (27.1)	11.4 (23.9)
Brake Specific Fuel Consumption kg fuel/kW-hr (1), kg/km (2)	0.288[a,b,j]	0.294[a,j]	0.302[a,j]	0.286[b]	0.296	0.297	0.405	0.504	0.398	0.476
Test Cycle	7-Mode	Transient	Bus Cycle	7-Mode	Transient	Bus Cycle	Transient	Bus Cycle	Transient	Bus Cycle
Total Individual HC mg/kW-hr (1), mg/km (2), (mg/kg fuel)	Not Run	190[j] (610)	Not Run	Not Run	110 (380)	120 (400)	200 (500)	220 (440)	93 (230)	97 (200)
Total Aldehydes mg/kW-hr (1), mg/km (2), (mg/kg fuel)	29[j,i] (95)	31[j] (95)	12[j] (36)	28 (91)	46[c] (160)	120[c] (412)	41[d] (100)	170 (350)	190[d] (470)	120 (260)
Total Phenols mg/kW-hr	Not Run	e,j	e,j	f	f	f	f,d	f	f,d	f
Total Intensity of Aroma (TIA) by LCA (by LCO)	1.55[j] (1.20)	1.80[j] (1.66)	Not Run	1.86 (1.99)	1.88 (1.22)	1.70 (1.71)	2.15[d] (2.56)	1.81 (2.14)	2.20[d] (2.50)	1.85 (2.18)
Total Particulate[g] g/kW-hr (1), g/km (2), (g/kg fuel)	0.70[j] (2.3)	0.75[a] (2.6)	0.78[a] (2.6)	0.15 (0.48)	0.29[h] (0.98)	0.25[h] (0.84)	4.4 (11)	6.2 (12)	0.35 (0.88)	0.43 (0.90)
Sulfate, $SO_4^=$ mg/kW-hr (1), mg/km (2), (mg/kg fuel)	25[j] (81)	28[j] (87)	Not Run	5.2 (17)	9.3 (31)	23 (78)	13 (32)	16 (33)	11 (27)	24 (51)
Soluble Organic Fraction (SOF) g/kW-hr (1), g/km (2), (mg/kg fuel)	0.20[j] (0.65)	0.40[j] (1.2)	0.54[j] (1.6)	0.11 (0.36)	0.25 (0.84)	0.20 (0.67)	0.31 (0.75)	0.41 (0.81)	0.040 (0.10)	0.049 (0.10)
BaP, μg/kW-hr (1), μg/km (2), (μg/kg fuel)	<0.04[i]	<0.08[i]	<0.11[i]	0.12 (0.38)	0.28 (0.92)	0.11 (0.37)	0.0502 (0.12)	<0.008[i]	0.055 (0.14)	0.022 (0.044)

NOTE: Superscript numbers in parentheses represent corresponding units

[a] New baseline - these data acquired prior to installation of trap
[b] Data were also acquired in front of the trap and were: HC 1.79, CO 6.38, NO_x 9.91 g/kW-hr, with a BSFC of 0.286 kg/Kw-hr
[c] Most of this total was comprised of formaldehyde and benzaldehyde
[d] Transient composite was composed of a 1 cold and 3 hot transient runs
[e] Phenol 2-n-propylphenol was noted at a level of 58 mg/kW-hr, but potential analysis interference makes the measurement quiestionable
[f] Below the minimum detectable levels
[g] Without trap Federal smoke for DDAD 6V71 coach engine were: A 4.0, B 7.0. C 7.2 percent opacity; with trap: A <1, B <1, C <1 percent opacity; without trap, the GMC RTS-II coach was regarded as a "smokey" bus, with trap, no smoke emissions were visible
[h] Based on four runs for particulate
[i] Below minimum detectable level of 0.0002 μg BaP/mg SOF
[j] Original baseline data obtained under previous contract. BSFC for "baseline" 13-mode, transient, and bus cycle were 0.308, 0.323, and 0.339, respectively.

the trap. The trap appeared to have mixed effects on the emission of aldehydes and the odor index, referred to as total intensity aroma (TIA). There was little difference in emissions of CO or NO_x attributed to the trap. Differences in BSFC with the trap were minimal. It is difficult to say whether or not the relatively small changes noted above were due to the exhaust gases passing through the particulate-laden trap, or whether the changes were due to influences on engine backpressure (which ranged from 3.0 to 6.0 in. Hg during testing with the trap) or simply test-to-test repeatability. Much more detailed work would be needed to isolate the effect of the particulate-laden trap on various hydrocarbon species, aldehydes, NO_x, and sulfate emissions.

During regeneration of the trap, with the test engine at idle and the fuel burner operating, the HC and NO_x emissions were similar to the levels obtained during idle; but the level of CO emission was about 10 times greater. Total particulate emissions and the level of SOF over the regeneration "cycle" were above the levels obtained during normal idle with the trap, but were still lower than the levels obtained without the trap. Sulfate emission during regeneration was about 3 times greater than that from idle without the trap, and sulfur accounted for approximately 7 percent of total particulate. No significant change in smoke, selected hydrocarbons, aldehydes, phenols, or odor (by DOAS) occurred during regeneration of the trap.

III. TEST PLAN, DESCRIPTION OF TEST APPARATUS, AND PROCEDURES USED FOR EVALUATION

The intent of this program was to characterize regulated gaseous emissions along with particulate and unregulated emissions from the DDAD 6V71 coach engine, with and without particulate trap aftertreatment, using both engine dynamometer and chassis dynamometer test procedures. This section describes the test plan, as comprehensive as possible within the effort available, used to collect and analyze emissions samples. It also gives some of the pertinent specifications and description of the engine, vehicle, fuels, trap, and burner used in this program. Procedures are described, including both engine and chassis dynamometer test procedures used to generate and acquire the emission samples, and the procedures used to analyze the samples.

A. Test Plan

The basic test plan used in this program initially required confirming a portion of baseline emissions from the test engine (DDAD 6V71 coach engine). After approval of the baseline "repeat data" by the Project Officer, the particulate trap was to be installed, and during trap accumulation experiments, a method for regeneration was to be developed. Following successful accumulation/regeneration cycles of the trap, exhaust emissions were to be characterized. Table 2 illustrates the maximum extent of emission characterization to be performed. With the engine on the engine dynamometer, emissions were to be determined over both steady-state and transient cycle operation during trap accumulation. Emissions listed in Table 2 were also to be measured during the regeneration process insofar as possible.

Assuming that the engine dynamometer test work was completed, the trap and regeneration system were to be transferred to an actual bus vehicle and operated in a "service-like" manner during trap accumulation. Following a few successful cycles of accumulation/regeneration, the bus (with the trap) was to be tested on the chassis dynamometer over transient cycles in order to measure the emissions shown in Table 2. The testing of this bus was to be coordinated with on-going test work for EPA (Contract No. 68-02-3722),[9] under which a similar emission characterization of the bus run without the trap would be conducted, if possible.

B. Fuels

The fuel used during testing of the DDAD 6V71 coach engine on the engine dynamometer was coded EM-400-F. This was a No. 1 diesel emissions test fuel, and was the same fuel used during previous work with this engine in which the baseline emissions were characterized under Contract No. 68-03-2884.[3] The fuel used during road work and chassis testing of the bus was EM-455-F. This fuel was also a No. 1 diesel fuel, and met the specifications for No. 1 emissions test fuel. Pertinent properties of both fuels used in this program are given in Table 3.

TABLE 2. PARTICULATE TRAP EVALUATIONS, 6V71 COACH ENGINE

Emission Measurement(s) or Characterization[c]	Test Sequence: EPA Transient Cold	EPA Transient Hot	Bus Transient	Steady-States	Federal Smoke
Visible smoke, PHS	comparison traces only			13 modes	1 set
Regulated gaseous	2	2	2	13 modes	--
Aldehydes	2	2	2	7 modes	--
Individual HC	2	2	2	--	--
Odor Index (DOAS)	1	1	1	7 modes	--
Phenols, filtered	1	1	1	--	--
Particulate Mass	2	2	2	7 modes	--
C,H,N,S	1	1	1	7 modes	--
Sulfate	2	2	2	7 modes	--
Metals	1	1	1	7 modes	--
Solubles, mass	2	2	2	7 modes	--
C,H,N,S	1 Composite[a]		1	--	--
Boiling Range	1 Composite		1	--	--
BaP	1 Composite		1	Composite[b]	--

[a]Transient "composite" consists of 1 cold-start filter and 6 hot-start filter extracts

[b]Steady-state "composite" consists of weighted combination of extracts from 7 modes

[c]Emissions should be measured during regeneration

TABLE 3. PROPERTIES OF THE TWO DIESEL TEST FUELS

	Fuel Code	
	EM-455-F	EM-400-F
Fuel Description	DF-1 Emissions Test Fuel	DF-1 Emissions Test Fuel
Properties		
Density, g/mℓ	0.809	0.812
Gravity, °API	43.0	42.9
Cetane Index, (D-976)	47.5	49.0
Viscosity, cs (D-445)	1.7	1.69
Flash Point, °C	53	70
Sulfur, wt. % (D-1266)	0.19	0.17
Gum, mg/100 mℓ	--	4.6
Carbon, wt. %	--	86.37
Hydrogen, wt. %	--	13.54
Nitrogen, wt. %	--	0.006
FIA:		
Aromatics, %	13.6	10.5
Olefins, %	3.8	1.5
Saturates, %	82.6	88.0
Distillation (D-86)		
IBP, °C	187	190
10% point, °C	207	203
20% point, °C	210	207
30% point, °C	214	209
40% point, °C	217	212
50% point, °C	219	214
60% point, °C	222	217
70% point, °C	226	221
80% point, °C	231	227
90% point, °C	242	238
95% point, °C	262	258
EBP, °C	294	293
recovery, %	99	99
residue, %	0.5	1
loss	0.5	0

C. Test Engine and Test Vehicle

A 1979 DDAD 6V71 coach engine, which had been used as a test engine in another program, was chosen for this project. The engine was originally a 125-hr emissions test engine and was received by SwRI for use under EPA Contract Nos. 68-03-2707(10) and 68-03-2884. Under those contracts, emissions were characterized in both baseline and malfunction configurations. The malfunction configuration included changing injectors, retard of timing, maladjustment of throttle delay mechanism and increases in intake air restriction. Once the program was completed, the engine was reset back to manufacturer's specifications using the engine's original 125-hr injectors.

The DDAD 6V71 coach engine is a V-6 configuration with a displacement of 426 cubic inches. It developed approximately 175 to 180 hp (observed) on No. 1 diesel fuel at 2100 rpm. Low idle was set at 400 rpm. Engine rotation is clockwise (viewed from flywheel). This engine operates on a two-stroke cycle and uses a "Roots" type blower for scavenging. Maximum restrictions of 25 in. H_2O inlet depression and 6 in. Hg exhaust backpressure were set at maximum power conditions for 13-mode baseline emissions testing. Transient operation restrictions of 17 in. H_2O inlet depression and 4 in. Hg exhaust backpressure were set a maximum power conditions for transient power performance map and transient cycle baseline emissions testing.

For chassis test work, Bus No. 356, a 1980 GMC RTS-II powered by a DDAD 6V71 coach engine, was obtained locally from VIA Metropolitan Transit Company of San Antonio. This particular bus was randomly selected. The bus was tested in the "as-received" configuration, in that no adjustments or verification of manufacturer's specifications were conducted. This bus vehicle had a GVWR of 36,000 lbs; 13,000 lbs on the front axle and 23,000 lbs on the single rear axle with dual wheels. The bus was equipped with an automatic transmission. All test work was conducted with the bus air conditioning not operating. This bus and engine had accumulated 163,732 miles. No major maintenance had been performed (only routine preventive maintenance). General observaitons indicate that this bus was relatively smoky. The low idle speed of the engine was 600 rpm.

D. Regeneration-Burner Development

To regenerate a non-catalyzed particulate trap, temperatures up to 1200°F are required.(11) Regeneration techniques generally consist of methods to obtain this high trap temperature by means of engine-generated exhaust heat or by externally supplied heat sources, such as fuel injection, torch heating, etc. There were concerns over the ability to generate 1200°F temperatures in the trap with this engine, because it was a 2-stroke design with blower scavenging, which results in cooler exhaust gases than would be obtained from a similarly-sized 4-stroke diesel engine. Obtaining high exhaust temperatures on the engine dynamometer was readily conceivable, but it was likely that attempts to reproduce high power operation on the chassis dynamometer would result in tire or transmission damage. Considering possible regeneration schemes, the most promising ones would take place during idle, using an externally supplied heat source to raise the trap temperature.

Ideally, the heat source would be simple and easily constructed, and able to use the onboard fuel, namely No. 1 diesel fuel. The most direct method to obtain the high temperature needed appeared to be the use of an in-exhaust-stream fuel burner or heater. An initial attempt to increase the exhaust gas temperature at idle (400 rpm on stationary test engine) was to utilize two Robert Bosch cold starting aids (intake air preheaters). These devices are readily available in Europe, but not in the United States. They are quite compact, and have a built-in 24 volt thermal ignition source. These devices are normally applied in the intake manifold, and are located where the flow of air is fully developed around the flame holders. After a brief experiment with the two units, we found them unsuitable for trap regeneration purposes. The fuel flow was much too low (about 1 lb/hr), and the units would require careful placement in the exhaust duct to achieve clean burning.

As an alternative, a fuel burner combustor assembly from a distillate-fueled fan-forced portable space heater was obtained at reasonable cost (about $100) from Stone Construction Equipment,Inc. The steady-state combustor assembly consisted of a burner can, containing the fuel nozzle and spark igniter, and a secondary chamber for additional air. The unit was rated for approximately 160,000 BTU/hr. Modifications were made to adapt the "burner can" to the exhaust system. Figure 1 illustrates the basic layout of the

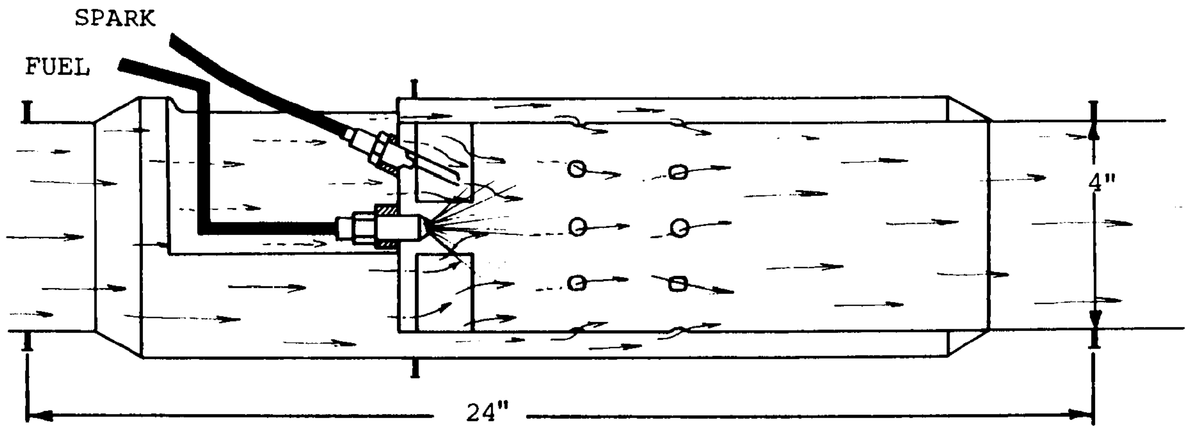


Figure 1. Burner assembly used in exhaust duct

"fuel burner" as used in this program. The burner assembly was constructed so that it could be removed from the exhaust system and the "combustor can" cover removed for modification to the burner can during development experiments. Selection of this burner-nozzle size was based on the following assumptions:

1. Idle Exhaust Flow @ 400 rpm of DDAD 6V-71 is about 500 lb/hr @ 200°F (660°R)

2. Specific heat of exhaust gases (at idle) is the same as for air @ 0.24 BTU/lb °R

3. Heating Value of No. 1 diesel fuel is 18,000 BTU/lb

4. Exhaust gases would have to reach 1200°F (1660°R) to initiate trap regeneration, and

5. Fuel rate of burner = $\frac{500\ lb_{air}/hr \times 0.24\ BTU/lb_{air}\ ^\circ R \times (1660^\circ R - 660^\circ R)}{18{,}000\ BTU/lb\ fuel}$

$= 6.67$ lb fuel/hr

6. Assume 7-10 lb fuel/hr nozzle flow would be needed to account for system heat losses.

The selected spray nozzle was designed to operate with a nominal fuel pressure of 125 to 90 psig. The burner flame was ignited by use of a spark plug with extended electrodes.

Since regeneration was to be conducted during idle, exhaust oxygen was expected to be about 18 percent. Assuming a/f ratio of 14.6 for burner operation, only 146 lbs/hr of the 500 lb/hr exhaust (air) flow would be needed for combustion of 10 lb/hr burner fuel, so no problem with oxygen deficiency was expected.

Preliminary operation of the regeneration burner shown in Figure 2, was performed. The spark ignition system worked well, and burner light-off was easily achieved. The flame obtained with this first attempt appeared to be very rich, in that it was smokey and very yellow in color. The fuel nozzle flowrate was determined to be about 5 lb/hr at 100 psi. This flowrate was well below the 7-10 lb/hr anticipated to provide some latitude for system heat loss and burner inefficiency.

Some very preliminary experiments with air deflection into the nozzle fuel spray portion indicated the need for improvement of the air handling method. A relatively crude air deflector was made to introduce the combustion air in a swirling motion as shown in Figure 3. This made a vast improvement in the appearance of the flame quality, and gave burner exhaust temperature of about 800°F. Performing a few experiments with attempts to introduce more air in front of the flame, instead of after the flame, caused the ignition to be somewhat erratic and the flame to be too lean (blue in color, but some puffs of white smoke). Based on these observations, larger nozzles were ordered; one at 7 lb/hr at 100 psi, and one at 9 lb/hr at 100 psi.

The 9 lb/hr fuel burner nozzle was installed in the burner assembly. Following some adjustment of the nozzle position, the burner developed exhaust temperatures in the range of 1200°F. The "cleanest" flame, with respect to observed odor and eye irritants, was obtained when the nozzle was positioned for a yellow-white flame. Not much more"optimization" of the flame burner assembly was planned for this program.

Following some engine operation at higher load, the burner assembly was removed from the system and checked. Much of the air handling fin assembly, which had been formed of brass shim stock, had cracked away. The air handling fin assembly was recut of heavier materials and the burner assembly was generally improved for durability.

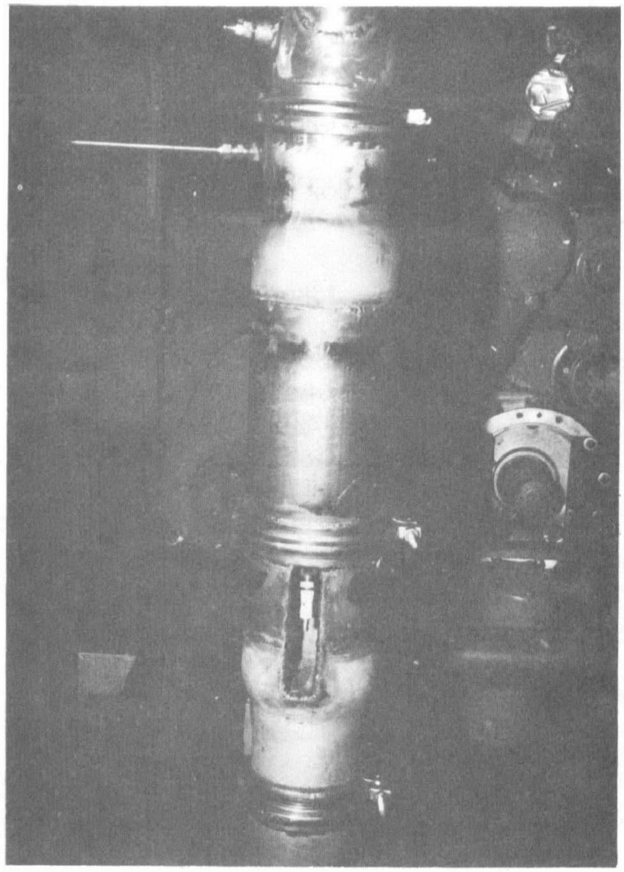


Figure 2. Regeneration burner assembly

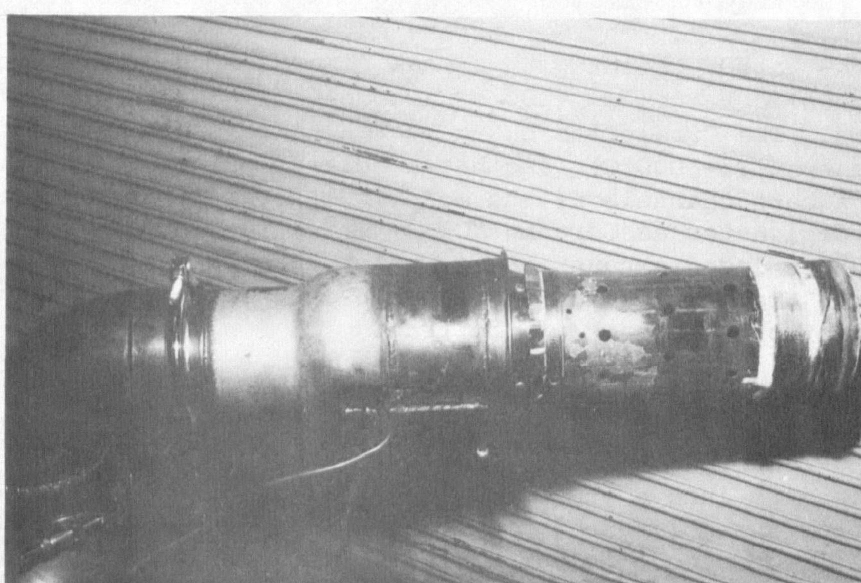


Figure 3. Regeneration burner with cover removed

In working with the burner, some problems with ignition were prevalent. These problems were overcome by reducing the fuel spray pressure to approximately 25 psig. Once ignition occurred, the fuel pressure was increased to 110 psig to obtain a good flame.

The fuel burner was mounted into the exhaust system. The burner was successfully ignited and operated in the vertical position. Burner exhaust temperatures are given in Table 4. From work with the burner, very little eye irritation or odor from the burner exhaust were noted with a fuel pressure of 100 psig. Below 100 psig, the odor and eye irritation increased dramatically. Above 100 psig, only a "dry heat" odor was noted.

TABLE 4. BURNER EXHAUST TEMPERATURES OBTAINED WITH VARIOUS FUEL PRESSURES

Fuel Pressure	Burner Exhaust Temp.
50 psig	1000°F
75 psig	1163°F
100 psig	1300°F
110 psig	1375°F
125 psig	1480°F

E. Description of Trap and Fuel Burner Installations

The particulate trap used in this work was obtained through Corning Glass Works. The trap material was Corning "Cordierite" and was designated as Corning "EX-47". The Cordierite material ($2MgO \cdot 2Al_2O_3 \cdot 5SiO_2$) has a porosity of 49 to 50 percent with a mean pore size of 12.5 microns. The substrate configuration was 100 square cells/in^2 with a wall thickness of 0.017 inches. The Cordierite has a thermal expansion of 12×10^{-7} in/in°C (average value from 25-1000°C), and has a melting point of 1410°C. Alternate cells or square channels of the monolithic configuration were plugged with a cement designated as Corning "CF-37".[5] The intentional plugging causes particulate laden exhaust gases, which enter a square channel at the front of the trap, to filter through the channels' walls to adjacent channels for exit out the back of the trap.

The ceramic portion of the trap was 12 inches long and 11.25 inches in diameter. Each substrate was built up from nine sections of 4 inch square segments cemented together, then machined to a round shape. The substrate was packed into a stainless steel shell by Arvin Automotive. The finished trap assembly was approximately 11.5 inches in diameter and 26 inches long. Thermocouples and pressure fittings were placed about 3 inches up- and down-stream of trap surface. Figure 4 shows the trap installed in the exhaust system used in this test work. A single "diffuser", illustrated in Figure 5, was welded into the trap inlet to prevent the hot gases needed for regeneration from concentrating in the center of the trap. Two trap assemblies were ordered from Corning in case of trap failure during regeneration or the need to lower exhaust pressure drop.

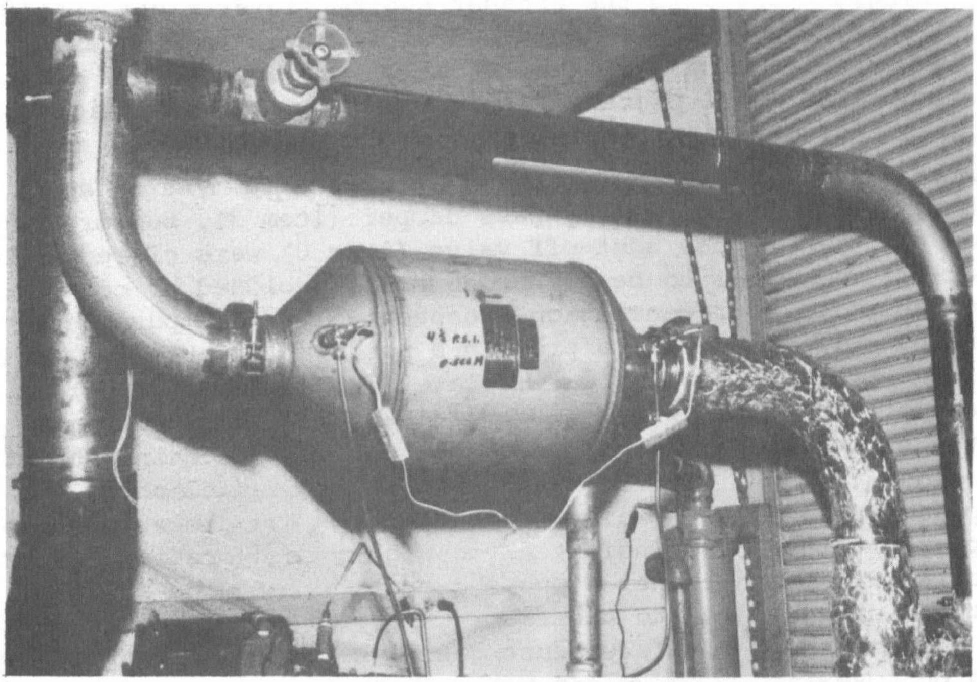


Figure 4. Particulate trap installed in exhaust system

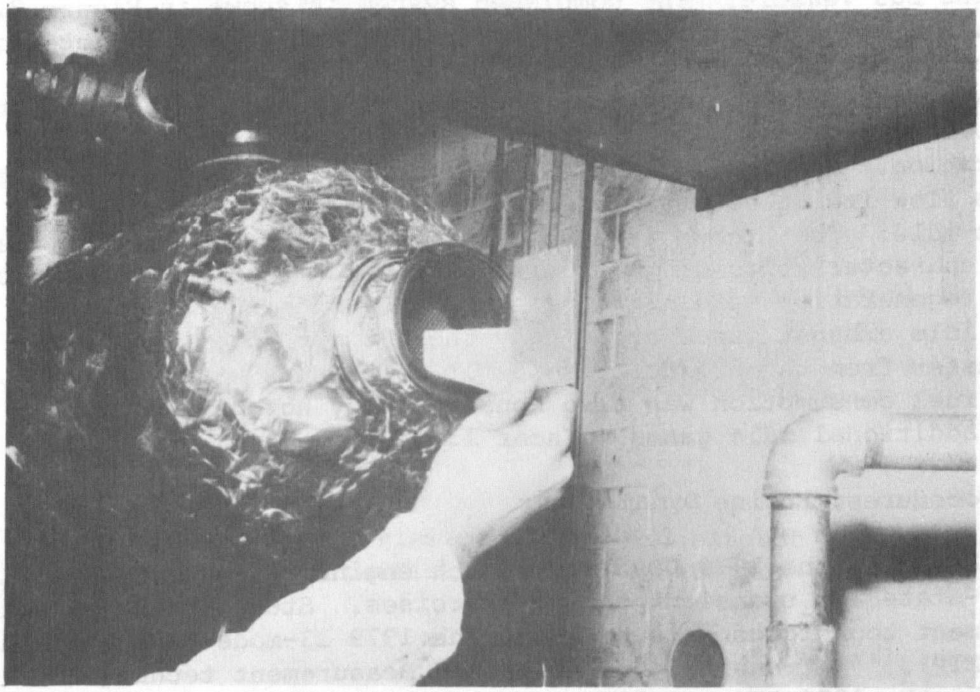


Figure 5. Trap inlet diffuser prior to installation

Figure 6 shows the engine's left and right bank exhausts brought together for single entry into the exhaust system (lower right portion of Figure 6). A side view of the exhaust system is given in Figure 7. There were three damper valves and one shut-off valve, along with the regeneration burner and dummy-trap spool piece. During normal engine operation, or trap particulate accumulation, engine exhaust was routed across the main exhaust damper (item 2) and through the trap or the dummy-trap spool piece (item 5); while the burner by-pass damper (item 3), burner-trap damper (item 4), and by-pass shut-off valve (item 6) were closed. The by-pass shut-off valve was to be either completely closed or completely open for accumulation or regeneration, respectively. The purpose of the by-pass shut-off valve was to provide a positive exhaust gas seal during engine operation for trap particulate accumulation. In order to initiate regeneration with the engine at idle, the by-pass shut-off valve and the burner-by-pass damper were opened, and the main exhaust damper was closed. Once ignition of the burner was established, the burner-trap damper was opened while the burner-by-pass damper was closed. If the trap exit temperature indicated too high a regeneration temperature, the burner-trap and burner-by-pass dampers were to be adjusted to reduce heat and oxygen input to the trap; or the fuel to the burner was to be shut off and the engine's exhaust gas flow routed through the trap for cooling purposes.

Once sample collection was completed on the engine mounted to the engine dynamometer, the trap was regenerated and the "clean" trap and the associated exhaust piping system were transferred from the stationary engine to the bus vehicle. The completed system is shown in Figure 8. The fuel burner was removed for test work to prevent potential deterioration to the burner assembly. Note the additional gate valve mounted parallel with the fuel burner position. This additional valve was used to "bleed off" excess idle exhaust gases during fuel burner operation for regeneration. The fuel burner had been set up to perform using the exhaust gas flow from a 400 rpm idle. The bus mounted engine was set up for 600 rpm idle. The higher idle speed of the bus engine altered the combustion characteristics of the fuel burner, such that high temperatures needed for regeneration were not attainable. By bleeding off the additional idle exhaust gases created by the 600 rpm idle, the fuel burner transfer from the engine dynamometer to the bus was simplified, and burner fuel consumption was also conserved (by not having to heat all of the additional idle gases to near 1300°F).

F. Test Procedures, Engine Dynamometer

Emissions from the 1979 DDAD 6V71 Coach engine were measured during both steady-state and transient engine exercises. Steady-state operation and measurement techniques were based on the 1979 13-mode Federal Test Procedure (FTP).[1] Transient operation and measurement techniques were based on the 1984 FTP and 1986 Proposed Heavy-Duty FTP, which includes particulate sampling and analysis.[2,5] In addition, emissions were measured over an experimental transient bus cycle.

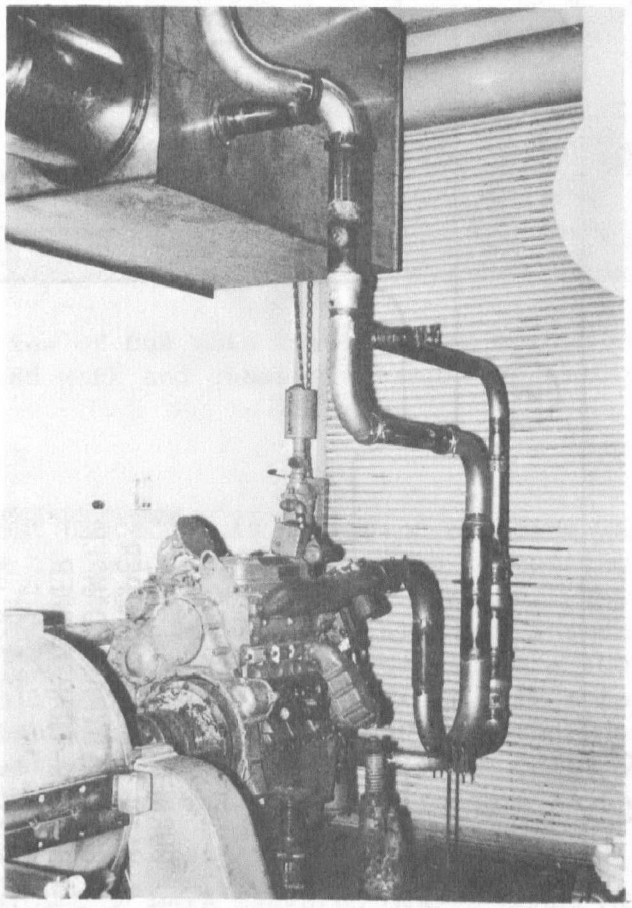


Figure 6. Overall view of engine and exhaust system used for particulate trap evaluation

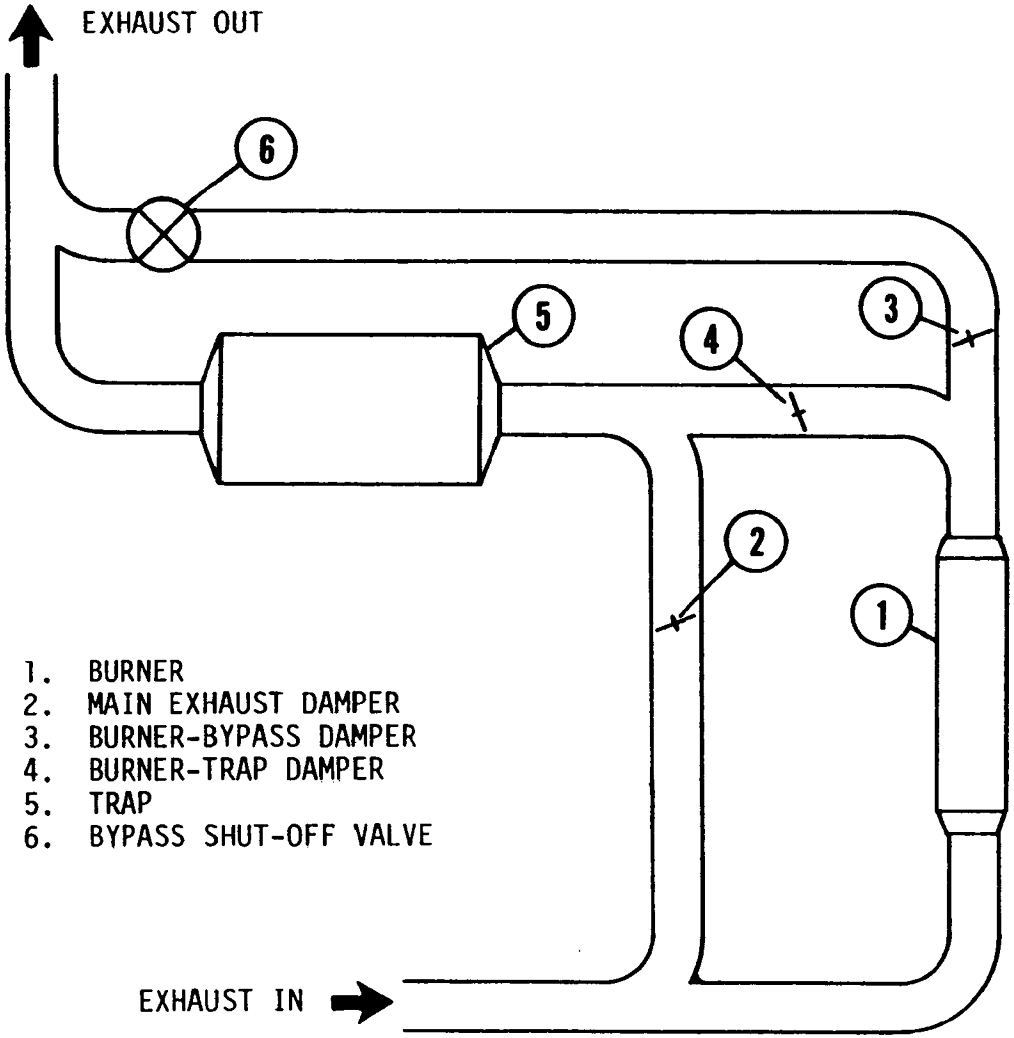


Figure 7. Exhaust system for DDAD 6V-71 trap experimentation

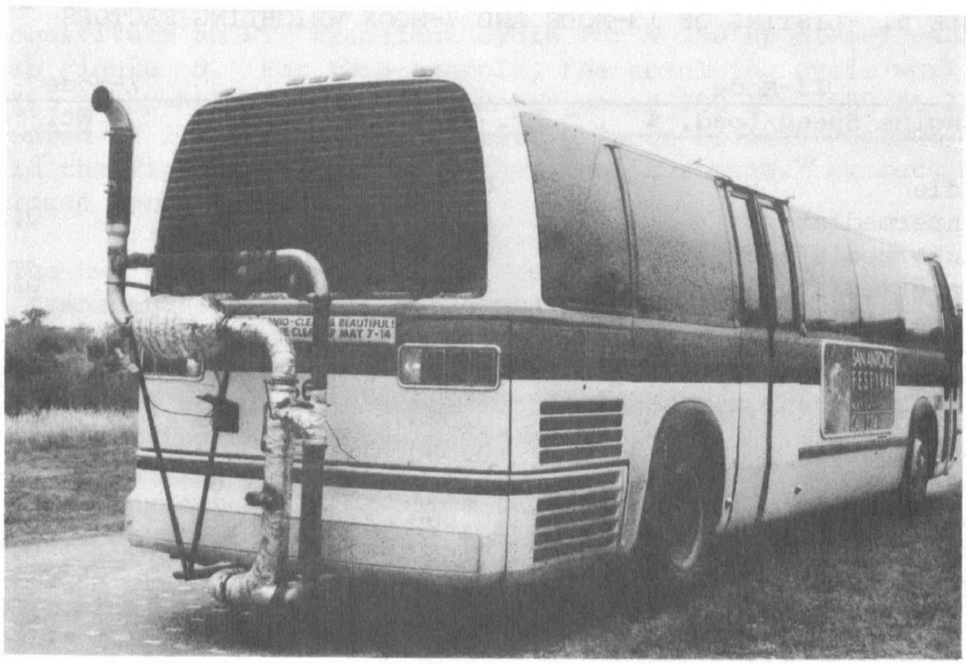


Figure 8. View of bus with trap exhaust system installed for road work and chassis dynamometer testing

The 13-mode test procedure is an engine exercise which consists of 13 individual modes of steady-state operation. Starting with a fully warmed engine, the first mode is an idle condition. This idle is then followed by 2, 25, 50, 75 and 100 percent load at intermediate speed followed by another idle mode; then to rated speed - 100, 75, 50, 25, and 2 percent of full load, followed by a final idle mode. Intake air, fuel, and power output are monitored along with other data to be used in calculating modal emission rates. A 13-mode composite emission rate is calculated on the basis of modal weighting factors as specified in the Federal Register.(1)

Unregulated emissions were measured over 7 modes of steady-state operation instead of 13 modes. This 7-mode procedure is a variation of the 13-mode procedure and consists of only the 2, 50 and 100 percent loads at intermediate and rated speeds, plus one idle condition.

On the basis of the 13-mode FTP weighting factors, 7-mode composite emissions were computed using weighting factors shown in Table 5. As the number of modes decreases, each modal point represents more time in mode and a wider range of power; thus the weighting for each of the 7 modes must be increased compared to its factors for 13-mode use. For both the 13-mode and 7-mode procedures, the idle condition accounts for 20 percent of the composite value (equivalent to 20 percent of operating time).(12)

TABLE 5. LISTING OF 13-MODE AND 7-MODE WEIGHTING FACTORS

13-Mode			7-Mode	
Mode	Engine Speed/Load, %	Wt. Factor	Mode	Wt. Factor
1	Idle	0.067		
2	Intermediate/2	0.080	1	0.12
3	Intermediate/25	0.080		
4	Intermediate/50	0.080	2	0.16
5	Intermediate/75	0.080		
6	Intermediate/100	0.080	3	0.12
7	Idle	0.067	4	0.20
8	Rated/100	0.080	5	0.12
9	Rated/75	0.080		
10	Rated/50	0.080	6	0.16
11	Rated/25	0.080		
12	Rated/2	0.080	7	0.12
13	Idle	0.067		
	Composite	1.000	Composite	1.00

Transient engine operation was performed in accordance with the 1984 Transient FTP for Heavy-Duty Diesel Engines.[2] The procedure specified a transient engine exercise of variable speed and load, depending on the power output capabilities of the test engine. The cycle required relatively rapid dynamometer control, capable of loading the engine one moment and motoring it the next. The system used in this program consisted of a GE 570 hp motoring/ 600 hp absorbing dynamometer (rated at 3150 to 7000 rpm) with a suitable control system fabricated in-house.

The 1984 Transient cycle is described in the Federal Register by means of percent torque and percent rated speed for each one-second interval, over a test cycle of 1199 seconds duration. The 20-minute transient cycle, developed from heavy-duty truck data, is composed of four five-minute segments. The four segments are described below:

Transient Cycle	
Segment	Time, sec.
New York Non-Freeway (NYNF)	297
Los Angeles Non-Freeway (LANF)	300
Los Angeles Freeway (LAF)	305
New York Non-Freeway (NYNF)	297

In order to generate the transient cycle for the DDAD 6V-71 engine, the engine's full power curve was obtained from 400 rpm to maximum no load engine speed. Data from this "power curve," or engine map, was used in conjunction with the specified speed and load percentages to form the transient cycle.

As an example, a graphic presentation of speed and torque commands which constitute an FTP transient cycle for a 250 hp diesel engine is given in Figure 9. For this example, the resulting cycle work was 11.68 kW-hr (15.66 hp-hr) based on a peak torque of 880 N•m (650 ft-lbs) and a rated speed of 2200 rpm. The relatively large negative torque commands shown in the figure are to insure that the "throttle," or rack control, goes closed for motoring operation.

The two NYNF segments, which are initial and final cycle segments of the transient cycle, together contain approximately 23 percnet of the total reference work called for by the transient cycle. The LANF segment contains 20 percent, and the LAF contains 57 percent of the total transient cycle reference work. This comparison illustrates that most of the work is produced during the LAF cycle segment.

The transient cycle is perceived as a lightly-loaded duty cycle. The average duty factor over the entire transient cycle is approximately 20 percent of available engine power. The NYNF only calls for an average of 9 percent of the maximum power available from the engine; whereas the LANF calls for approximately 15 percent and the LAF requires about 45 percent. In addition, each NYNF segment contains 165 seconds of idle and 27 seconds of motoring, the LANF contains 98 seconds of idle and 79 seconds of motoring, and the LAF segment contains 11 seconds of idle and 45 seconds of motoring.

Of the 1199 seconds of the transient cycle, closed rack commands account for 617 seconds. Therefore, the engine must attempt to produce the reference cycle work within the remaining 582 seconds. These statistics mean that the engine has to produce an equivalent of 40 percent of its These observations stress the relative importance of pollutant emissions during idle, accelerations and medium- to light-loads conditions.

A Transient FTP Test consists of a cold-start transient cycle and a hot-start transient cycle. The same engine control or command cycle is used in both cases. For the cold-start, the engine was operated over a "prep" cycle, then allowed to stand overnight in an ambient soak temperature of 20 to 30°C (68 to 86°F). The cold-start transient cycle begins when the engine is cranked for cold start-up. Upon completion of the cold-start transient cycle, the engine is shut down and allowed to stand for 20 minutes. After this hot soak period, the hot-start cycle begins with engine cranking.

All engines react somewhat differently to the transient cycle commands, due to both cycle and engine characteristics. In order to judge how well the engine follows the transient cycle command, engine responses are compared to engine commands using least squares regression techniques and several statistics are computed. According to the Federal Register, the following regression line tolerances should be met.[2]

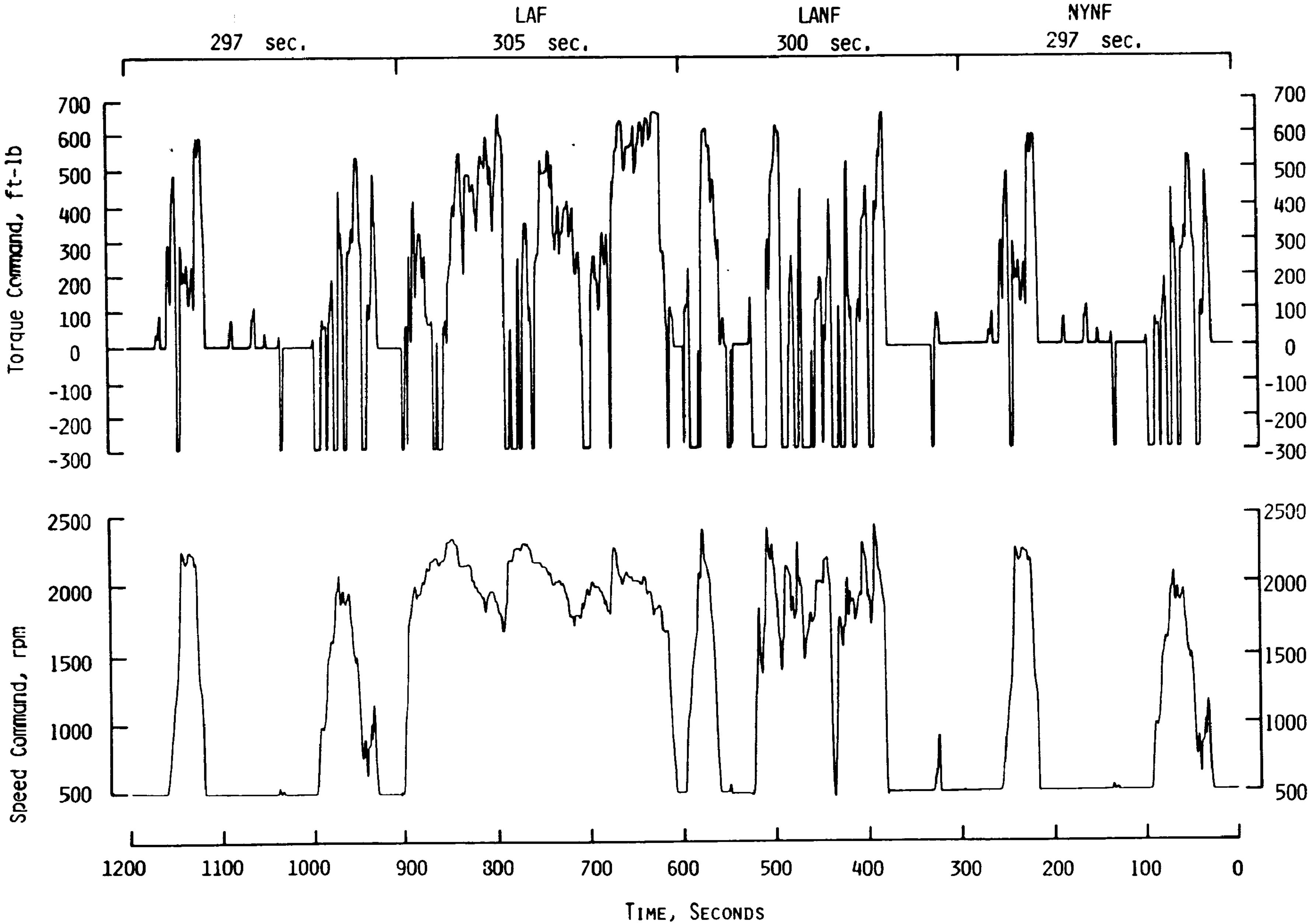


Figure 9. Graphic representation of torque and speed commands for the 1984 Transient FTP cycle for a 250 hp at 2200 rpm diesel engine

REGRESSION LINE TOLERANCES

	Speed	Torque	Brake Horsepower
Standard Error of Estimate (SE) of Y on X	100 rpm	13% of Maximum Engine Torque	8% of Maximum Brake Horsepower
Slope of the Regression Line, M	0.970 1.030	0.83-1.02 Hot 0.77-1.02 Cold	0.89-1.03 (Hot) 0.87-1.03 (Cold)
Coefficient of Determination, R^2	0.9700 1/	0.8800 (Hot) 1/ 0.8500 (Cold) 1/	0.9100 1/
Y Intercept of the Regression Line, B	±50 rpm	±15 ft lbs	±5.0 of brake horsepower

1/ Minimum

In addition to these statistical parameters, the actual cycle work produced should not be more than 5 percent above, or 15 percent below, the work requested by the command cycle.

If the statistical criteria are not met, then adjustments to throttle servo linkage, torque span points, speed span points, and gain to and from error feedback circuits can be made in order to modify both the engine output and the dynamometer loading/motoring characteristics. After completion of the cold-start and the hot-start transient cycles, transient composite emissions results are computed by the following:

$$\text{Brake Specific Emissions} = \frac{1/7 \text{ (Mass Emissions, Cold)} + 6/7 \text{ (Mass Emissions, Hot)}}{6/7 \text{ (Cycle Work, Cold)} + 6/7 \text{ (Cycle Work, Hot)}}$$

Similar to the 1984 Transient FTP cycle which was developed from heavy-duty truck data, a bus cycle was developed from CAPE-21 bus data. The bus cycle was first introduced as a research test cycle during the heavy-duty diesel baseline test work.[13] It was used in this program to indicate emissions trends from the DDAD coach engine in city bus applications. The 833 second transient bus cycle is composed of three segments, as shown below.

Bus Cycle

Segment	Time, Seconds
New York Combined	273
Los Angeles Combined	287
New York Combined	273

As an example, a graphic presentation of the speed and torque commands which constitute the bus cycle used for a 250 hp diesel engine is given in Figure 10. For this example, the resulting cycle work was 5.57 kW-hr (7.47 hp-hr) based on a peak torque of 880 N•m (650 ft-lbs) and a rated speed of 2200 rpm. The bus cycle was run only as a hot-start test cycle, and was always preceded by a 20-minute soak.

The engine was also operated over the 1979 Smoke FTP exercise.(1) It essentially consists of a 5-minute idle followed by full throttle acceleration to rated speed, and finally, a full throttle lug-down from rated speed to intermediate speed. This transient smoke test cycle was run only for the measurement of smoke emissions.

During steady-state or modal engine exercises, regulated and some unregulated gaseous emissions can be sampled from the raw exhaust stream since a representative and proportional sample can be obtained. Obtaining proportional samples during transient engine operation requires the use of a constant volume sampler (CVS).(6) All transient cycle test work run for regulated emissions of HC, CO, and NO_x, as well as particulate was conducted with a main tunnel flow of 1000 SCFM, which provided approximately a 4:1 cycle dilution ratio of the total exhaust introduced for gas sampling. Unregulated gaseous emissions of aldehydes, individual hydrocarbons, phenols, and odor were sampled from the primary tunnel during the transient testing. During these runs for regulated emissions, particulate mass emissions were determined by use of a small secondary dilution tunnel. This small secondary tunnel, shown in Figure 11, is attached to the primary tunnel and dilutes the primary-diluted exhaust further to an overall ratio of about 12:1. The small secondary dilution tunnel was operated at approximately 4 SCFM total flow in order to collect particulate on two 90 mm T60A20 Pallflex filters, in series. Weight gains from these two filters were used to determine the filter effeciency. If the filter efficiency was greater than or equal to 95 percent, then only the weight gain from the first filter was used; whereas if the filter efficiency was less than 95 percent, then weight gains from both filters were used to determine the total particulate mass emission from the engine.

In order to obtain large particulate samples for organic extraction and to obtain samples of total particulate for other analysis during transient operation, the primary tunnel was operated as a single-dilution CVS. To obtain approximately a 12:1 dilution ratio, the CVS flow was increased to about 4500 SCFM during the transient cycle, which permitted collection of large quantities of particulate on 20x20 inch filters.

Large filter holders and the associated tunnel are shown in Figure 12. This same CVS system was used to collect particulate samples for steady-state operation of the engine, by altering the main dilution tunnel flow to accommodate the total exhaust from the engine without exceeding 52°C (125°F) at the particulate filter face. Figure 12 shows portions of the CVS sampling system.

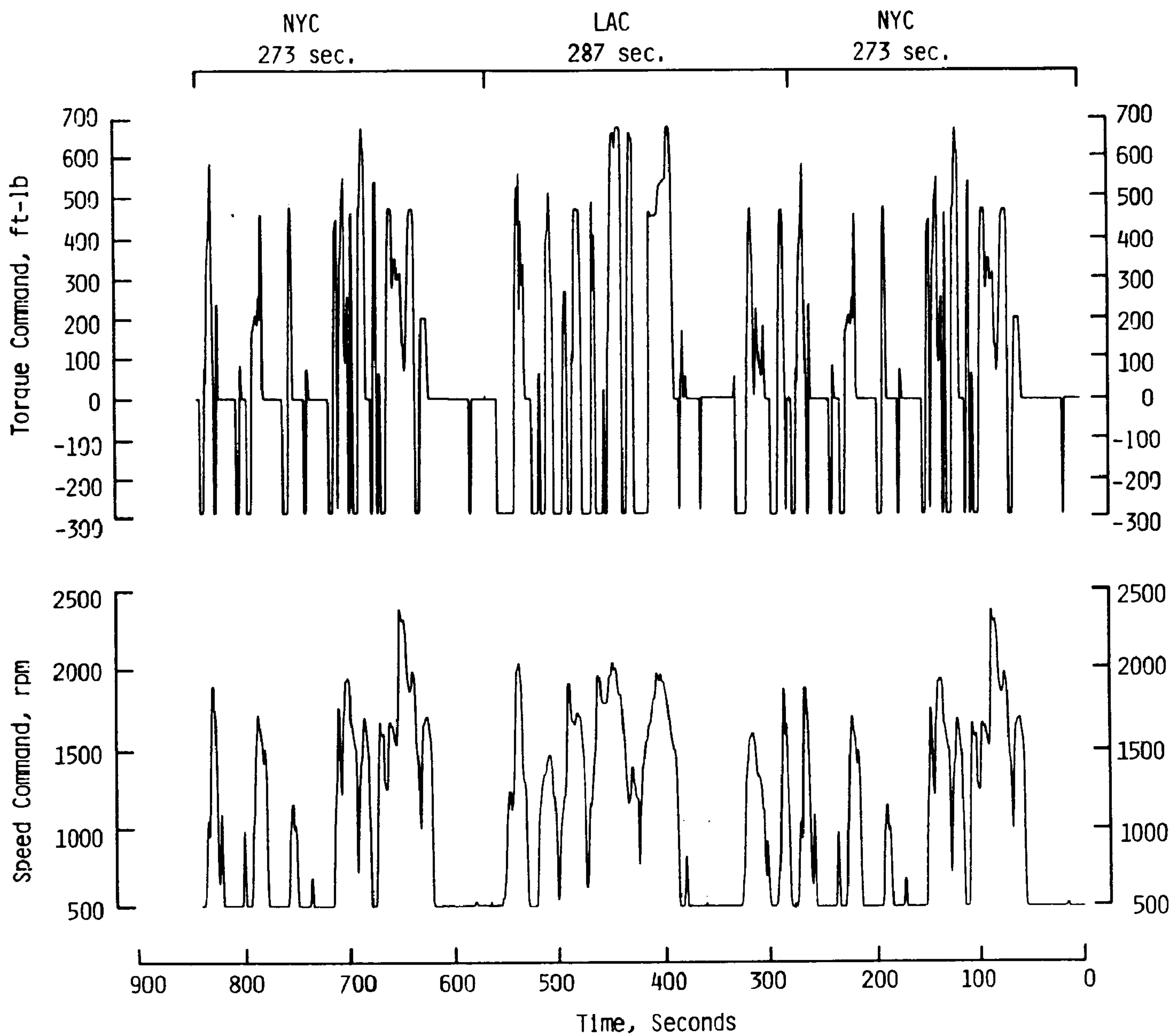


Figure 10. Graphic representation of torque and speed commands for the experimental bus cycle for a 250 hp at 2200 rpm diesel engine

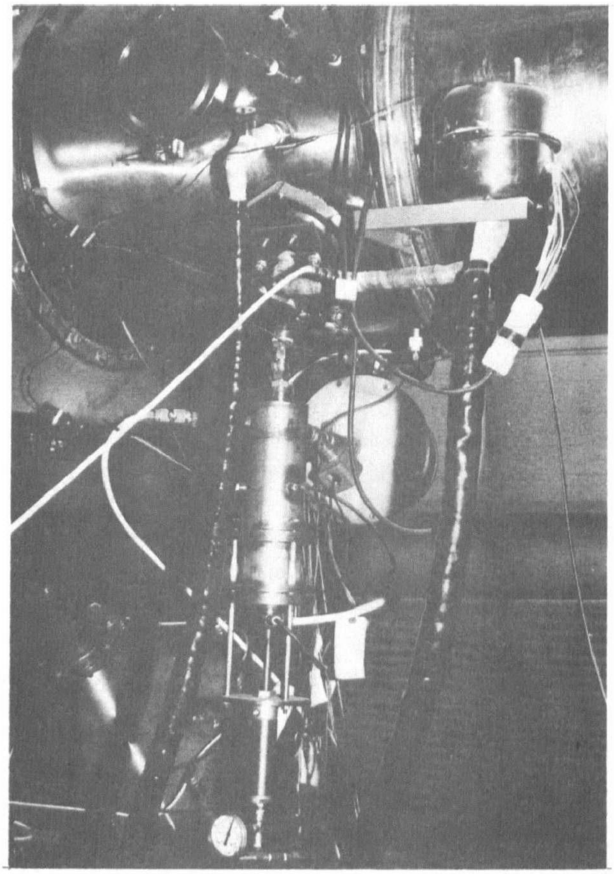


Figure 11. Secondary dilution tunnel for particulate mass rate by 90 mm filters

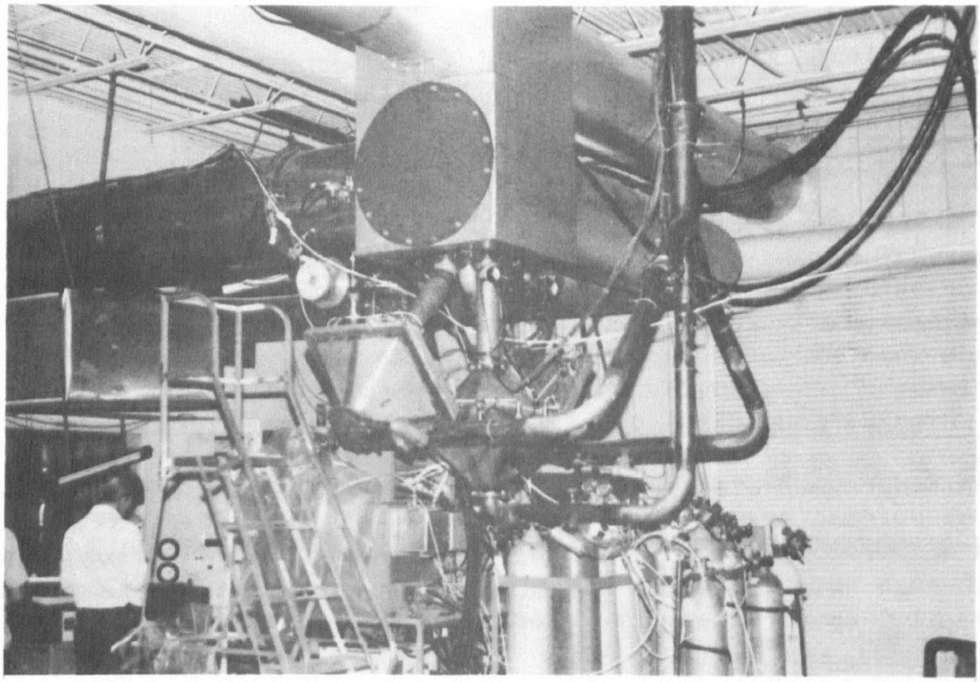


Figure 12. Large 20x20 filter holders attached to primary tunnel of CVS

G. Test Procedures, Chassis Dynamometer

Emissions from the 1980 GMC RTS-II coach vehicle were measured over a chassis version of the heavy-duty transient test and the heavy-duty transient bus cycle. Emissions measurement techniques were essentially the same as used during engine dynamometer testing of the bus engine. Test procedures outlined in the EPA Recommended Procedure were followed as closely as was practical.(7)

The procedure specified a speed-time exercise to be followed, similar to that used in chassis dynamometer testing of light-duty vehicles. The chassis dynamometer used in this program was essentially a tandem-axle Clayton heavy-duty chassis dynamometer modified by the addition of eddy current power absorbers. Electronic programming of the system enables obtaining essentially any required speed-power curve. By utilizing an electrical signal from the vehicle braking system, electrical braking of the dynamometer rolls is also provided. Each of the absorption units in tandem has dual rolls that are 8.625 inches in diameter. Inertia simulation is provided by an appropriate combination of directly-connected inertia wheels. The inertia wheels and eddy current power absorbers are shown in Figure 13. Maximum inertia simulations readily attainable are 49,000 pounds for single-drive-axle vehicles and 76,000 pounds for tandem-drive-axle vehicles. Using the programmable dynamometer, the procedure developed for road load simulation of a vehicle on the dynamometer involves establishing the speed-power curve, determining of inertia simulation, and determining system friction.

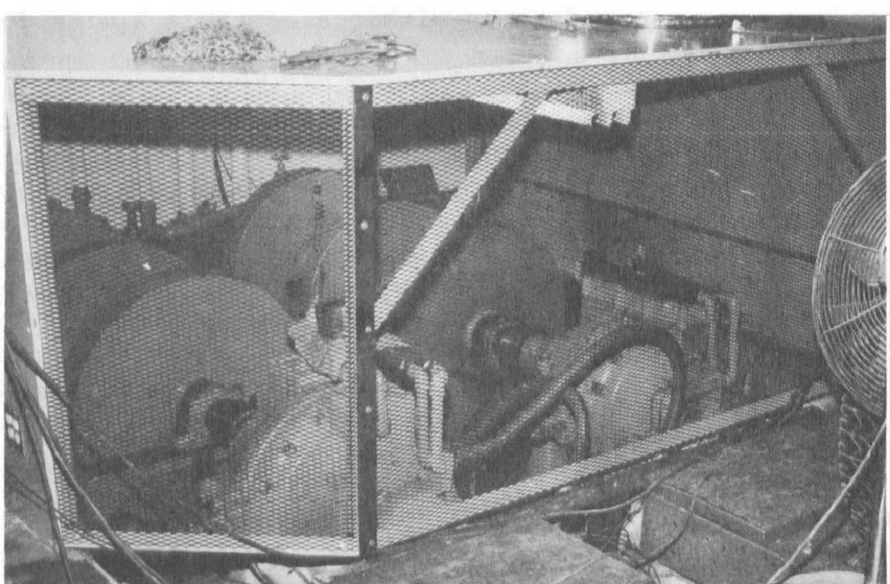


Figure 13. Chassis dynamometer inertia wheels and eddy current power absorption units

The equation selected for calculation of the speed-power curve to be used for evaluations on the chassis dynamometer is as follows:

$$RLP = F \times 0.67(H-0.75)W \times (V/50)^3 + 0.00125 \times LVW \times V/50$$

Where:

RLP = Road Load Power in horsepower
F = 1.00 for tractor-trailer and 0.85 for city bus
H = Average maximum height in feet
W = Average maximum width in feet
LVW = Loaded vehicle weight in pounds
V = Velocity in mph

The equation used for determination of dynamometer torque and load are as follows:

Dynamometer Torque = HP×134.8/mph, foot-pounds
Dynamometer Load = Torque×12/Load Arm in inches, pounds

In keeping with the general provision in the EPA Recommended Procedure,[7] the equivalent inertia set in the dynamometer system for evaluation of a tractor-trailer was equal to 70 percent of the gross combined weight. For buses, the equivalent inertia is equal to the sum of the empty weight, plus half passenger load, plus the driver (at 150 pounds per person), plus the equivalent inertia weight of the nonrotating vehicle wheel assemblies. For the GMC RTS-II, an inertia weight of 28,300 pounds was used in this test work. A deviation equal to one percent of the total inertia, rather than the 250 pounds specified in the EPA Recommended Procedure, was assumed to be within acceptable limits for such test work.

With the vehicle installed on the dynamometer and with the appropriate inertia wheels connected, the total system absorbed horsepower was determined using coastdowns. This was accomplished by obtaining repeatable 55 to 5 mph coastdown speed vs time data and then solving for the instantaneous decelerations. From instantaneous decelerations, the power absorption of the vehicle-dynamometer system was determined as a function of vehicle speed. The speed-power curve for programming into the dynamometer controller was then determined by difference between the total power required on the road (based on previous documentation obtained under Contract 68-02-3722) and the power absorbed by the vehicle-dynamometer system.[14]

Total road load for the bus was 76.2 hp at 50 mph. Of this total, 40.8 hp was due to air resistance, and the balance of 35.4 was attributed to rolling resistance.

Figure 14 shows the rear axle of the bus on the front pair of rolls of the programmable dynamometer. The fans are used to minimize the potential for tire damage. Tire pressure was 100 psig, which is the normal inflation pressure during in-service operation. Figure 15 shows the front portion of the bus along with the driver's station for monitoring road load, speed, roll counts and driver's aid. To the left of the bus in this figure is the single-dilution CVS used in conjunction with heavy-duty chassis test work. Since all test work was performed under transient operation of the bus, all emission samples were taken from the CVS. This single-dilution CVS has a capacity from 1000 to 12,000 SCFM. The tunnel is 46 inches in diameter and is 57 feet long. Similar to the CVS system used for engine dynamometer testing, this single-dulition CVS has the capacity to obtain three 20x20 filter samples of particulate matter along with additional samples needed for analysis of the total particulate. Unlike the systems used with the engine dynamometer, this system used two 47 mm Pallflex filters to determine the particulate mass emissions and the respective filter efficiency.

The speed vs time trace, referred to as the Heavy-Duty Chassis Transient Test Cycle, is given in Figure 16. Of the 1060 second duration of the cycle, 326 seconds are idle. The distance over the test is 5.57 miles. The maximum speed called for by the cycle is 58 mph. The speed vs time trace of the experimental bus cycle is given in Figure 17 for comparison. Of the 1191 seconds duration of the cycle, 396 seconds are idle. The distance over the test is 2.90 miles. Both cycles originated from CAPE-21 data accumulated on several heavy-duty trucks and buses during in-service operation.

H. Analytical Procedures

The analytical systems used for each category of emission measurements are described in this section. The section is divided into two parts, the first dealing with gaseous emissions characterization and the second with total particulate emissions and the constituents of the total particulate. Gaseous emissions included HC, CO, CO_2, NO_x, and some unregulated pollutants. Unregulated gaseous emissions included individual hydrocarbons, aldehydes, phenols, and odor. Particulate emissions included determination of the total particulate mass, and its content of sulfate, metals, carbon, hydrogen, and nitrogen. The soluble fraction of the total particulate was determined using methylene chloride extraction. This soluble fraction was characterized for BaP content, boiling point distribution, and for carbon, hydrogen, nitrogen and sulfur content.

1. Gaseous Emissions

Regulated gaseous emissions of HC, CO, and NO_x were measured according to the 1979 13-mode FTP and the 1984 transient FTP.[1,2,6] The regulated emissions along with CO_2 were determined from raw exhaust samples

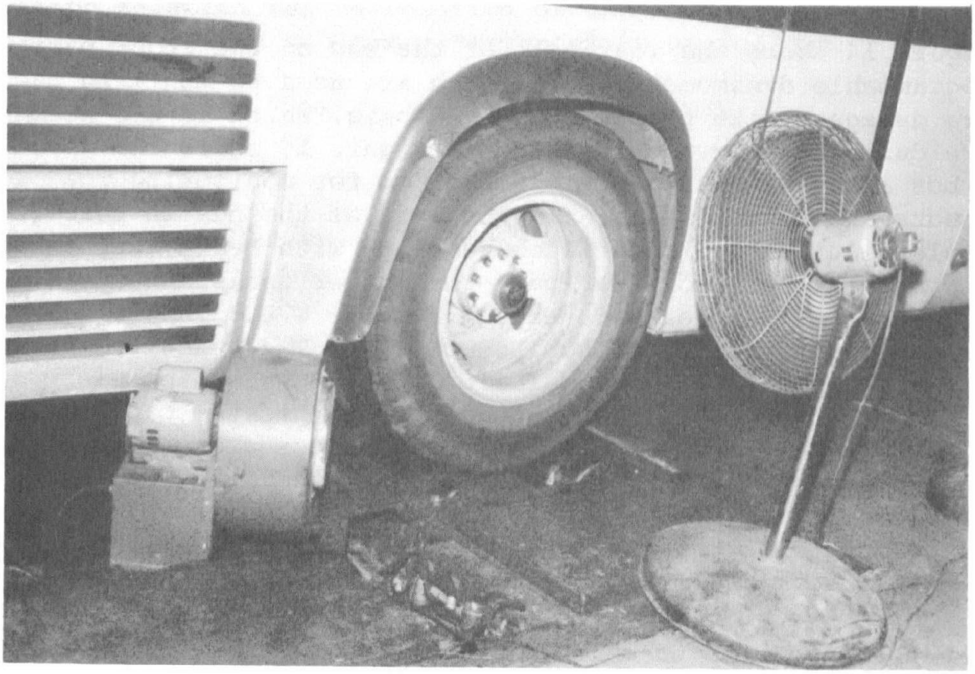


Figure 14. GMC RTS-II coach on heavy-duty chassis dynamometer rolls

Figure 15. GMC RTS-II coach alongside CVS

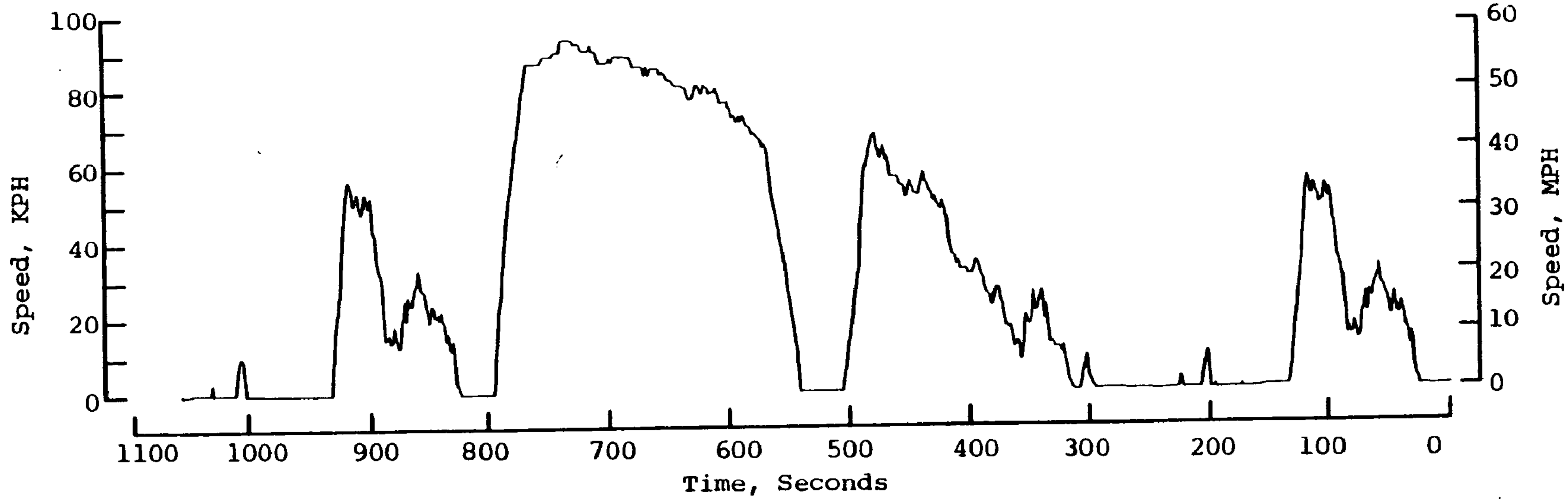


Figure 16. Heavy-duty chassis driving cycle

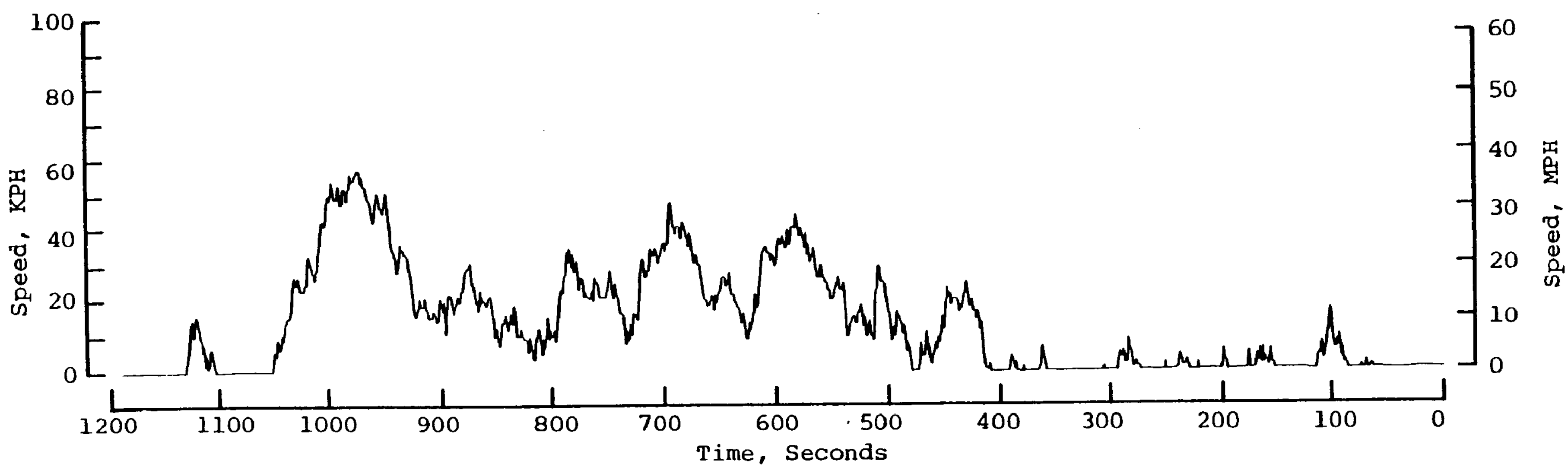


Figure 17. Heavy-duty chassis bus driving cycle

taken during the 13-mode steady-state procedure using the instrumentation shown in Figure 18. These same four constituents were determined in dilute exhaust samples taken during the transient procedure. The transient procedure required that HC be determined from integration of continuous concentration monitoring of the CVS dilute exhaust. The procedure provides the option of determining CO, CO_2, and NO_x from either dilute sample bags or from integration of continuous concentration monitoring.

Hydrocarbons were measured over both test procedures using the specified heated sample train (190°C). During steady-state operation, raw exhaust sample was transferred to a Beckman 402 heated flame ionization detector (HFID) by heated Teflon sample line. During transient oepration, CVS-diluted exhaust was taken from the main dilution tunnel using the prescribed heated probe and heated filter, and was transferred to the 402 HFID by heated stainless steel sample line.[2]

Carbon monoxide was measured during both engine test procedures using non-dispersive infrared (NDIR) instruments. Emissions of CO_2 were also determined by NDIR for use in fuel consumption calculations by carbon balance. Both CO and CO_2 were determined from raw exhaust samples transferred by heated Teflon sample lines during the 13-mode procedure. During transient test procedures, CO and CO_2 levels were determined from proportional dilute exhaust bag samples.

NO_x emissions were determined by chemiluminescence (CL) from raw exhaust during steady-state operation, and from dilute sample bags during transient operation. NO_x correction factors for intake humidity were applied as specified in the applicable test procedures for steady-state or transient testing. In the case of the transient test operation on the engine dynamometer, the engine intake humidity and temperature were controlled to 60-90 grains/lb of dry air and 68-86°F so a NO_x correction of 1.00 could be used.

Some selected individual hydrocarbons (IHC) were determined from dilute exhaust bag samples taken over transient cycles using the CVS. A bag sample of raw exhaust was also taken during the regeneration mode. A portion of the exhaust sample collected in the Tedlar bag was injected into a four-column gas chromatograph using a single flame ionization detector and dual sampling valves. The timed sequence selection valves allowed the baseline separation of air, methane, ethane, ethylene, acetylene, propane, propylene, benzene, and toluene.[15]

Aldehydes and ketones were determined using the 2,4-dinitrophenylhydrazine (DNPH) method.[15] Raw exhaust samples were taken during steady-state operation; whereas dilute samples were taken from the main CVS dilution tunnel during transient testing. In both cases a heated Teflon sample line and filter were maintained at 190°C (375°F). The procedure consists of bubbling filtered exhaust gas, dilute or raw, through glass impringer traps containing a solution of DNPH and HCl kept at 0°C. The sample apparatus used for collecting the aldehyde sample is shown on the left side of Figure 19. The aldehydes form their respective phenylhydrazone derivatives (precipitates). These derivatives are removed by filtration, and subsequently extracted with pentane and evaporated in a vaccum oven. The

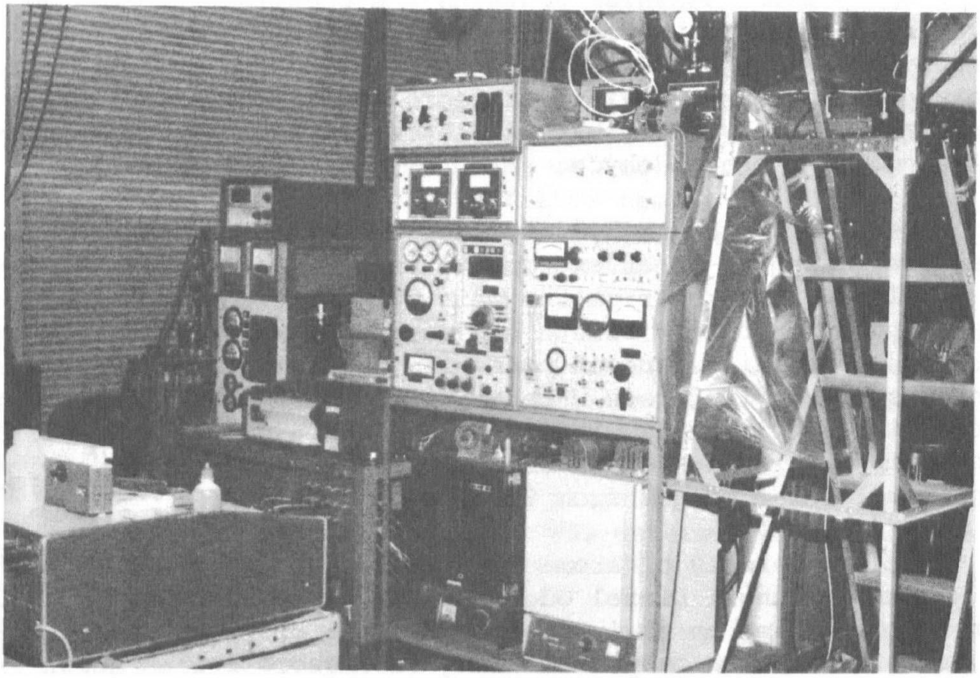


Figure 18. Emissions cart for determining concentrations of HC, CO, CO_2, and NO_x in raw exhaust

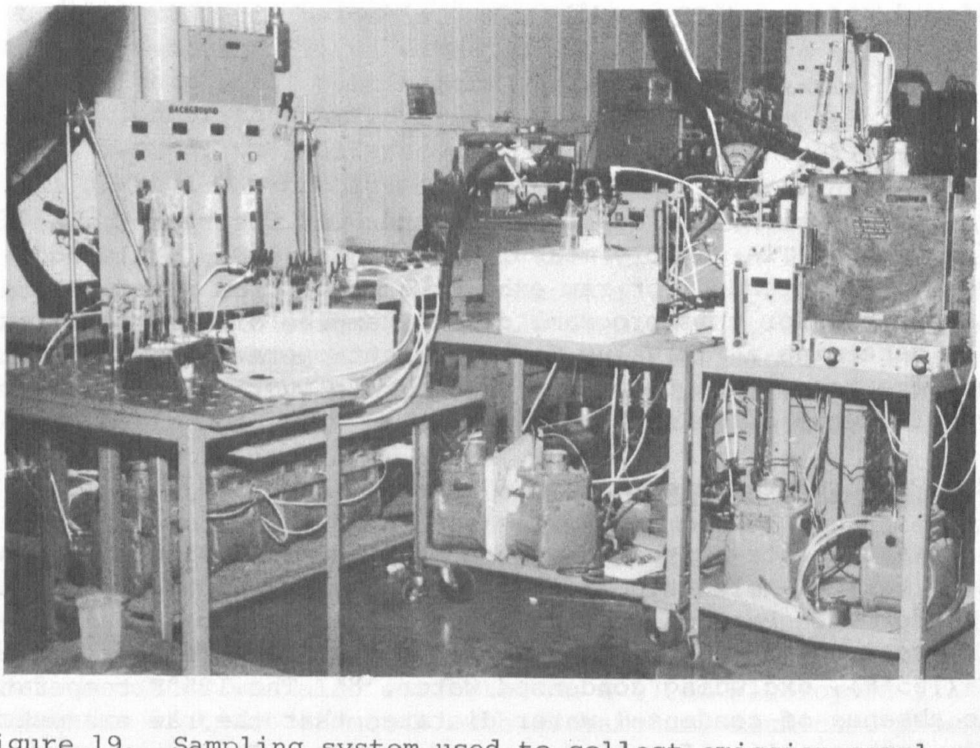


Figure 19. Sampling system used to collect emission samples for aldehydes, phenols, and DOAS (left to right)

remaining dried extract, which contains the phenylhydrazone derivatives, is dissolved in a specific volume of methanol with anthracene internal standard. A portion of this dissolved extract is injected into a liquid chromatograph and analyzed using an ultraviolet detector to separate formaldehyde, acrolein, acetone, propionaldehyde, isobutyraldehyde, methylethyketone, crotonaldehyde, hexanaldehyde, and benzaldehyde.

Phenols, which are hydroxyl derivatives of aromatic hydrocarbons, were measured using an ether extraction procedure detailed in Reference 15. Dilute samples were taken from the main CVS dilution tunnel during transient operation only. Dilute exhaust samples were filtered and collected in impingers containing aqueous potassium hydroxide (as shown in Figure 19). The contents of the impingers were acidified with sulfuric acid, then extracted with ethyl ether. This extract was injected into a gas chromatograph equipped with an FID in order to separate 11 different phenols ranging in molecular weight from 94.11 to 150.22.

Total intensity of aroma (TIA) was quantified by using the Coordinating Research Council Diesel Odor Analytical System (DOAS). Dilute or raw sample, depending on engine operation, was drawn off through a heated sample train and into a trap containing Chromosorb 102 as shown in right portion of Figure 19. The trap was later eluted and injected by syringe into the DOAS instrument, which is a liquid chromatograph that separates an oxygenate fraction (liquid column oxygenates, LCO) and an aromatic fraction (liquid column aromatics, LCA). The TIA values (TIA by LCO preferred) are defined as:

$$\text{TIA} = 1 + \log_{10} (\text{LCO}, \mu g/\ell)$$

or

$$\text{TIA} = 0.4 + 0.7 \log_{10} (\text{LCA}, \mu g/\ell)$$

A.D. Little, the developer of the DOAS instrument, has related this fraction of TIA sensory measurement by the A.D. Little odor panel.[16] The system was intended for raw exhaust samples from steady-state operating conditions, but for this program, dilute samples of exhaust were taken in order to determine a TIA value for transient operation. Where dilute samples were taken, the resulting values were increased in proportion to the overall cycle dilution ratio.

2. Particulate Emissions

Particulate emissions were determined from dilute exhaust samples utilizing various collection media and apparatus, depending on the analysis to be performed. Particulate has been defined as any material collected on a fluorocarbon-coated glass fiber filter at or below a temperature of 51.7°C (125°F), excluding condensed water.[6] The 125°F temperature limit and the absence of condensed water dictates that the raw exhaust be diluted, irrespective of engine operating mode. The temperature limit generally requires dilution ratios of approximately 12:1 (total mixture: raw exhaust).

Total particulate-rate samples were collected on 90 mm Pallflex T60A20 fluorocarbon-coated glass fiber filter media, by means of a double-dilution technique for transient operation and a single-dilution technique for steady-state operation during stationary dynamometer test work. Only single-dilution techniques were used during chassis dynamometer test work. Gravimetric weight gain, representing collected particulate, was determined to the nearest microgram after the filter temperature and humidity were stabilized. This weight gain, along with CVS flow parameters and engine data, was used to calculate the total particulate mass emission of the engine under test.

Smoke and total particulate are related in that the relative level of smoke opacity indicates the relative level of particulate. The absence of smoke, however, does not indicate the absence of particulate. Smoke was determined by the end-of-stack EPA-PHS smokemeter, which monitored the opacity of the raw exhaust plume as it issued from the 3 inch diameter exhaust pipe. Smoke opacity was determined for 13-mode operation, power curve operation, and for the smoke FTP.

Since total particulate, by definition, includes anything collected on fluorocarbon-coated glass fiber filter media, there has always been an interest in finding out what constitutes the "total particulate." The following paragraphs describe the methods and analysis used to determine some of the properties of the total particulate.

Sulfate, originating from the combustion of sulfur-containing fuel, was collected as part of the particulate matter in the form of sulfate salts or sulfuric acid aerosols. A 47 mm Fluoropore (Millipore Corp.) fluorocarbon membrane filter with 0.5 micron pore size was used to collect the sample. This total particulate sample was ammoniated to "fix" the sulfate portion of the particulate. Using the barium chloranilate (BCA) analytical method, the sulfates were leached from the filter with an isopropyl alcohol-water solution (60% IPA). This extract was injected into a high pressure liquid chromatograph (HPLC) and pumped through a column to scrub out the cations and convert the sulfate to sulfuric acid. Passage through a reactor column of barium chloranilate crystals precipitates out barium sulfate and releases the highly UV-absorbing chloranilate ions. The amount of chloranilate ion released was determined by a sensitive liquid chromatograph UV detector at 301-313 nanometers. "Sulfate" should be understood to mean $SO_4^=$ as measured by the BCA method.[15]

Carbon, hydrogen, metals, and other elements that make up the total particulate are also of interest. A sample of "total particulate" was collected on 47 mm Type A (Gelman) glass fiber filter media for the purpose of determining the carbon and hydrogen weight percentages. This analysis was performed by Galbraith Laboratories using a Perkin-Elmer Model 240B automated thermal conductivity CHN analyzer. A sample of total particulate matter was also collected on a 47 mm Fluoropore filter for the determination of trace elements such as calcium, aluminum, phosphorus, and sulfur by x-ray fluorescence. This analysis was conducted at the EPA, ORD Laboratories in Research Triangle Park, NC using a Siemens NRS-3 x-ray fluorescence spectrometer.

Diesel particulate generally contains significant quantities of condensed fuel-like or oil-like hydrocarbon aerosols generated in incomplete combustion zones. In order to determine to what extent total particulate contains these various hydrocarbons, large particulate-laden filters (20x20 inch) were washed with an organic solvent, methylene chloride, using 500 mℓ soxhlet extraction apparatus. The dissolved portion of the "total particulate" carried off with the methylene chloride solvent has been referred to as the "soluble organic fraction" (SOF). All filter handling, extraction processes, and handling of concentrated SOF were carried out according to EPA recommended protocol.[17] The SOF may be composed of anything carried over in the extraction process, so its composition is also of interest. Generally the SOF contains numerous organic compounds, many of which are difficult to isolate and quantify.

Benzo(a)pyrene (BaP) is considered to be a very general indicator of the relative poly nuclear aromatic (PNA) content of the SOF. The analytical method used for the determination of BaP is described in Reference 16. The procedure is based on high-performance liquid chromatography to separate BaP from other organic solubles in particulate matter, and it incorporates fluorescence detection to measure BaP. The instrument used was a Perkin-Elmer 3B liquid chromatograph equipped with a MPF-44 fluorescence spectrophotometer. Excitation was at a wavelength of 383 nanometers, and emission was read at 430 nanometers.

The boiling range of the SOF was determined by SwRI's Army Fuels and Lubricants Laboratory using a high-temperature variation of ASTM-D2887-73. Approximately 50 mg of the SOF was dissolved in solvent and an internal standard (C_9 to C_{11} compounds) was added. This sample was then submitted for instrumental analysis of boiling point distribution. In some cases, insufficient sample was available to use internal standards.

Carbon, hydrogen, sulfur, and nitrogen were determined for the SOF. Carbon and hydrogen content of the"dried" extract were determined by Galbraith Laboratories using a Perkin-Elmer 240B automated thermal conductivity CHN analyzer. A portion of the extract was submitted to SwRI's Army Fuels and Lubricants Laboratory for nitrogen analysis by chemiluminescence and sulfur analysis by x-ray fluorescence.

IV. RESULTS

This section describes the results obtained from numerous emissions measurements and sample analyses conducted on both the 1979 DDAD 6V71 coach engine with the trap and the 1980 GMC RTS-II coach vehicle with and without the trap. It is divided into five parts. The first part presents the results obtained to qualify the baseline emissions established for the DDAD 6V71 engine in an earlier program. The second part describes some of the pertinent details associated with trap particulate accumulation and regeneration processes used and gives a general chronology of emission sampling conducted during the program. A third part details the relative changes in HC, CO, CO_2, NO_x and O_2 gas concentrations as the trap underwent the regeneration process. The fourth and fifth parts detail the accumulated gaseous and particulate data obtained during the test work. Overall emission trends and general remarks are given along with the results.

A. Baseline Repeat

The DDAD 6V71 coach engine was mounted on the stationary dynamometer. This was the same engine characterized under Contract No. 68-03-2706 in both baseline and malfunction configurations. Upon completing installation of the engine and the exhaust system, experiments were conducted to develop the fuel burner to be used for regeneration. After regeneration fuel burner design and performance were acceptable, emphasis was placed on acquiring "baseline repeat" data.

A single 13-mode emissions tests was run on the DDAD 6V71 for comparison to results acquired prior to the malfunction program. The "original baseline" 13-mode test was conducted prior to maladjustment in that program. The "new baseline" 13-mode test run for this program was conducted with the engine reset to manufacturer's specifications. Copies of the computer printouts from both the "original baseline" (run in replicate) and "new baseline" 13-mode tests are given in Appendix A as Tables A-1, A-2, and A-3 for reference. Thirteen-mode composite values from these tests are given in Table 6.

TABLE 6. ORIGINAL AND NEW BASELINE 13-MODE EMISSION RESULTS FROM THE DDAD 6V71 COACH ENGINE

	13-Mode FTP			
	Emissions, g/kW-hr			BSFC
Test Notes	HC	CO	NO_x	kg/kW-hr
Original Baseline[a]	2.37	9.92	9.60	0.297
New Baseline[b]	1.64	9.62	9.79	0.288

[a] Average of two tests
[b] "New Baseline" represents results "without trap"

Except for HC emissions, the results from the new baseline test were nearly the same as those from the original baseline runs. Examining the modal results, the lower HC emissions appeared in all modes of operation.

In order to check the baseline emissions over the transient test cycle, the DDAD 6V71 was mapped using No. 1 diesel fuel, EM-400-F. This is the same fuel as used in the baseline/malfunction program under Contract No. 68-03-2706. Results from this most recent transient map and the original baseline map are given in Table 7. The maximum power obtained over the most recent map was about 6 percent greater than over the original map. Using the most recent map data, the transient cycle work was about 4.3 percent greater and the bus cycle work was about 3.6 percent greater than obtained with the original map data. Considering that this engine was maladjusted and then reset back to manufacturer's specifications, the repeatability appeared to be good.

Replicate transient cycle FTP and bus cycles were conducted on the engine in order to establish or confirm the engine's transient emissions baseline for regulated emissions of HC, CO, NO_x, and particulate. Transient composite and bus cycle results from these tests are given in Table 8, along with similar results from "original baseline" testing and "return to baseline" testing. Copies of the computer printouts from transient testing to establish a "new baseline" are given in Appendix B. Three transient cold-starts were run and are given as Tables B-1, B-2, and B-3. Two hot-starts are given as Table B-4 and B-5, and two bus cycles are given as Tables B-6 and B-7. "Return to baseline" test work was conducted immediately after the engine had completed test work in the malfunction configuration and the engine was reset to manufacturer's specifications. A more complete table of transient emissions will be given later, in Table 14.

Gaseous and particulate emissions from the "new baseline" repeated reasonably well compared to the levels obtained over the "original baseline"runs and the single run for the "return to baseline" emissions. As with the 13-mode test results, the HC emissions were down slightly. Over transient test operation, CO and NO_x emissions from the "new baseline" were slightly lower. The particulate emissions repeated quite well. The BSFC from the "new baseline" decreased by about 9 percent and the cycle work was up by about 10 percent over the transient composite from the "original baseline".

In addition to repeat gaseous emission tests, a "new baseline" was conducted for comparison of smoke emissions as well. Results from operating the engine over the Federal Smoke Test are given in Table 9. Repeatability of the smoke data was excellent. In addition, steady-state smoke was also checked and found to be slightly lower. Maximum power smoke over the "original baseline" ranged from 2.3 to 2.5, whereas the "new baseline" values ranged from 1.5 to 1.7 percent opacity. For 1260 rpm/full load operation, "original baseline" smoke ranged from 7.5 to 8.6, and the "new baseline" smoke ranged from 6.2 to 7.5.

TABLE 7. TRANSIENT MAP RESULTS FROM THE DDAD 6V71

Engine Speed, rpm	New Baseline[a] Torque, ft. lb.	Original Baseline Torque, ft. lb.
400	520	430
500	528	486
600	555	520
700	568	540
800	568	546
900	574	556
1000	574	554
1100	568	558
1200	561	546
1300	555	538
1400	555	534
1500	541	521
1600	535	508
1700	524	501
1800	510	488
1900	497	478
2000	485	462
2100	469	443
2200	450	420

	New Baseline[a]	Original Baseline
Idle Speed	400 rpm	400 rpm
Max. Power	188 hp @ 2100 rpm	177 hp @ 2100 rpm
Max. Torque	574 ft-lb @ 900 rpm	558 ft-lb @ 1100 rpm
Transient Test Work, hp-hr		
Segment 1	1.48	1.41
Segment 2	2.42	2.36
Segment 3	7.05	6.73
Segment 4	1.48	1.41
Total	12.42	11.91
Bus Cycle Work, hp-hr		
Segment 1	1.73	1.67
Segment 2	2.54	2.44
Segment 3	1.73	1.67
Total	6.00	5.79

[a]"New baseline" represents "without trap"

TABLE 8. COMPARATIVE BASELINE EMISSIONS FROM THE DDAD 6V71 COACH ENGINE

Cycle Type	Regulated Emissions, g/kW-hr HC	CO	NO_x[a]	Part.	Cycle BSFC kg/kW-hr	Cycle Work kW-hr
			Original Baseline			
Transient Composite	2.47	5.87	9.96	0.72	0.323	8.03
Bus Cycle	2.72	4.65	11.02	0.83	0.339	3.31
			Return to Baseline			
Transient Composite	1.73	5.76	9.26[b]	0.71	0.316	8.10
Bus Cycle	1.52	5.86	10.87[b]	1.05	0.322	3.47
			New Baseline[c]			
Transient Composite	1.90	5.18	8.17	0.75	0.294	8.85
Bus Cycle	1.93	4.13	9.02	0.78	0.302	4.09

[a] NO_x emissions based on bag measurements
[b] NO_x values projected from results obtained from continuous NO_x measurements
[c] "New Baseline represents "without trap"

TABLE 9. SMOKE OPACITY FROM THE DDAD 6V71 COACH ENGINE IN THE BASELINE CONFIGURATION

Federal Transient Smoke Cycle Opacity	Smoke Opacity, % "A"	"B"	"C"
Original Baseline	3.3	6.9	7.3
New Baseline	4.0	7.0	7.2

[a] "New baseline" represents "without trap"

On the basis of these values, no gross change in the "original baseline" was noted. Hence, it was assumed that the unregulated emissions values obtained during the "original baseline" work would be adequate to represent the engine in its present test configuration, so that the values could be used for comparative purposes when the emissions characterizations with the trap were completed.

B. Trap Particulate Accumulation and Regeneration

Prior to mounting the particulate trap into the exhaust system, a brief look at power and backpressure dependence was conducted. The results, given in Table 10, indicate about a 2 percent decrease in power with a 2.4 in. Hg increase in 13-mode exhaust restriction.

TABLE 10. FULL LOAD PERFORMANCE OF DDAD 6V71 AT RATED SPEED WITH INCREASING BACKPRESSURE

Exhaust Backpressure, in. Hg	4.2	6.0[a]	8.4
Intake Restriction, in. H_2O	25.5	25.2	24.6
Air Box Pressure, in. Hg	13.0	14.3	16.0
Engine Speed, rpm	2100	2100	2100
Brake Horsepower, observed	182.5	180.2	176.5

[a] 13-mode set points were 6.0 in. Hg exhaust backpressure and 25.0 in. Hg intake restriction

A single trap was installed in the exhaust system as shown in Figure 20. With the trap in place and all engine exhaust routed through the trap, the exhaust backpressure during maximum power operation was approximately 4.2 in. Hg. It was decided that the Δp across the trap would be monitored during the 2100 rpm/50 percent load condition During this condition, an initial trap Δp was recorded as 26 in. H_2O. Five hot-start transient cycles were conducted, representing a total work output of 58.4 hp-hr, and the Δp increased to approximately 37 in. H_2O. It was decided that this would be a sufficient trap loading to attempt regeneration.

The regeneration was conducted with the use of the burner and the engine at idle. The trap exit temperature reached a maximum of 635°C. After gradually cooling the trap, using idle gas flow, the engine was brought up to 2100 rpm/50 percent load and the trap Δp was observed as 16 in. H_2O. It was not known why the trap Δp, after regeneration, was lower than the clean Δp. The trap was visually inspected and no problems were noted. The regeneration had proceeded very slowly and no thermal shocks were suspected. The trap face had been cleaned of all particulate.

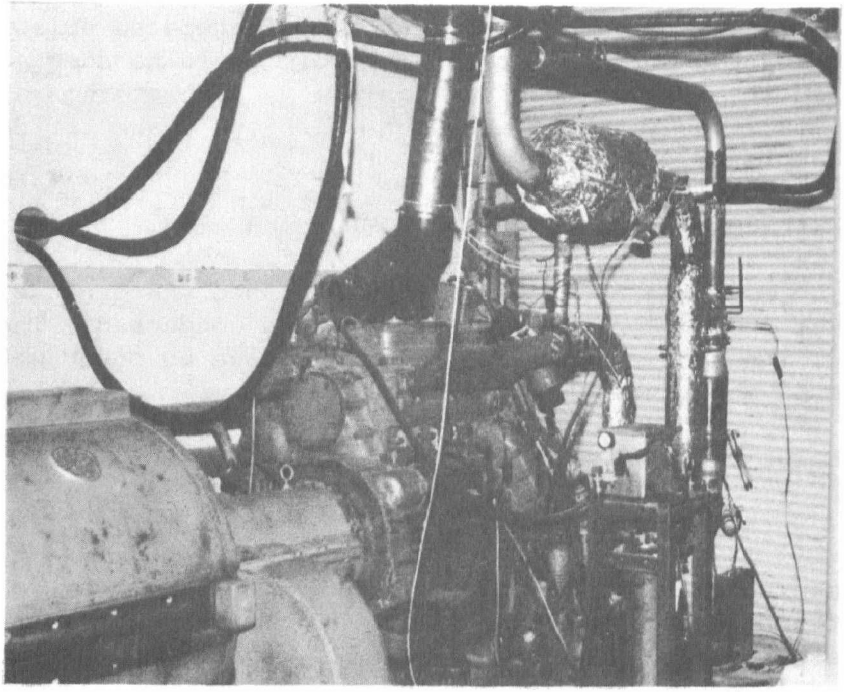


Figure 20. DDAD 6V71 with insulated exhaust system and particulate trap aftertreatment

With all the exhaust flow routed through the trap, the exhaust gases were diverted to the CVS. The CVS was operated with all particulate filter systems in operation in order to help stabilize the tunnel and sampling apparatus in anticipation of low particulate emissions. Four hot-start transients were run. The trap Δp had been increased to 33 in. H_2O at the 2100 rpm/50 percent load condition. During the next regeneration, the trap exit temperature reached a maximum of 585°C with a stable inlet gas temperature of 620°C. After cooling the trap, the Δp was 12 in. H_2O at the reference engine condition of 2100 rpm/50 percent load.

The latest trap Δp was about half the level initially obtained. It was decided that the trap Δp appeared to be very sensitive to any initial engine operation after regeneration. When the reference condition was held for a relatively long time (5 minutes), the trap Δp would increase gradually even though the exhaust temperatures had essentially stabilized. More attention was given to minimizing any engine operation immediately after regeneration was completed, until the trap Δp could be recorded.

The engine, with trap, was operated over a cold-start transient cycle for smoke measurement, then over seven modes of the 13-mode test to collect emission samples for aldehydes and DOAS. The trap Δp measured 38 in. H_2O after about 2 hours of engine operation. The trap was regenerated and the exit temperature reached a maximum of 675°C with a stabilized inlet temperature of 630°C. After allowing the trap to cool, the trap Δp was 10 in. H_2O at the reference condition.

A 13-mode emissions test was conducted while measuring raw gaseous emissions before and after the trap. The next day, replicate cold- and hot- start transient tests, along with replicate bus cycles were run for regulated emissions, particulate (by 90 mm double dilution tunnel), and for samples of individual hydrocarbons, aldehydes, phenols, and DOAS. Trap temperature and pressure data were taken over the cold-start transient cycle, and over the bus cycle. Continuous traces of these data are given in Figures 21, 22, and 23, respectively. Temperatures in and out of the trap are labeled as "T in" and "T out." Differential pressure across the trap is labeled as ΔP and the backpressure trace is labeled as "BP." The maximum trap inlet temperature reached during the 1984 Transient FTP was about 360°C, occurring around 650 seconds into the cycle. Similarly the maximum trap outlet temperature was about 330°C near the same point in the cycle. Over the bus cycle, the maximum trap inlet and outlet temperatures were 320 and 210°C, respectively, occurring near 430 seconds into the engine dynamometer cycle. The trap had accumulated particulate for about 3.5 engine hours.

The CVS flow rate was set up to 5000 cfm and the 20x20 filter holders were engaged. Replicate cold- and hot-start transient cycles along with replicate bus cycles were run in order to collect particulate samples. In addition, cold- and hot-start transient, and bus cycles were run to determine smoke opacity using the end of stack smokemeter. These tests were followed by runs for 13-mode and power curve smoke as well as the Federal Smoke Cycle. Zero smoke opacity was reocrded for all modes of engine operation with the trap. Engine-trap hours since the last regeneration were about 6.5 hours. The trap Δp measured 54 in. H_2O.

Assuming that clean trap Δp was 12 in. H_2O, the Δp had increased by about a factor of 4.5. Since there was substantial trap loading, preparations were made to characterize as many of the exhaust emissions during regeneration as possible. Figure 24 shows the loaded trap inlet. Raw exhaust samples of HC, CO, CO_2, NO_x, IHC, aldehydes, phenols, and DOAS were collected. Dilute exhaust samples of particulate were collected on various filter media for elemental and soluble analysis. During regeneration the trap exit temperature increased from 550°C to a peak of 710°C in about 36 seconds, while the inlet gas temperature was held at 600°C. The fuel to the burner was shut off when the trap exit temperature reached 700°C. The inlet gas temperature to the trap dropped quickly to about 320°C. As the temperature of the trap started to decrease, the fuel burner was re-ignited, but promptly turned off due to a sudden spike in the exit temperature from about 705°C to 800°C. The trap exit temperature fell back to 705°C within 10 seconds. The trap was allowed to cool gradually, and the engine was shut down. The trap was visually checked and no damage was apparent. Figure 25 shows the trap inlet after regeneration. Records of trap Δp across this clean up after regeneration indicated a Δp of 15 in. H_2O. This regeneration event is described in greater detail in the next section.

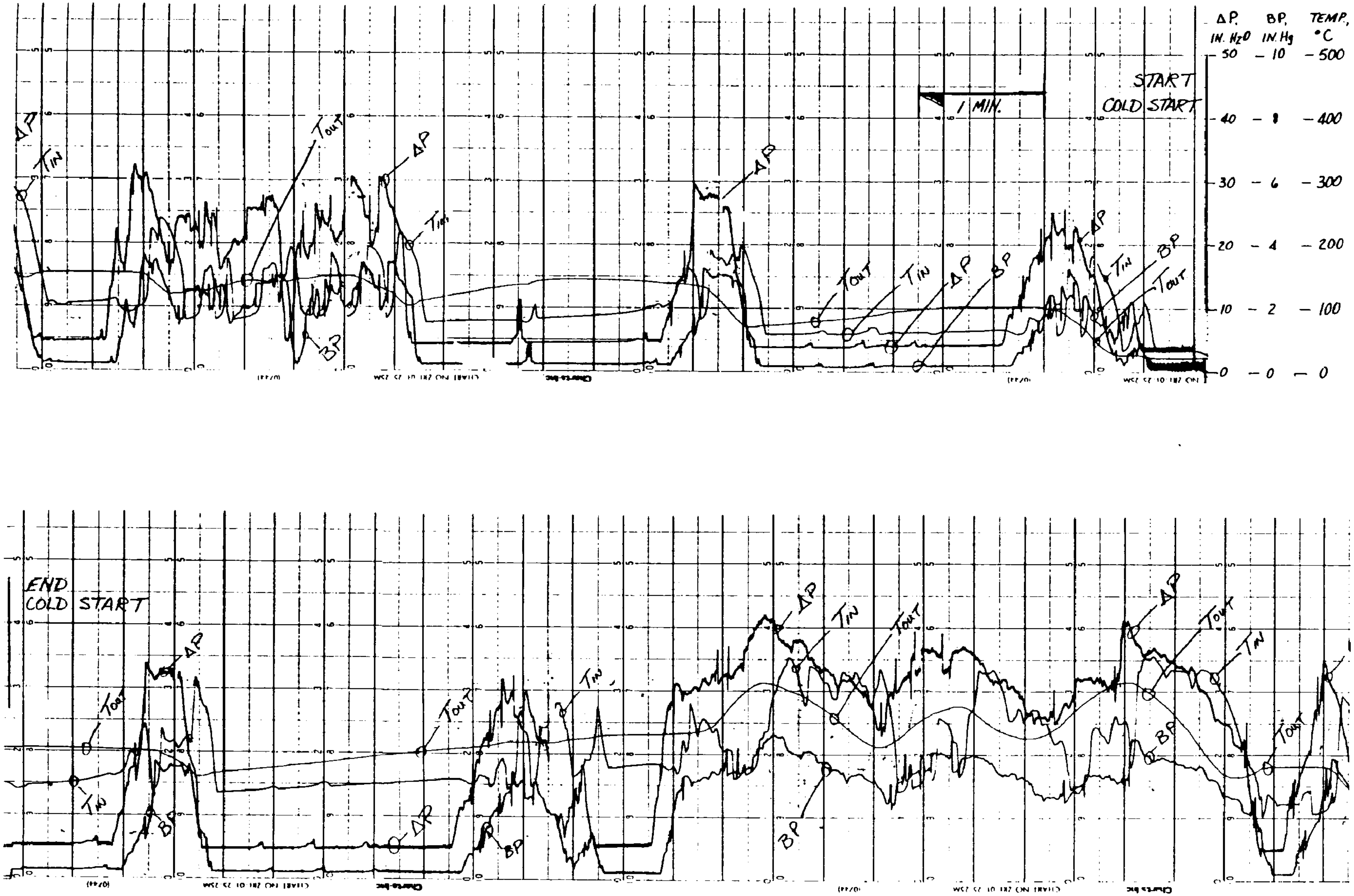


Figure 21. Trap temperature and pressure traces over the cold-start transient cycle

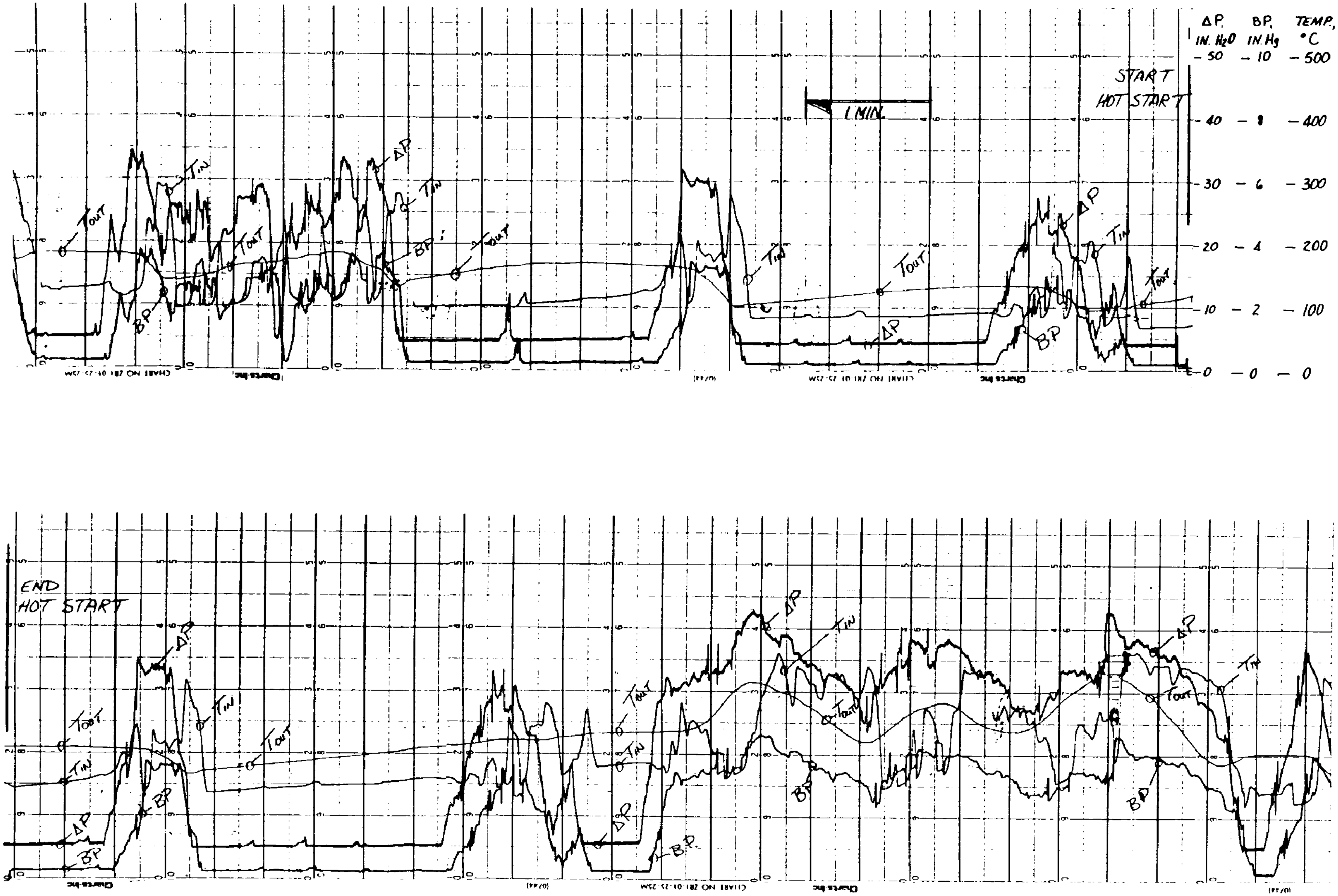


Figure 22. Trap temperature and pressure traces over the hot-start transient cycle

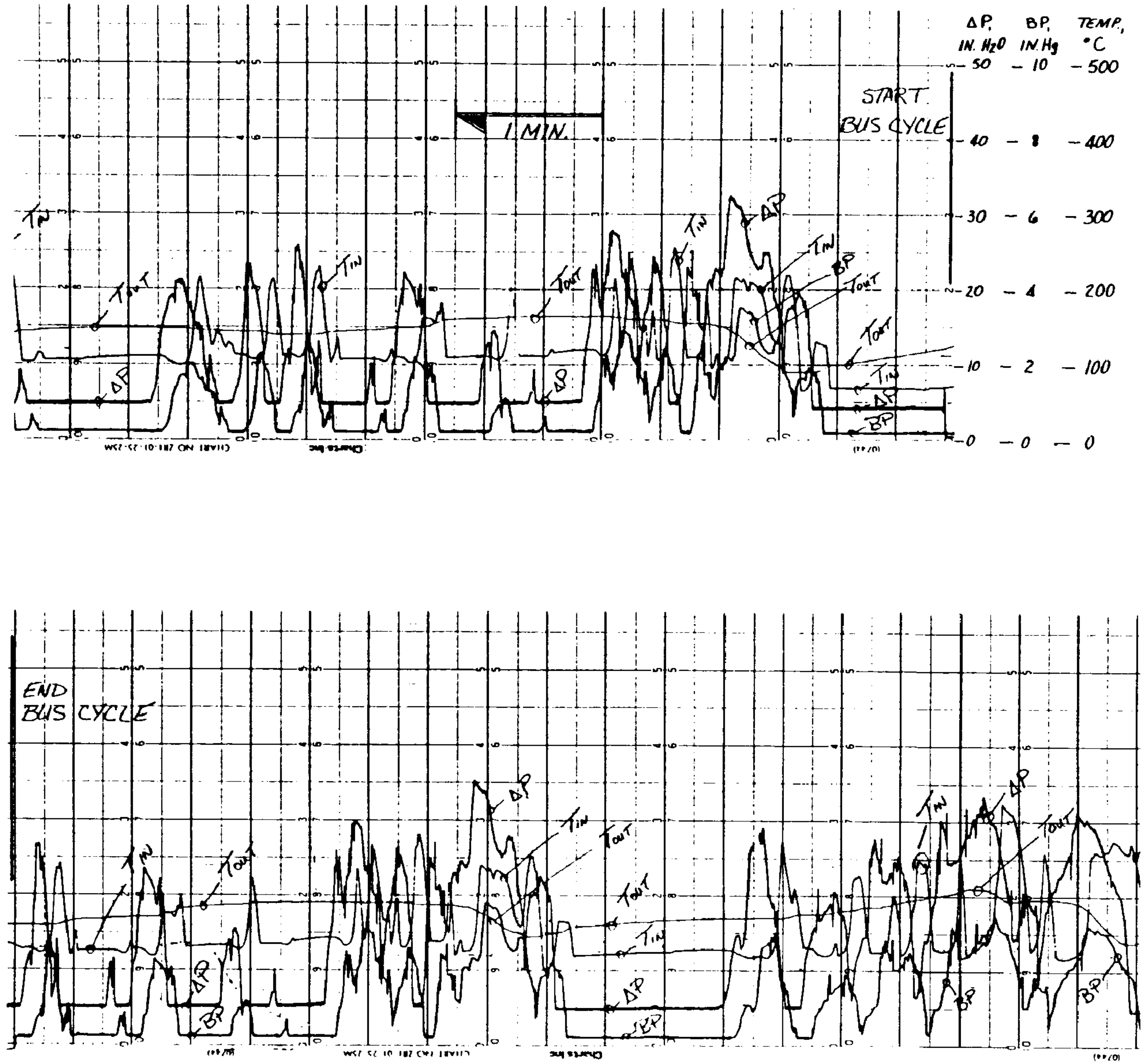


Figure 23. Trap temperature and pressure traces over the bus cycle

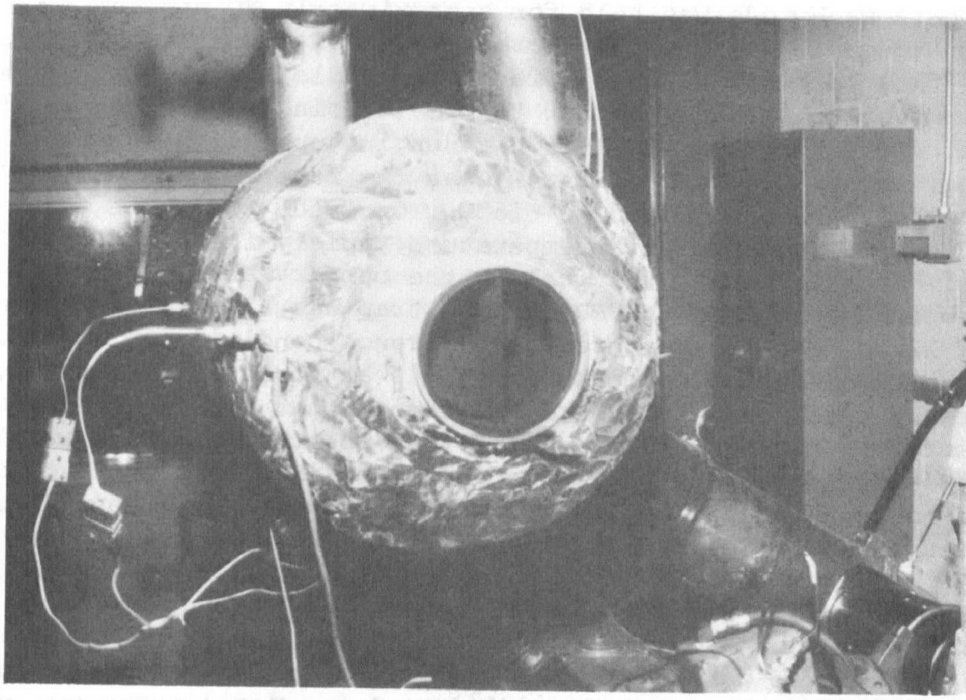


Figure 24. Inlet of particulate trap prior to regeneration

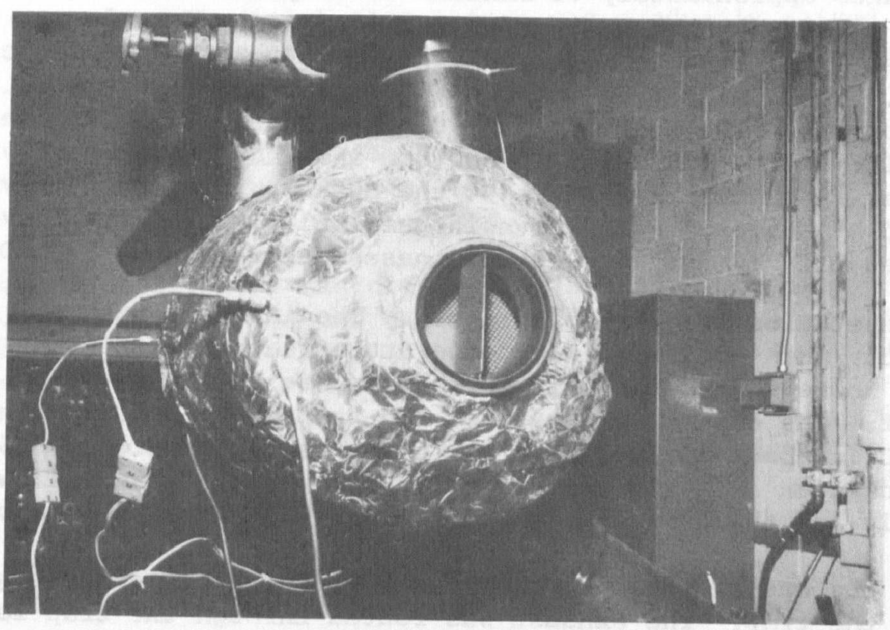


Figure 25. Inlet of trap following regeneration

Particulate samples were collected over seven modes of steady-state operation. Each mode was held for approximately 20 minutes in order to acquire adequate samples for characterization of the total particulate. The CVS flow rate ranged from 1000 cfm, at idle, to near 7000 cfm, for the maximum power condition in order to provide single dilution of the total exhaust. Following the completion of engine operation for particulate sampling, the trap Δp was 51 in. H_2O at the reference condition. The trap inlet temperature was raised to 615°C. Once the trap exit temperature reached 530°C, the trap exit temperature rapidly increased to 780°C in 28 seconds. At this point, the fuel to the burner was shut off and the trap exit temperature peaked at 790°C. The trap was allowed to cool gradually. A Δp of 12 in. H_2O was measured at reference conditions. Following some steady-state operation to measure trap Δp at various light loads, the regeneration process was repeated to insure that a clean trap would be transferred to the bus vehicle. The trap inlet temperature was held stable at 620°C and the trap exit temperature stabilized at 590°C. The trap was allowed to cool and the engine was shut down. The trap was visually inspected and no problems were noted.

The bus vehicle was fitted with the same exhaust system used for engine dynamometer test work. A new reference condition to measure the Δp of the trap was set as 1260 rpm with the transmission in neutral. During an initial check, the trap Δp was 7 in. H_2O. Since our objective was to accumulate particulate on the trap in a service-like manner, the bus left SwRI enroute to the "San Antonio Road Route" with all exhaust gases routed through the trap. This route has been used in several programs over the years and includes typical city driving with stop-and-go traffic as well as a few minutes of high speed freeway driving. The route takes approximately 30 minutes to complete seven miles.[17]

After a total of 24 miles of road work, the trap Δp increased to 30 in. H_2O. The fuel burner was ignited, and the fuel pressure was brought to 110 psi, but the burner outlet temperature would not exceed 530°C. The engine in the bus idled at 600 rpm and thus provided too much exhaust gas relative to the fuel input to the burner. The exhaust system was modified by adding a gate valve in parallel with the burner, in order to "bleed off" excess idle exhaust gases generated by the 600 rpm idle.

Regeneration was attempted again. The inlet to the trap was raised to 615°C. When the trap exit temperature reached 490°C, the exit temperature increased to 580°C in 10 seconds, so the fuel to the burner was shut off. The exit temperature of the trap continued to rise and peaked to 755°C in about 45 seconds. The trap was reheated with 635°C inlet gas and reached an exit temperature of 630°C. The trap was allowed to cool gradually and the trap Δp measured 11 in, H_2O at the reference condition.

The bus was returned to the road route with the exhaust gases bypassing the trap. The exhaust was routed through the trap for the start of the first road route cycle. The bus was operated over the road route twice, accumulating 15 miles. The trap Δp increased to 27 in. H_2O. The bus accumulated another 16 miles as it was returned to the lab with all the exhaust gases passing through the trap. The trap Δp was 40 in. H_2O

prior to regeneration. Because the trap was thought to be heavily loaded with particulate, the inlet temperature to the trap was held to 520°C allowing the trap exit temperature to gradually increase to about 450° C over a 10 minute period. The inlet gas temperature was brought up to 600°C. The trap exit temperature gradually reached 715°C then started to cool down to 610°C while the inlet temperature was brought up to 630°C. When both temperatures were stable, the fuel to the burner was shut off and the idle gas bleed valve was closed. The trap exit temperature increased from 610°C to 740°C over 60 seconds, then gradually cooled. Regeneration was assumed to be complete. The engine was shut down and the bus was prepared for emissions testing on the chassis dynamometer.

Chassis testing included operating the bus with the trap over the cold-start transient driving cycle, then three hot-start cycles followed by two bus cycles. Although continuous temperature and pressure data across the trap were recorded, the format of the chart recording could not be reproduced for the report. Over cold and hot transient chassis testing, the maxmimum trap inlet temperature reached 475°C, the maximum outlet temperature reached 460°C. The highest backpressure recorded was about 8 in, Hg and the differential trap pressure exceeded the transducer range of 80 in. H_2O. During the chassis version of the bus cycle, the trap inlet reached 400°C and outlet reached 330°C near the end of the cycle. Both regulated and unregulated emissions samples were taken using the single dilution CVS set for 7000 CFM. Upon completion of chassis testing, the trap Δ measured 65 in. H_2O at the reference condition. The inlet temperature of the trap was held near 520°C for 20 minutes allowing the trap exit temperature to reach 500°C. The inlet gas temperature was increased to 560°C. When the trap exit temperature increased to 535°C the exit temperature began to increase faster and reached 630°C in about 60 seconds. The inlet temperature was gradually raised to 654°C and the exit temperature started to decreased to 545°C, then started to increase. When the trap exit temperature gradually reached 570°C, it rapidly increased to 700°C in 18 seconds. The fuel burner was shut off, but the temperature kept increasing and peaked to 990°C, 66 seconds after the fuel to the burner was shut off. The trap was allowed to cool and the Δp measured 4 in. H_2O at the reference condition.

Visual inspection of the trap outlet showed signs of particulate breakthrough. Figure 26 shows the failed trap cut in half. A large crack across the body of the trap, near the outlet portion is clearly visible. The cells near the crack were distorted with some of the walls melted away. In addition to the main crack, there were about 4 hairline cracks across the ceramic cells originating from the outer edge of the trap surface (O.D.) and extending about 1 to 2 inches into trap body.

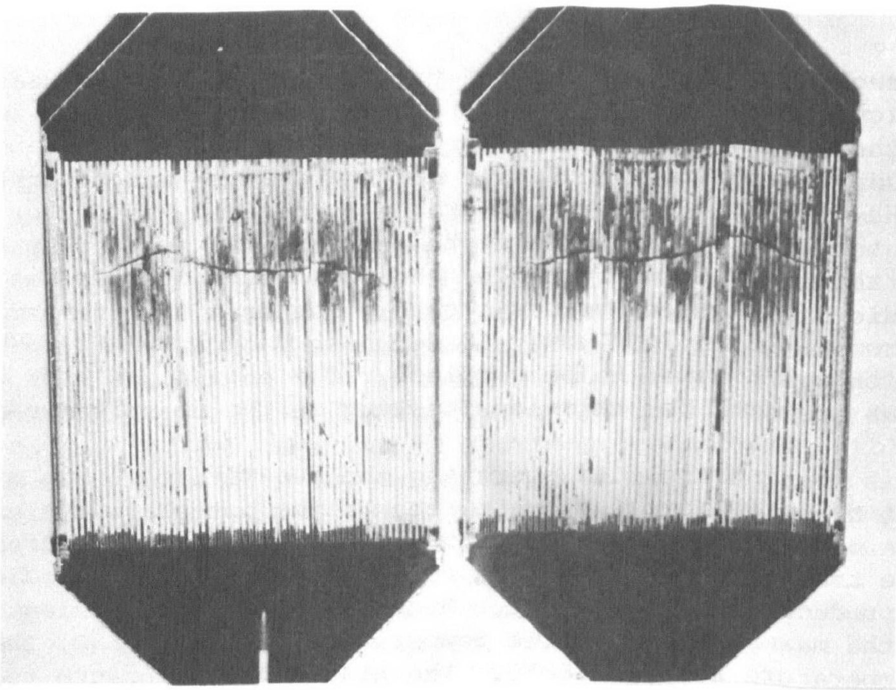


Figure 26. Failed trap after outlet temperature peaked to 990°C (inlet at bottom of figure)

C. Gaseous Emissions During Regeneration

In order to determine the emissions during regeneration, raw exhaust gases were sampled continuously during the regeneration process. Portions of the exhaust gas concentrations measured during regeneration are attributed to engine idle, fuel burner and trap regeneration emissions. Table 11 gives steady-state emissions of the burner exhaust while operated at

TABLE 11. EXHAUST EMISSIONS WITH CORRESPONDING FUEL FLOW AND BURNER EXHAUST TEMPERATURES

	Steady State Emission, g/hr			Fuel Flow	Burner Exh.
	HC	CO	NO_x	lb/hr	Temp., °C
Idle Before Regeneration	15	23	63	2.2[e]	Off
With Burner at					
50 psi[c]	25	237	84	7.8[b]	540
75 psi[c]	12	183	83	8.9[b]	630
100 psi[c]	5	63	83	9.9[b]	700
110 psi[c]	6	31	81	10.1[b]	750
125 psi[c]	6	26	82	10.5[b]	804
During Regeneration[a,d]	14[a]	396[a]	71[a]	10.1[b,d]	750
Idle After Regereration	13	20	59	2.2[e]	Off

[a] Integrated raw emission levels were: HC 118 ppm, CO 1720 ppm, CO_2 3.83%, NO_x 196 ppm and O_2 15.13%
[b] Total fuel for engine idle and fuel burner
[c] Bypassing trap
[d] Burner fuel pressure of 110 psi
[e] Fuel for engine idle

various fuel pressures. These emissions were determined shortly after burner development was completed. Emissions "during regeneration" were processed using the gaseous concentrations integrated from 3.5 to the 11.5 minutes portion of the trap regeneration shown in Figure 27. This period represents the time interval in which the burner was ignited, particulate was oxidized, burner was turned off, and the trap allowed to cool down.

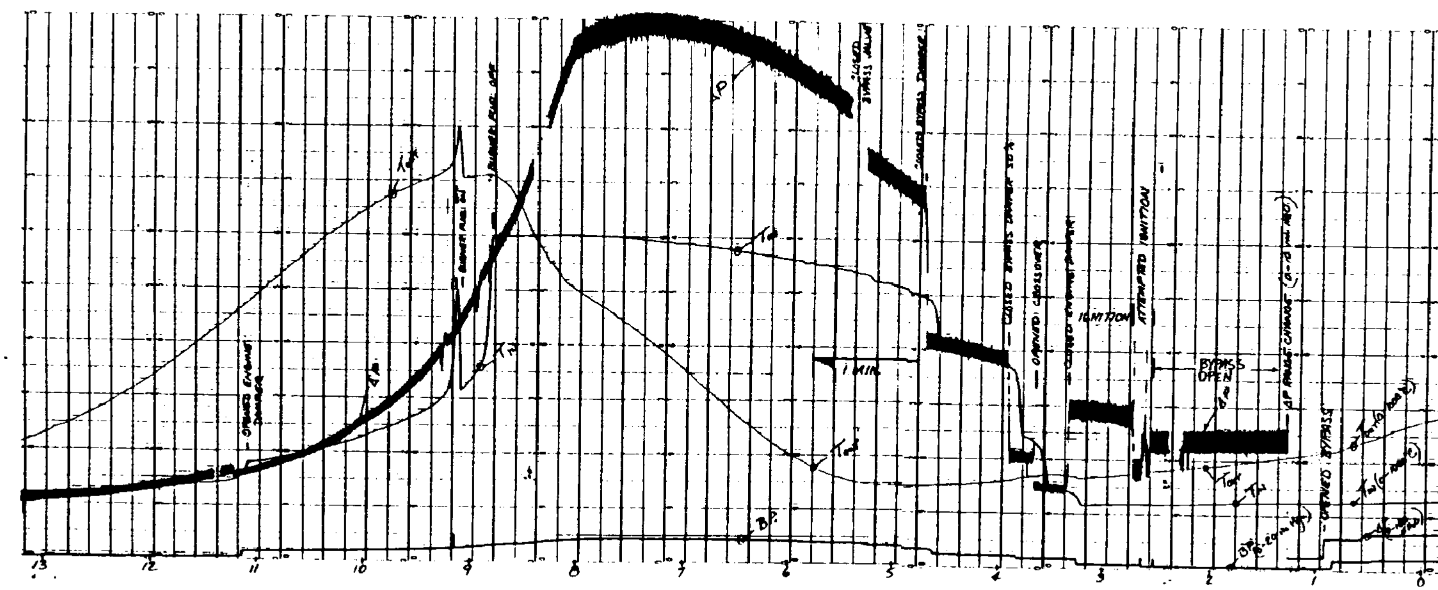
Continuous traces of pressures and temperatures which occurred during the trap regeneration for which emissions were measured are given in the top portion of Figure 27. Emission traces of HC, CO, CO_2, NO_x, and O_2 are given in the lower portion of Figure 27. These traces are the result of monitoring the regeneration of the trap which had accumulated 54 in. H_2O Δp. Prior to the start of regeneration the engine was run to check the Δp and to insure that the trap was warm (relative to room temperatures).

The engine was brought to an idle. At one minute, as indicated in Figure 24, the "bypass valve" and the "bypass damper" were opened. This reduced the flow through the trap causing the trap Δp to drop from 7 to 2.3 in. H_2O and the engine backpressure to drop from 0.4 to 0.1 in. Hg. At this time, the HC concentration appeared to change from 64 to 120 ppm C for some unknown reason. (It is doubtful that the change was due to alteration of backpressure alone).

The fuel burner was ignited at 2.5 minutes, then the main exhaust damper was closed around 3.5 minutes. Normally, the "main exhaust damper" is closed prior to burner ignition to cause all the idle exhaust gas to flow through the burner, but the sequence was inadvertently changed during this run. The HC concentration exceeded 800 ppm C during burner ignition and likely reached 1000 ppm on the basis of previous emission measurements. Concentration of CO_2 increased in proportion to the fuel consumed by the fuel burner.

After ignition of the burner was established, both HC and CO concentrations decreased rapidly. Once the main exhaust damper was closed, the HC and CO concentrations increased substantially. Most of this change was likely due to changes in fuel burner air flow conditions. The burner-trap crossover damper was opened at 3.7 minutes, then the bypass damper was moved to the half closed position at 4 minutes. This caused an increased portion of the hot burner exhaust gases to flow through the trap. The trap inlet gas temperature went from 250 to 400°C. This inlet was held near 400°C for almost one minute, then the bypass damper was fully closed at 4.8 minutes increasing the trap inlet temperature to near 500°C. The bypass valve was closed at 5.3 minutes to insure that all gases were routed through the trap.

The HC concentration increased rapidly with the increase in trap inlet temperature from 160 ppm to 256 ppm C, then it began to fall. It is assumed that lighter hydrocarbon or fuel-like matter was being driven off the walls of the exhaust system and the trap. As temperatures in the system increased, partial oxidation of the hydrocarbons appeared as increases in CO concentrations. By 5.5 minutes, the trap inlet temperature reached 540°C and the trap exit temperature began to increase from about



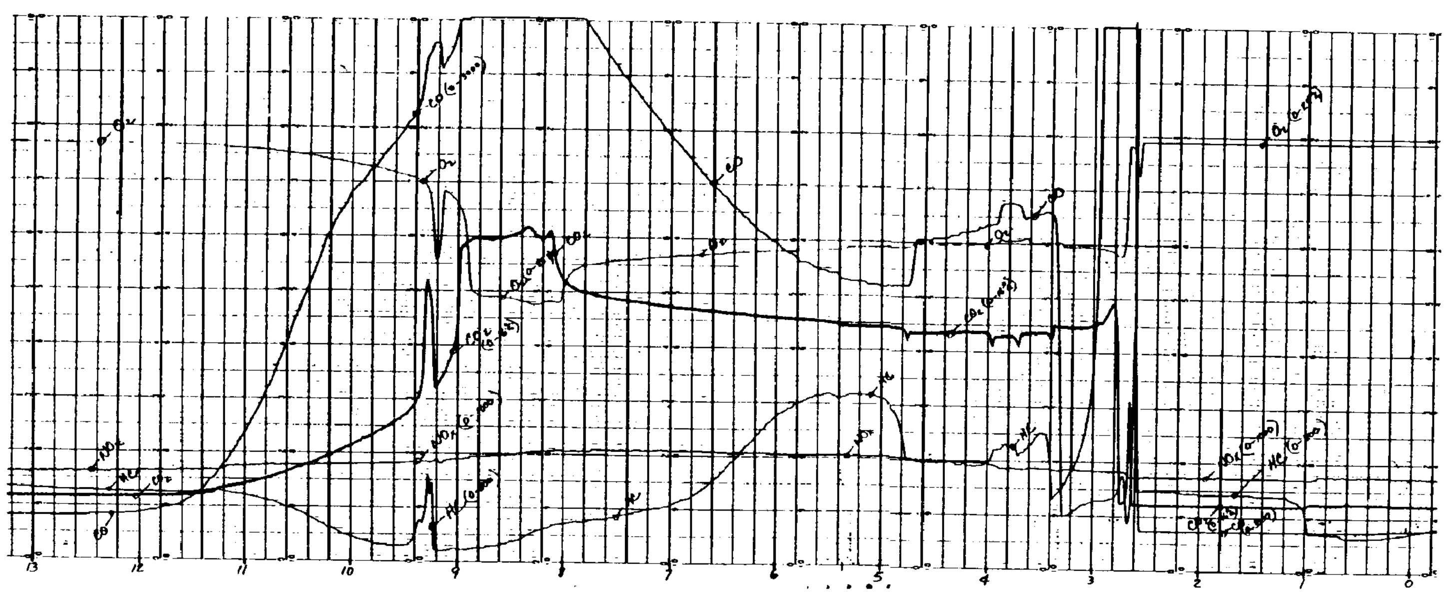


Figure 27. Pressure and temperature trace and gaseous emissions trace during trap regeneration

150°C. As the trap inlet and exit temperatures reached 595 and 400°C, respectively, the trap Δp peaked to 10 in. H_2O. At this point, concentrations of CO and CO_2 were still increasing while O_2 and HC concentrations were decreasing. Concentrations of NO_x changed very little, but did seem to peak along with the trap Δp and backpressure. Even though the trap inlet temperature continued to increase slightly, the trap Δp began to drop off.

At eight minutes, the trap inlet and exit temperatures reached 600°C and 520°C, respectively, and the trap Δp started dropping rapidly and the exit temperature began to rise quickly. The CO_2 concentration simultaneously began to increase to 7 percent and the $_2$ concentration went down to 11.9 percent. The CO concentration was in excess of 3000 ppm at this point. By 8.9 minutes, the CO_2 concnetration started to decrease and the $_2$ concentration was gradually increasing. When the trap exit temperature peaked to 710°C, the fuel to the burner was shut off. As the exit temperature started to decline, the burner was re-ignited at 9.2 minutes, but was promptly turned off as the exit temperature spiked to 800°C.

The HC concentration, which had reached a minimum of about 16 ppm during regeneration with the fuel to the burner shut off, started to gradually increase as the trap cooled. Concentrations of CO and CO_2 started to decrease while the O_2 concentration increased. The trap Δp continued to fall off as the trap cooled.

The main exhaust damper was opened at 11.2 minutes and the burner-trap-crossover was closed. It appears that regeneration or oxidation reactions continued until the trap exit temperature fell below 400°C at 11.5 minutes. Sampling continued until the trap exit temperature reached 200°C, 13.6 minutes from the start of sampling. Results from measurements of unregulated emissions over this regeneration cycle are reported along with summary tables of the respective emissions. The trap Δp at the reference condition of 2100 rpm/50 percent load was 15 in. H_2O.

D. Gaseous Emissions

Gaseous emissions of HC, CO, and NO_x were determined for the DDAD 6V71 coach engine over the 13-mode FTP, the 1984 Transient FTP, and the bus cycle using a transient-capable engine dynamometer facility. These species were also determined for the 1980 GMC RTS-II coach vehicle over a chassis version of the 1984 Transient FTP and the bus cycle. Results from analysis of samples for selected individual hydrocarbons, aldehydes, phenols and total intensity of aroma (TIA) may also be considered gaseous emissions, and are presented in this section of the report.

1. Thirteen-Mode Emissions

Once the baseline repeat data on the DDAD 6V71 coach engine were approved, the trap was installed in the engine's exhaust system. Two cycles of accumulation/regeneration were conducted on the trap prior to any emissions sampling. The engine's exhaust backpressure was 6.5 in. Hg and the inlet depression was set to 25 in. H_2O. During a single 13-mode FTP, gaseous emissions concentrations were determined from both before and after the trap by use of appropriate valves and heated sample lines.

The 13-mode composite results from this test are given in Table 12, along with the results obtained over the "original" and "new" baseline. Copies of the corresponding computer printouts are given in Appendix A and give detailed information obtained on a modal basis.

TABLE 12. SUMMARY OF 13-MODE EMISSION RESULTS FROM THE DDAD 6V71 COACH ENGINE

	13-Mode FTP			
	Emission, g/kW-hr (g/hp-hr)			BSFC
Test Notes	HC	CO	NO_x	kg/kW-hr, (lb/hp-hr)
Original Baseline[a]	2.37 (1.77)	9.92 (7.40)	9.60 (7.16)	0.297 (0.488)
Without Trap (New Baseline)	1.64 (1.22)	9.62 (7.18)	9.79 (7.30)	0.288 (0.474)
Before Trap	1.79 (1.34)	6.38 (4.76)	9.91 (7.39)	0.286 (0.471)
After Trap	1.68 (1.25)	6.24 (4.66)	10.00 (7.46)	0.286 (0.471)

[a]Average of two runs

The effect of placing the trap in the exhaust system appears to be relatively minor, on the basis of comparison between the "new baseline" and the "before trap" values. The 13-mode composite CO emission, measured before the trap was 34 percent lower than without the trap in the system. Composite HC emission was about 9 percent higher with the trap in place. The slight difference in NO_x and BSFC were likely due to test-to-test variability.

Comparison of 13-mode composite emissions from the "new baseline" and "after trap" indicate the same trends as noted above. In comparing 13-mode composite emission results from "before" and "after" the trap, there were essentially no significant changes due to the trap itself. The measurements were made back-to-back to reduce problems in variability and the same engine parameters were used to process data. The composite hydrocarbon value after the trap was about 6 percent lower than determined before the trap. In comparing modal data, some reduction in hydrocarbons seemed apparent, especially during the idle and 2 percent load condition where fuel-like aerosols are typically found. Emissions of CO were slightly lower measured after the trap, during the higher load, higher exhaust heat conditions. Virtually no definite changes in NO_x are readily attributable to the trap, but slightly higher NO_x emission rates were noted after the trap during high load, high exhaust heat conditions.

Temperature data corresponding to 13-mode testing with the trap are given in Table 13. Exhaust temperatures were monitored at the termination of each exhaust manifold. Trap inlet and outlet temperatures were monitored about 3 inches upstream and downstream of the trap substrate. Temperatures were recorded near the end of each mode. Since the trap was relatively massive, the thermal inertia of the trap was substantial. This caused the trap exit temperature to be higher than the inlet temperature during all but the maximum power condition of the 2nd segment of the 13-mode test. As shown in Figure 20, the exhaust system and trap were well insulated. The maximum exhaust temperature reached was near 520°C, and the maximum trap inlet and outlet temperatures both reached 498°C.

TABLE 13. EXHAUST AND TRAP TEMPERATURE OVER 13-MODE STEADY-STATE OPERATION

	Exhaust, °C[a]		Trap, °C[a]	
Mode	Right	Left	Inlet	Outlet
1	130	130	120	150
2	121	124	111	118
3	179	181	163	163
4	253	256	238	238
5	371	374	355	355
6	486	489	480	480
7	124	124	155	205
8	522	515	498	498
9	460	454	437	442
10	354	360	338	345
11	251	255	250	252
12	187	188	182	198
13	110	110	115	130

[a] Temperatures recorded near end of sampling time for a given mode

Unregulated emissions of aldehydes, TIA, and those related to particulate emissions were determined for seven modes of the 13-mode FTP. Results from these determinations will be presented in sections designated for discussion of these species. No steady-state emissions were measured for the GMC RTS-II coach vehicle.

2. Transient Emissions

Transient cycle emissions from the DDAD 6V71 coach engine were measured and calculated in accordance with the 1984 Transient FTP and the proposed 1986 Transient FTP (which includes particulate). The power map established during the "baseline repeat" emissions testing was used to generate the transient command cycle used to evaluate the effect of the trap. Replicate runs of cold- and hot-start cycles, as well as bus cycles, were run with particulate trap aftertreatment. Copies of the respective computer printouts are given in Appendix C, Tables C-1 through C-6. The average of these replicate test results are given in Table 14. Results obtained from this engine for the "original baseline," "return to baseline," and the "new baseline," all obtained without a particulate trap, are also presented.

In comparing the emission levels "without trap" to those obtained "with trap," the most significant change in transient emissions occurred for particulate. Cold- and hot-start particulate emissions were reduced by 54 and 61 percent, respectively. Bus cycle particulate was reduced by 68 percent. Discussion of particulate data will be given in a later section.

Gaseous emissions of HC were essentially unchanged with the trap over cold- and hot-start transient testing. Results from the bus cycle indicated a slight decrease (5.2 percent) in HC emissions due to the trap. Emissions of CO over cold- and hot-start transient test with the trap were about 14 percent lower than obtained without the trap. However, no change in CO emission levels were noted over the bus cycle. Emissions of NO_x over transient testing were about 5 percent lower with the trap than without it. This was opposite of the trend noted for NO_x emissions over the 13-mode steady-state FTP. No change in BSFC was noted. Although all transient tests were statisically valid, the work over transient cycle testing with the trap was generally 5 percent lower than obtained over "without trap" runs.

The GMC RTS-II coach vehicle powered by a similar DDAD 6V71 coach engine was operated over the heavy-duty chassis driving cycle and over a chassis version of the heavy-duty bus cycle. Chassis testing for gaseous emissions with trap aftertreatment was limited to single runs over these cycles due to problems encountered with regeneration of the trap. Replicate runs for gaseous emissions were conducted without the trap. Copies of the computer printouts from tests without the trap are given in Appendix D, Tables D-1 through D-6. Computer printouts from chassis testing with the trap are given in Appendix E, Tables E-1 through E-3. Table 15 summarizes the regulated emissions results obtained from chassis testing. Fuel economy is also given to enable computation of emissions on a fuel specific basis for comparison purposes.

Gaseous emissions determined during chassis test work utilized a single dilution CVS system from which particulate emission samples were also collected. In order to stay below the 125°F limit for particulate collection purposes, the CVS was operated near 7000 cfm. Use of this relatively high dilution rate caused the gaseous emission concentrations to be relatively low. In order to compensate for high dilution ratios, more sensitive ranges on gaseous emissions analyzers were used. Test-to-test variability over chassis testing is greater than for stationary engine testing. Since more sensitive ranges were used, test-to-test variability tends to be greater than when emission concentrations are greater. In addition, for chassis test work, the operator controls the engine through feedback from the drivers aid and is likely to be less repeatable that the computer controlled engine testing conducted on the engine dynamometer. In cases where the vehicle could not match the driver's trace during accelerations, the operator went to wide-open-throttle (WOT), or full rack, until the trace could be followed again. Incidentally, during most accelerations, the operator fully depresses the foot pedal.

TABLE 14. SUMMARY OF AVERAGE TRANSIENT EMISSIONS FROM THE DDAD 6V71 COACH ENGINE

Cycle Type	Regulated Emissions, g/kW-hr (g/hp-hr) HC	CO	NO_x[a]	Part.	BSFC, kg/kW-hr (lb/hp-hr)	Cycle Work, kW-hr (hp-hr)
			Original Baseline			
Cold[e] Start	2.49 (1.86)	6.03 (4.50)	11.01 (8.21)	0.86 (0.64)	0.372 (0.612)	6.77 (9.07)
Hot[f] Start	2.47 (1.84)	5.84 (4.36)	9.79 (7.30)	0.70 (0.52)	0.313 (0.515)	8.24 (11.05)
Transient Composite	2.47 (1.84)	5.87 (4.38)	9.96 (7.43)	0.72 (0.54)	0.323 (0.529)	8.03 (10.77)
Bus[e] Cycle	2.72 (2.03)	4.65 (3.47)	11.02 (8.22)	0.83 (0.62)	0.339 (0.557)	3.31 (4.41)
			Return to Baseline (After Maladjustment)			
Cold[c] Start	1.93 (1.44)	5.04 (3.76)	8.98 (6.70)[b]	0.86 (0.64)	0.354 (0.583)	7.41 (9.93)
Hot[c] Start	1.70 (1.27)	5.88 (4.39)	9.32 (6.95)[b]	0.68 (0.51)	0.310 (0.510)	8.22 (11.02)
Transient Composite	1.73 (1.29)	5.76 (4.30)	9.26 (6.91)	0.71 (0.53)	0.316 (0.520)	8.10 (10.86)
Bus[c] Cycle	1.52 (1.13)	5.86 (4.37)	10.87 (8.11)[b]	1.05 (0.78)	0.322 (0.530)	3.47 (4.65)
			Without Trap (New Baseline)			
Cold[d] Start	1.85 (1.38)	4.73 (3.53)	8.61 (6.42)	0.64 (0.48)	0.317 (0.522)	8.25 (11.05)
Hot[e] Start	1.91 (1.42)	5.26 (3.92)	8.10 (6.04)	0.77 (0.57)	0.290 (0.476)	8.95 (12.00)
Transient Composite	1.90 (1.42)	5.18 (3.87)	8.17 (7.10)	0.75 (0.56)	0.294 (0.483)	8.85 (11.86)
Bus[e] Cycle	1.93 (1.44)	4.13 (3.08)	9.02 (6.72)	0.78 (0.58)	0.302 (0.496)	4.09 (5.48)
			With Trap			
Cold[e] Start	1.88 (1.40)	4.06 (3.03)	8.36 (6.24)	0.29[g] (0.22)	0.325 (0.534)	7.68 (10.30)
Hot[e] Start	1.89 (1.41)	4.52 (3.37)	7.67 (5.72)	0.30[g] (0.22)	0.291 (0.478)	8.48 (11.37)
Transient Composite	1.89 (1.41)	4.45 (3.32)	7.77 (5.80)	0.29[g] (0.22)	0.296 (0.486)	8.37 (11.22)
Bus[e] Cycle	1.83 (1.36)	4.12 (3.08)	8.59 (6.41)	0.25[g] (0.19)	0.297 (0.488)	3.92 (5.25)

[a] NO_x emissions determined from bag samples
[b] NO_x values projected results obtained with Continuous NO_x measurement
[c] Single test
[d] Average of three tests
[e] Average of two tests
[f] Average of four tests
[g] Average total particulate value based on two runs for regulated emissions and two runs for particulate emissions only

TABLE 15. SUMMARY OF AVERAGE TRANSIENT EMISSIONS FROM A GMC RTS-II COACH

Cycle Type	Regulated Emissions g/km, (g/mile) HC	CO	NO_x[c]	Part.	Fuel Economy liter/100 km (miles/gal)	kg/km (lb/mile)	Distance km, (miles)
				Without Trap			
Cold[a] Cycle	1.78 (2.86)	68.40 (110.05)	11.86 (19.08)	5.45 (8.77)	60.76 (3.88)	0.492 (1.75)	8.25 (5.13)
Hot[a] Cycle	1.52 (2.44)	51.10 (82.22)	9.92 (15.95)	4.25 (6.48)	48.24 (4.88)	0.390 (1.38)	8.83 (5.49)
Transient Composite	1.56 (2.51)	53.57 (86.20)	10.20 (16.41)	4.42 (7.11)	50.03 (4.74)	0.405 (1.44)	8.75 (5.44)
Bus[a] Cycle	2.25 (3.62)	70.59 (128.06)	12.94 (20.82)	6.22 (10.00)	62.34 (3.78)	0.504 (1.79)	4.79 (2.98)
				With Trap			
Cold[b] Cycle	1.10 (1.76)	59.64 (95.95)	10.75 (17.29)	0.59 (0.94)	56.30 (4.18)	0.456 (1.62)	8.53 (5.30)
Hot[b] Cycle	1.01 (1.63)	42.31 (68.08)	10.85 (17.46)	0.31 (0.49)	48.07 (4.89)	0.389 (1.38)	8.70 (5.40)
Transient Composite	1.02 (1.65)	44.70 (72.06)	10.84 (17.43)	0.35 (0.56)	49.25 (4.79)	0.398 (1.41)	8.68 (5.39)
Bus[b] Cycle	1.47 (2.37)	66.05 (106.27)	11.35 (18.26)	0.43 (0.70)	58.83 (4.00)	0.476 (1.69)	4.69 (2.92)

[a]Average of two tests
[b]Based on single run
[c]NO_x emissions determined from bag samples

The trap reduced particulate emissions by 92 and 93 percent over the composite transient and bus cycle run on the chassis dynamometer. Further discussion of particulate reduction will be given in a later section of this report.

The trap appears to have reduced the HC emissions over transient chassis testing by 35 percent. Emissions of CO were also reduced but by varying degrees. Over the truck cycle, the composite CO emissions were reduced by about 17 percent with the trap. Over the bus cycle, only a 7 percent reduction in CO was noted. Changes in NO_x emissions were mixed. The cold-start truck cycle indicated a 9 percent reduction in NO_x emissions with the trap, whereas the hot-start indicated the opposite. Over the bus cycle, the trap appeared to be responsible for a 12 percent reduction in NO_x emissions. Little, if any, change in NO_x emissions can be attributed to the trap itself. No significant change in fuel economy can be attributed to the use of the trap.

Even though the test engine and the engine in the RTS-II coach were both DDAD model 6V71, the differences in emissions without the trap were significant. On a fuel specific basis, HC, CO, NO_x, and particulate from the test engine were 6.46, 17.6, 27.8, and 2.58 g/kg of fuel, respectively. Emissions of HC, CO NO_x, and particulate from the vehicle's engine were 3.85, 132, 25.2 and 10.9 g/kg of fuel, respectively. Emissions of NO_x were similar, but CO and particulate emissions from the bus vehicle's engine were almost 5 times those of the test engine. Emission of HC from the coach vehicle engine was about half that of the stationary-mounted engine.

3. Selected Individual Hydrocarbons

Some individual hydrocarbons (IHC) were determined from dilute exhaust samples taken in replicate over transient operation of the DDAD 6V71 coach engine run on the engine dynamometer. Results from these analyses are given in Table 16 along with "baseline" values. The term "baseline" is used in the following tables to denote data accumulated during a previous program and are presented in this work to represent the engine's emission "without trap." In addition, raw exhaust samples for IHC were obtained during regeneration of the trap, and these results are also given in Table 16 for reference.

Over cold- and hot-start transient operation, levels of ethylene and propylene were about 20 percent lower with the trap. Levels of methane were below the background levels during these tests. Over the bus cycle, the brake specific levels of ethylene and propylene were about the same as obtained over cold- and hot-start transient testing with the trap. Analysis of raw exhaust samples obtained during trap regeneration showed ethylene and propylene to be predominant, but the presence of benzene, toluene, and acetylene were also indicated. It is uncertain what portions of these species can be attributed to engine idle, burner exhaust, or regeneration itself.

Individual hydrocarbons were also determined over chassis versions of the transient tests for trucks and buses. Results from analysis of single samples of CVS dilute exhaust, with and without the trap, are given in Table 17. Only methane, ethylene, and propylene were detected above background levels. The levels of these species were reduced with the use of the trap.

TABLE 16. SUMMARY OF INDIVIDUAL HYDROCARBONS FROM TRANSIENT OPERATION OF THE DDAD 6V71 COACH ENGINE

Cycle Type	Units	Methane	Ethylene	Ethane	Acetylene	Propane	Propylene	Benzene	Toluene	"Total"
Baseline[a,e]	mg/test	--	790	--	--	--	410	--	63	1300
Cold	mg/kW-hr		120				60		9.2	190
Start	mg/kg fuel		320				160		23	500
Baseline[a,e]	mg/test	--	1000	27	--	--	520	86	--	1600
Hot	mg/kW-hr		120	3.2			61	10		190
Start	mg/kg fuel		390	11			200	33		630
With Trap[a]	mg/test	--	690	--	--	--	320	--	--	1000
Cold	mg/kW-hr		89	--			31			130
Start	mg/kg fuel		270				130			400
With Trap[a]	mg/test	--	760	--	--	--	170	--	--	930
Hot	mg/kW-hr		89				20			110
Start	mg/kg fuel		310				70			380
With Trap[a]	mg/test	--	310	--	--	41	120	--	--	470
Bus	mg/kW-hr		78			10	32			120
Cycle	mg/kg fuel		260			35	110			400
Regeneration[b,d]	µg/m³ exh.	1300[c]	7300	96	630	0	1900	1260	870	
	mg/kg fuel	52	290	3.8	25		75	50	35	530

[a] Measured dilute
[b] Measured raw
[c] This is slightly lower than the level generally noted for background
[d] It is uncertain what portion of these emissions are due to idle exhaust gases, burner exhaust gases or trap regeneration. Recall, that the burner was not optimized.
[e] Baseline represents "without trap"

TABLE 17. SUMMARY OF INDIVIDUAL HYDROCARBONS FROM TRANSIENT CHASSIS OPERATION OF THE GMC RTS-II COACH

Cycle Type	Units	Methane	Ethylene	Propylene
Without Trap	mg/test	460	1300	--
Cold	mg/km	58	170	230
Start	mg/kg fuel	120	340	460
Without Trap	mg/test	470	970	290
Hot	mg/km	54	110	197
Start	mg/kg fuel	140	280	524
Without Trap	mg/test	370	650	--
Bus Cycle	mg/km	78	140	
	mg/kg fuel	160	280	
With Trap	mg/test	--	810	--
Cold	mg/km		95	
Start	mg/kg fuel		210	
With Trap	mg/test	--	810	--
Hot	mg/km		93	
Start	mg/kg fuel		240	
With Trap	mg/test	82	450	--
Bus Cycle	mg/km	17	97	
	mg/kg fuel	37	200	

On a fuel specific basis, emissions of ethylene were nearly the same for both engine and chassis dynamometer testing. Trends toward lower levels of ethylene, propylene, and methane were noted over both types of testing when the trap was used.

4. Aldehydes

Aldehydes were determined in replicate from CVS diluted samples taken over cold- and hot-start transient testing of the DDAD 6V71 coach engine. Raw exhaust samples were collected over each of seven selected modes of the 13-mode FTP, including a sample during trap regeneration. Aldehyde levels obtained during 7-mode operation in the baseline configuration (without trap) and with the trap are given in Tables 18 and 19, respectively. The DNPH method for sample collection was used in both cases. However, a gas chromatographic procedure was used to analyze samples from "baseline" operation during an earlier program, and a liquid chromatographic procedure

TABLE 18. SUMMARY OF ALDEHYDES FROM MODAL OPERATION OF THE DDAD 6V71 COACH ENGINE IN BASELINE CONFIGURATION

		Test Condition, rpm/load, %						
Aldehyde[a,b]	Units	1260 2	1260 50	1260 100	Idle	2100 100	2100 50	2100 2
Formaldehyde	$\mu g/m^3$ exh.	1600	960	2100	480	4700	870	760
	mg/hr	970	590	1300	85	4500	820	720
	mg/kW-hr	540	12	13	--	34	12	270
	mg/kg fuel	260	48	53	100	130	39	78
Acetaldehyde	$\mu g/m^3$ exh.	220	230	150	--	820	--	--
	mg/hr	130	140	92	--	780	--	--
	mg/kW-hr	73	2.9	0.93	--	5.9	--	--
	mg/kg fuel	34	11	3.7	--	22	--	--
Isobutyraldehyde	$\mu g/m^3$ exh.	340	360	--	--	--	--	210
	mg/hr	210	220	--	--	--	--	200
	mg/kW-hr	120	4.5	--	--	--	--	74
	mg/kg fuel	56	18	--	--	--	--	22

[a] In addition no crotonaldehyde, methylethylketone, benzaldehyde or hexanaldehyde were found.
[b] Gas Chromotographic Procedure

was used to analyze samples obtained with the trap in this program. The liquid chromatographic analysis is preferred due to its ability to resolve the acetone peak, observed using the gas chromatographic analysis, into peaks representing acrolein, acetone, and propionaldehyde. Minimum detectable values for both methods of analysis are given in Table 20.

Formaldehyde was prevalent for both configurations of the coach engine with and without the trap. Although a greater variety of species were detected from analysis of samples obtained from engine operation with the trap, total aldehydes were about the same. In addition, the lower the concentration of the species, the more difficult it is to be certain of the quantative value of the species. Aldehyde emissions during regeneration were lower than obtained over the idle mode.

Table 21 gives the aldehydes emission levels obtained over cold- and hot-start transient testing, and over the bus cycle. As mentioned earlier, baseline values (without trap) were obtained during a previous program. More formaldehyde and hexanaldehyde, but less isobutyraldehyde emissions were noted with the trap.

TABLE 19. SUMMARY OF ALDEHDYES FROM MODAL OPERATION OF THE DDAD 6V71 COACH ENGINE WITH TRAP

		Test Condition, rpm/load, %							
Aldehyde[a]	Units	1260 2	1260 50	1260 100	Idle	2100 100	2100 50	2100 2	Trap Regeneration
Formaldehyde	$\mu g/m^3$ exh.	2000	--	240	490	740	960	840	390
	mg/hr	1200		140	86	700	900	770	70
	mg/kW-hr	590		1.5	--	5.1	13	290	--
	mg/kg fuel	300		5.6	96	19	41	93	16
Acetaldehyde	$\mu g/m^3$ exh.	550	--	--	--	170	190	130	--
	mg/hr	320				160	180	120	
	mg/kW-hr	160				1.1	2.6	44	
	mg/kg fuel	41				4.3	8.2	14	
Acrolein	$\mu g/m^3$ exh.	120	--	--	--	--	--	--	--
	mg/hr	71							
	mg/kW-hr	36							
	mg/kg fuel	9.1							
Propionaldehyde	$\mu g/m^3$ exh.	370	--	--	--	60	110	62	26
	mg/hr	220				60	110	57	4.6
	mg/kW-hr	110				0.44	1.6	21	--
	mg/kg fuel	28				1.7	4.9	6.9	1.0
Acetone	$\mu g/m^3$ exh.	500	300	76	140	64	63	50	--
	mg/hr	290	180	45	24	60	59	46	
	mg/kW-hr	150	3.7	0.46	--	0.44	0.86	17	
	mg/kg fuel	38	15	1.8	27	1.7	2.7	5.5	
Crotonaldehyde	$\mu g/m^3$ exh.	140	--	44	--	--	--	--	69
	mg/hr	84		26					12
	mg/kW-hr	42		0.27					--
	mg/kg fuel	11		1.0					2.8
Isobutyraldehyde	$\mu g/m^3$ exh.	290	--	--	--	--	100	29[b]	20[b]
	mg/hr	170					97	27	3.6
	mg/kW-hr	86					1.4	9.9	--
	mg/kg fuel	22					4.4	3.2	0.80
Methylethylketone	$\mu g/m^3$ exh.	660	410	100	82	94	100	87	61
	mg/hr	390	240	62	14	88	97	81	11
	mg/kW-hr	193	5.0	0.64	--	0.64	1.4	30	--
	mg/kg fuel	49	21	2.4	16	2.4	4.4	9.7	2.4
Hexanaldehyde	$\mu g/m^3$ exh.	1800	--	--	51	210	590	400	25[b]
	mg/hr	1100			9.0	200	560	370	4.5
	mg/kW-hr	540			--	1.5	8.1	140	--
	mg/kg fuel	140			10	5.5	25	44	1.0
Benzaldehyde	$\mu g/m^3$ exh.	280	38	150	--	150	77	76	79
	mg/hr	170	22	91		140	72	70	14
	mg/kW-hr	83	0.50	0.94		1.0	1.0	26	--
	mg/kg fuel	21	1.9	3.6		3.8	3.3	8.4	3.1

[a] Liquid Chromatographic Procedure
[b] Concentrations are below the minimum detectable values associated with reliable results

TABLE 20. MINIMUM DETECTABLE VALUES OF THE DNPH PROCEDURE

Compound	Molecular Weight	$\mu g/m^3$ per ppm	Min. Detection Value ppm	$\mu g/m^3$
Formaldehyde	30.03	1250	0.01	15
Acetaldehyde	44.05	1830	0.01	20
Acrolein[a]	56.07	2330	0.01	25
Acetone[a]	58.08	2415	0.01	25
Propionaldehyde[a]	58.08	2415	0.01	25
Isobutyraldehyde	72.11	3000	0.01	30
Methylethylketone	72.12	3000	0.01	30
Crotonaldehyde	70.09	2915	0.01	30
Hexanaldehyde	100.16	4165	0.01	40
Benzaldehyde	106.13	4415	0.01	45

[a]Using the gas chromatographic procedure, these three species are designated as "acetone"

Aldehydes were also determined in dilute exhaust samples collected from the single-dilution CVS system during transient chassis testing of the GMC RTS-II coach vehicle. Since the chassis dynamometer test work utilized the single-dilution CVS for gaseous and particulate sample collection simultaneously, the gaseous emissions were relatively dilute. In order to improve aldehyde sample recovery, a composite aldehyde sample was collected over one cold-start and three hot-start transients. This sample was considered to be the best compromise between accuracy and level of effort and coincided with the methods to be used under Contract 68-02-3773 to establish emissions without the trap.

Results of analysis for aldehydes for the vehicle with and without the trap are given in Table 22. Over the chassis test work, more species of various aldehydes were noted without the trap than with the trap. Formaldehyde, propionaldehyde, hexanaldehyde and benzaldehyde emissions over the truck cycle appeared to be greater with the trap. Over the bus cycle, only propionaldehyde and hexanaldehyde emissions appeared to be greater with the trap, all others being reduced below the detectable level.

Overall, it appears that the trap probably had little effect on aldehyde emissions. Although there were changes in aldehyde emissions with and without the trap during this brief test program, the degree of change relative to the sensitivity of the procedure is relatively small and mixed.

TABLE 21. SUMMARY OF ALDEHYDES FROM TRANSIENT OPERATION OF THE DDAD 6V71 COACH ENGINE[a,e]

Cycle Type	Units	Form-aldehyde	Acet-aldehyde	Propian-aldehyde	Isobutyr-aldehyde	Methylethyl ketone	Hexan-aldehyde	Benz-aldehyde
Baseline[b,f]	mg/test	190	--	--	180	--	33	--
Cold	mg/kW-hr	27			25		4.7	
Start	mg/kg fuel	76			70		13	
Baseline[b,f]	mg/test	170	--	--	44	--	--	--
Hot	mg/kW-hr	21			5.4			
Start	mg/kg fuel	67			17			
Baseline[b,f]	mg/test	--	--	--	40	--	--	--
Bus	mg/kW-hr				12			
Cycle	mg/kg fuel				36			
With Trap[c]	mg/test	340	17	26	5.0[d]	16	17	140
Cold	mg/kW-hr	44	2.2	3.4	0.65	2.1	2.3	18
Start	mg/kg fuel	140	6.8	11	2.0	6.5	7.1	57
With Trap[c]	mg/test	220	16	17	4.8[d]	15	6.1[d]	74
Hot	mg/kW-hr	26	1.9	2.0	0.57	1.8	0.72	8.8
Start	mg/kg fuel	90	6.6	6.9	2.0	6.2	2.5	30
With Trap[c]	mg/test	360	3.2[d]	8	--	21	6.2[d]	80
Bus	mg/kW-hr	91	0.82	2.1		5.4	1.6	20
Cycle	mg/kg fuel	310	2.8	7.1		18	5.4	69

[a] Average of two runs
[b] Gas Chromatographic Procedure
[c] Liquid Chromatographic Procedure
[d] Values over both runs were below the reliable minimum detectable level
[e] In addition, no acrolein, acetone, crotonaldehyde were noted for the samples processed
[f] Baseline represents "without trap"

TABLE 22. SUMMARY OF ALDEHDYES FROM TRANSIENT OPERATION OF THE GMC RTS-II COACH [a,e]

Cycle Type	Units	Formaldehyde	Acetaldehyde	Propionaldehyde	Methylethylketone	Hexanaldehyde	Benzaldehyde
Without Trap[b]	mg/test	200	--	18[d]	12[d]	79[d]	45[d]
Transient	mg/km	23		2.1	1.3	9.2	5.3
Composite	mg/kg fuel	56		4.8	3.2	22	13
Without Trap[c]	mg/test	390	68[d]	37[d]	87	160	56[d]
Bus	mg/km	82	14	7.6	18	34	12
Cycle	mg/kg fuel	170	29	16	37	69	24
With Trap[b]	mg/test	1000	--	74[d]	--	360	150[d]
Transient	mg/km	120		8.5		42	17
Composite	mg/kg fuel	300		21		103	42
With Trap[c]	mg/test	350	--	--	--	210	--
Bus	mg/km	75				46	
Cycle	mg/kg fuel	160				96	

[a]Based on results from single sample analysis
[b]Composite sample derived over 1 Cold + 3 Hot Transient Tests run in sequence
[c]Composite sample derived over 2 Bus Cycles run in sequence
[d]Based on concentrations which were below the minimum detectable level for reliable values
[e]In addition, no acrolein, acetone, crotonaldehyde, isobuturaldehyde were found in any of these samples

5. Phenols

Phenols were determined using a wet chemistry procedure outlined in Section III, H.1. and described in detail in Reference 13. Dilute exhaust samples were collected over transient and bus cycle operation of the DDAD 6V71 coach engine and the GMC RTS-II coach vehicle. In addition, a raw exhaust sample was collected during regeneration of the trap. The detection of individual phenols in dilute or raw exhaust is quite variable. The respective minimum detection levels are given in Table 23. During previous baseline work (without trap), only 2-n-propylphenol was noted over the cold- and hot-start transient test cycle (no phenols sample was taken over the bus cycle). Levels for the baseline cold-start were 130 mg/test, 19 mg/kW-hr and 15 mg/kg fuel. This phenol has a relatively high molecular weight and is difficult to quantify due to potential interferences. Analysis of dilute exhaust samples collected over transient operation with trap aftertreatment indicated no phenols emissions above the minimum detectable limits over the cold-start, hot-start or the bus cycle for either the test engine or the bus engine. Analysis of the raw exhaust sample collected during regeneration indicated a "phenol" concentration of 160 $\mu g/m^3$ exhaust or 6.3 mg/kg fuel. No other species of phenols were noted.

TABLE 23. MINIMUM DETECTABLE VALUES OF PHENOLS PROCEDURE

Phenol Group	Molecular Weight	$\mu g/m^3$ per ppm	Min. Detection Value ppm	Min. Detection Value $\mu g/m^3$
Phenol	94.1	3915	0.002	6
Salicylaldehyde	122.1	5080	0.002	12
m-cresol, p-cresol	108.2[a]	4499[a]	0.001[a]	6[a]
p-ethylphenol, 2-isopropylphenol, 2,2-xylenol, 3,5-xylenol, 2,4,6-trimethylphenol	127.8[a]	5316[a]	0.002[a]	12[a]
2-n-propylphenol	136.2	5666	0.001	6
2,3,5-trimethylphenol	136.2	5666	0.002	12
2,3,5,6-tetramethylphenol	150.2	6249	0.002	12

[a]Average

6. Total Intensity of Aroma

Total intensity of aroma (TIA) was determined over steady-state and transient operation of the DDAD 6V71 on the engine dynamometer with the trap. Results from 7 modes of steady-state testing with the trap are given in Table 24 along with results obtained previously with the engine in a baseline configuration (without trap). In addition, TIA during trap regeneration is also given. All of the results given in Table 24 are based on raw

TABLE 24. SUMMARY OF TIA FROM MODAL OPERATION OF THE DDAD 6V71 COACH ENGINE WITH AND WITHOUT TRAP

Test Condition rpm/load, %	Test Configuration	LCA μg/ℓ	TIA[a] LCA	LCO μg/ℓ	TIA[b] LCO
1260/2	Baseline[c]	62.9	1.66	1.04	0.92
	With Trap	186.	1.99	11.5	2.02
1260/50	Baseline[c]	71.3	1.70	0.78	0.79
	With Trap	194.	2.00	13.1	2.12
1260/100	Baseline[c]	5.76	0.93	1.55	0.92
	With Trap	193.	2.00	17.3	2.24
Idle	Baseline[c]	26.4	1.39	1.49	1.17
	With Trap	37.6	1.50	5.40	1.74
2100/100	Baseline[c]	69.4	1.69	4.56	1.66
	With Trap	110.	1.83	10.4	2.02
2100/50	Baseline[c]	74.2	1.71	3.17	1.50
	With Trap	101.	1.80	7.70	1.89
2100/2	Baseline[c]	103.	1.81	2.93	1.47
	With Trap	80.1	1.73	5.29	1.73
Regeneration of Trap		63.7	1.66	5.92	1.77
7-Mode Composite	Baseline	43.9	1.55	1.58	1.20
	With Trap	123.	1.86	9.75	1.99

[a] TIA_{LCA} = 0.4 + 0.7 (log LCA, μg/ℓ)
[b] TIA_{LCO} = 1.0 + log LCO, μg/ℓ
Note: Highest value of TIA is generally taken to be representative of relative odor intensity.
[c] Baseline represents "without trap"

exhaust samples. TIA computed on the basis of liquid column oxygenate (LCO) fractions were greater than those calculated on the basis of the liquid column aromatic (LCA) fractions using the diesel odor analysis system (DOAS). Over all the modes, there was generally little differences when the trap was used. TIA during regeneration was essentially the same as for idle during trap particulate accumulation.

Dilute exhaust samples were collected during transient operation of the engine with the trap on the engine dynamometer. Comparative results are given in Table 25. LCA and LCO concentrations were increased by a factor of 6 to account for the overall dilution of the raw exhaust by the CVS. The TIA by LCA, with the trap, was higher than without the trap. The opposite may be noted for the TIA by LCO. There were no comparative data over the bus cycle run with the trap.

TABLE 25. SUMMARY OF TIA FROM TRANSIENT OPERATION[a] OF THE DDAD 6V71 COACH ENGINE WITH AND WITHOUT TRAP

Test Configuration	Transient Cycle	LCA µg/ℓ	TIA[b] LCA	LCO µg/ℓ	TIA[c] LCO
Baseline[d]	Cold	144.	1.91	10.2	2.01
	Hot	93.9	1.78	3.66	1.56
	Composite	101.	1.80	4.59	1.66
With Trap	Cold	43.	1.54	1.9	1.28
	Hot	146.	1.91	1.6	1.20
	Composite	131.	1.88	1.64	1.22
	Bus Cycle	72.6	1.70	5.1	1.71

[a] Measurement during transient operation required dilute exhaust sampling. The values given in this table are based on a nominal dilution ratio of 6:1.

[b] $TIA_{LCA} = 0.4 + 0.7$ (log LCA µg/ℓ)

[c] $TIA_{LCO} = 1.0 +$ log LCO µg/ℓ

Note: Highest value of TIA is generally taken to be representative of relative odor intensity.

[d] Baseline represents "without trap"

TIA determined from single dilute exhaust samples, taken during chassis testing of the GMC RTS-II vehicle run over both truck and bus driving schedules, are given in Table 26. Since the CVS used was a single-diultion type, the LCA and LCO concentrations were increased by a factor of 18 to try to account for dilution of the raw exhaust over the transient cycle. TIA determined by DOAS over transient chassis operation essentially indicated that the trap had no effect on the level of TIA.

TABLE 26. SUMMARY OF TIA FROM TRANSIENT OPERATION[a] OF THE GMC RTS-II COACH WITH AND WITHOUT TRAP

Test Configuration	Transient Cycle	LCA μg/ℓ	TIA[b] LCA	LCO μg/ℓ	TIA[c] LCO
Without Trap	Transient Composite	319	2.15	36.4	2.56
	Bus Cycle	103	1.81	13.7	2.14
With Trap	Transient Composite	376	2.20	31.5	2.50
	Bus Cycle	119	1.85	15.3	2.18

[a]Based on dilute exhaust sampling, the values given in this table are based on an assumed dilution ratio of 18:1.
[b]TIA_{LCA} = 0.4 + 0.7 (log LCA μg/ℓ)
[c]TIA_{LCO} = 1.0 + log LCO μg/ℓ
Note: Highest value of TIA is generally taken to be representative of relative odor intensity.

E. Particulate Emissions

The purpose of trap after treatment is to reduce particulate emissions. In order to determine the effects of the trap on particulate emission rates and the character of the total particulate, samples were collected on several filter media for a variety of analyses. These analyses included total mass, sulfate, elemental analysis and organic extractables. Selected extractables were analyzed for benzo-a-pyrene (BaP), boiling range, and elemental content of C, H, N, and S. The following sections will detail the results obtained from smoke measurements and the various analyses conducted on the total particulate.

1. Smoke Emissions

Smoke and particulate emissions are related, smoke levels being a measure of the visible portion of particulate matter. Changes in particulate emissions are indicated by corresponding changes in smoke opacity, if the levels are high enough. Smoke data were accumulated on the DDAD 6V71 coach engine without the trap under a previous program and again under this program to confirm that the engine had not shifted significantly from the established baseline. Results from these smoke measurements are given in Table 27. These baseline values, representing "without trap" operation, were generally low over most modes of operation except for full load conditions.

When the trap was installed, the visible smoke during all engine operation essentially measured zero smoke opacity. Although the smoke opacity was virtually zero during all transient operation, including the Federal Smoke Test, the Transient FTP and the bus cycle, some white-blue smoke was noted for a brief period (5-8 seconds) during the first portion of the third segment of the transient test. This observed puff of smoke appeared to coincide with the trap exit temperature rising from an average of 150 to 300°C (around 625 seconds into the transient cycle) and the inlet temperature to the trap going from 150 to 340°C. It was thought that during the initial portion of the transient test, the trap was loading up with organic material and condensable hydrocarbons. These were subsequently boiled off when the trap was heated above approximately 250°C. Attempts to document this observation using the smokemeter were unsuccessful. It is assumed that the brief condition was dependent on conditions of trap loading which were not repeatable.

As mentioned earlier, the GMC RTS-II coach received for this work was considered to be a relatively smoky bus by general observations. With the bus under full throttle acceleration, the smoke appeared to be near 60 percent opacity (a No. 3, based on use of Ringleman chart). The trap system was installed on the bus and several comparative photographs were taken during operation with the exhaust routed through the trap and then, bypassing the trap. Figure 28 shows the smoke plume with the exhaust bypassing the trap. Figure 29 shows no smoke plume with the exhaust routed through the trap. These pictures were taken as the bus was accelerated from a stop with "wide-open-throttle" and with no transmission upshift.

2. Total Particulate

On the basis of substantial reductions in smoke opacity by the trap, significant reductions in total particulate were also anticipated. Total particulate was reduced over almost all operation of the engine and vehicle by the use of the trap. Total particulate emissions were determined over seven steady-state modes of the 13-mode test operation of the DDAD 6V71 coach engine. Particulate emissions were also measured during regeneration of the trap. Samples were collected for 20 minutes in each mode. Results from single-dilution measurement of total particulate, over these 7 modes with exhaust routed through the trap, are given in Table 28 along with particulate emissions determined in a previous program (without trap). Figure 30 graphically illustrates the significant reductions in total particulate emissions due to the trap.

The trap reduced particulate by almost 90 percent during full load operation at intermediate and rated speed. The trap was less effective at light load conditions such as the 2 percent load conditions. The trap was least effective during the 50 percent load/rated speed condition where efficiency was 38.5 percent. Filter weights obtained from various samples and computations over these modes were checked and no problems were found.

TABLE 27. SMOKE OPACITY FROM THE DDAD 6V71 COACH ENGINE WITHOUT TRAP

Federal Transient Smoke Cycle Opacity

Configuration	Smoke Opacity, % "a"	"b"	"c"
Baseline	3.3	6.9	7.3
Without Trap[a]	4.0	7.0	7.2

Steady-State Smoke Opacity

13-Mode FTP Mode	RPM	Power, %	Smoke Opacity, % Baseline	Without Trap[a]
1	Idle	--	0.2	0.0
2	1260	2	0.2	0.0
3	1260	25	0.3	0.0
4	1260	50	0.4	0.3
5	1260	75	0.9	0.8
6	1260	100	8.6	7.5
7	Idle	--	0.3	0.0
8	2100	100	2.3	1.5
9	2100	75	0.5	0.2
10	2100	50	0.3	0.0
11	2100	25	0.3	0.0
12	2100	2	0.3	0.0
13	Idle	--	0.2	0.0

Power Curve Smoke

RPM	Smoke Opacity, % Baseline	Without Trap[a]
2100	2.5	1.7
1900	2.2	1.8
1700	3.7	2.0
1500	4.1	3.2
1300	7.3	5.2
1260	7.5	6.2
1200	10.5	7.0

[a]Without Trap represents the "new baseline"

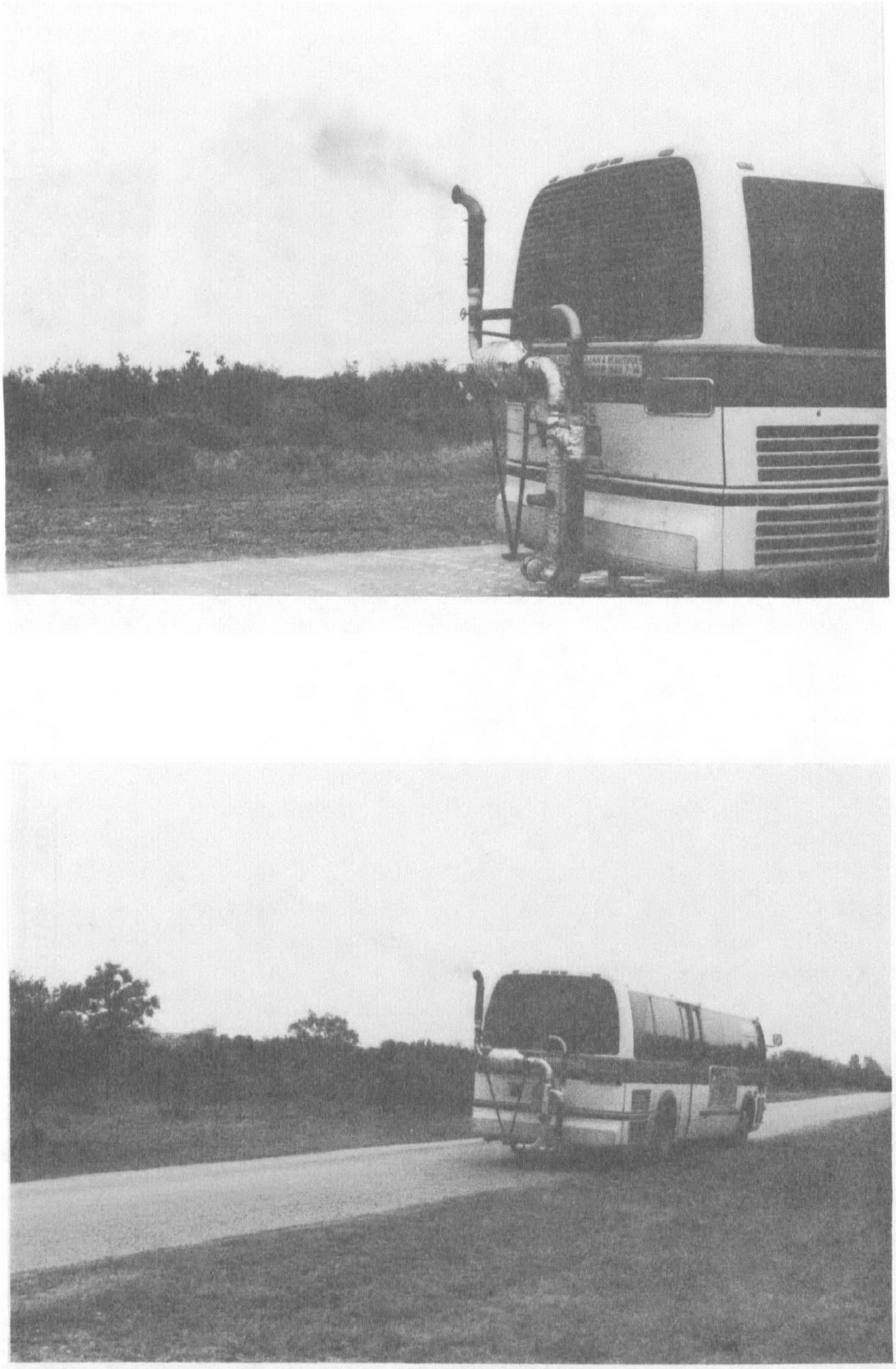


Figure 28. Smoke emissions during WOT acceleration from a stop with exhaust bypassing trap (upper photo taken at start, lower photo taken about 30 meters from start)

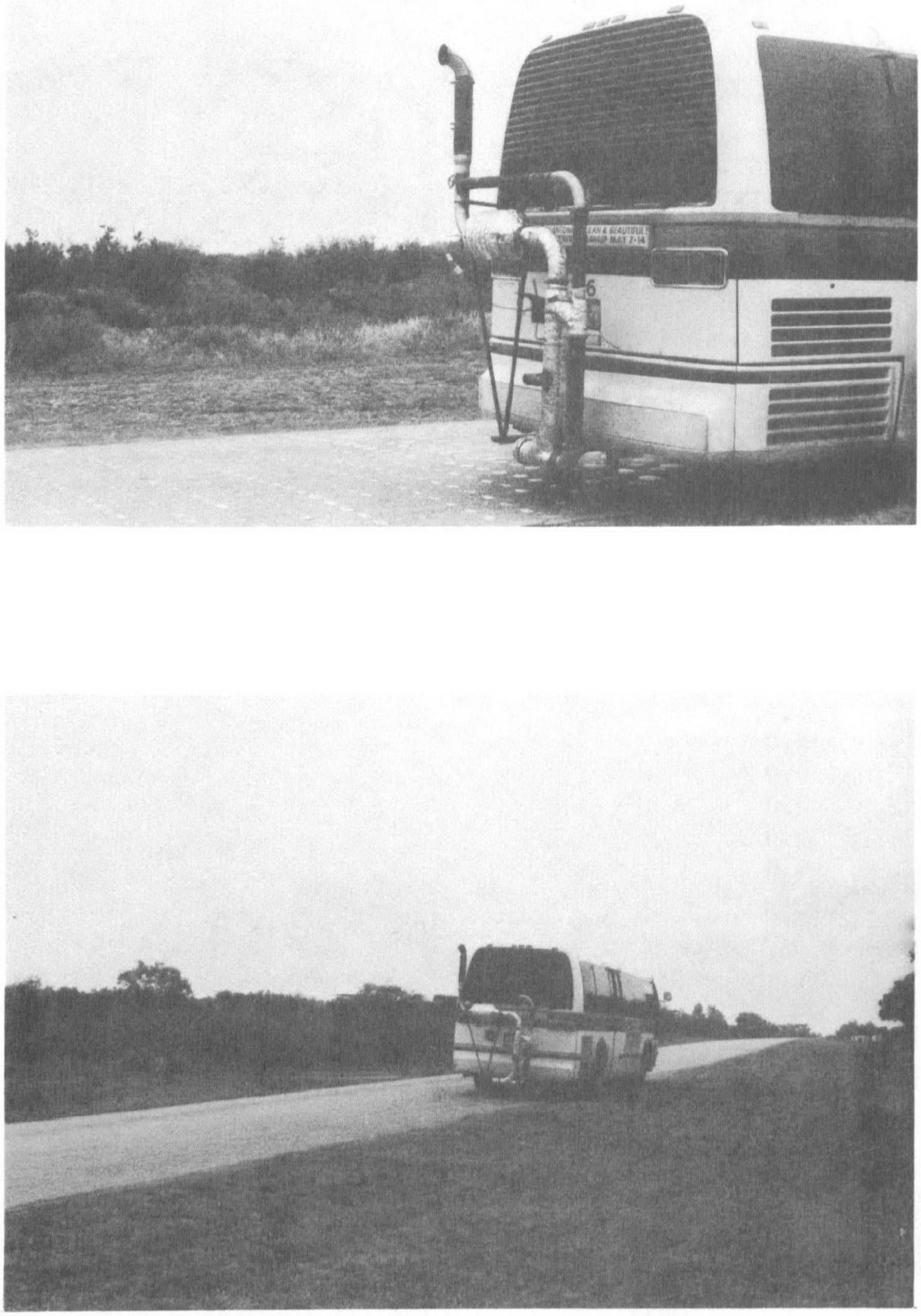


Figure 29. Smoke emissions during WOT acceleration from a stop with exhaust routed through the trap (upper photo taken at start, lower photo taken about 30 meters from start)

TABLE 28. SUMMARY OF MODAL PARTICULATE EMISSION FROM THE DDAD 6V71

Test Condition rpm/load, %	Test Configuration	Particulate Rate				Relative Trap Eff., %
		mg/m^3 exh.	g/hr	g/kW-hr	g/kg fuel	
1260/2	Baseline	12.45	7.54	4.21	2.00	63.3
	With Trap	4.73	2.77	1.39	0.71	
1260/50	Baseline	22.27	13.59	0.28	1.12	76.0
	With Trap	5.53	3.26	0.07	0.28	
1260/100	Baseline	161.46	98.93	1.01	3.96	95.2
	With Trap	7.94	4.71	0.05	0.19	
Idle	Baseline	8.64	1.53	--	1.82	66.0
	With Trap	2.95	0.52	--	0.58	
2100/100	Baseline	74.89	71.27	0.54	1.99	92.9
	With Trap	5.36	5.04	0.04	0.14	
2100/50	Baseline	42.37	39.97	0.61	1.91	38.5
	With Trap	26.24	24.59	0.36	1.12	
2100/2	Baseline	19.72	18.57	6.88	2.02	59.4
	With Trap	8.17	7.54	2.79	0.90	
(Regeneration of Trap)		7.04	1.26	--	0.28	N.A.

	Composite of 7-modes	
	Brake Specific, g/kW-hr	Fuel Specific, g/kg fuel
Baseline	0.70	2.27
With Trap	0.15	0.48

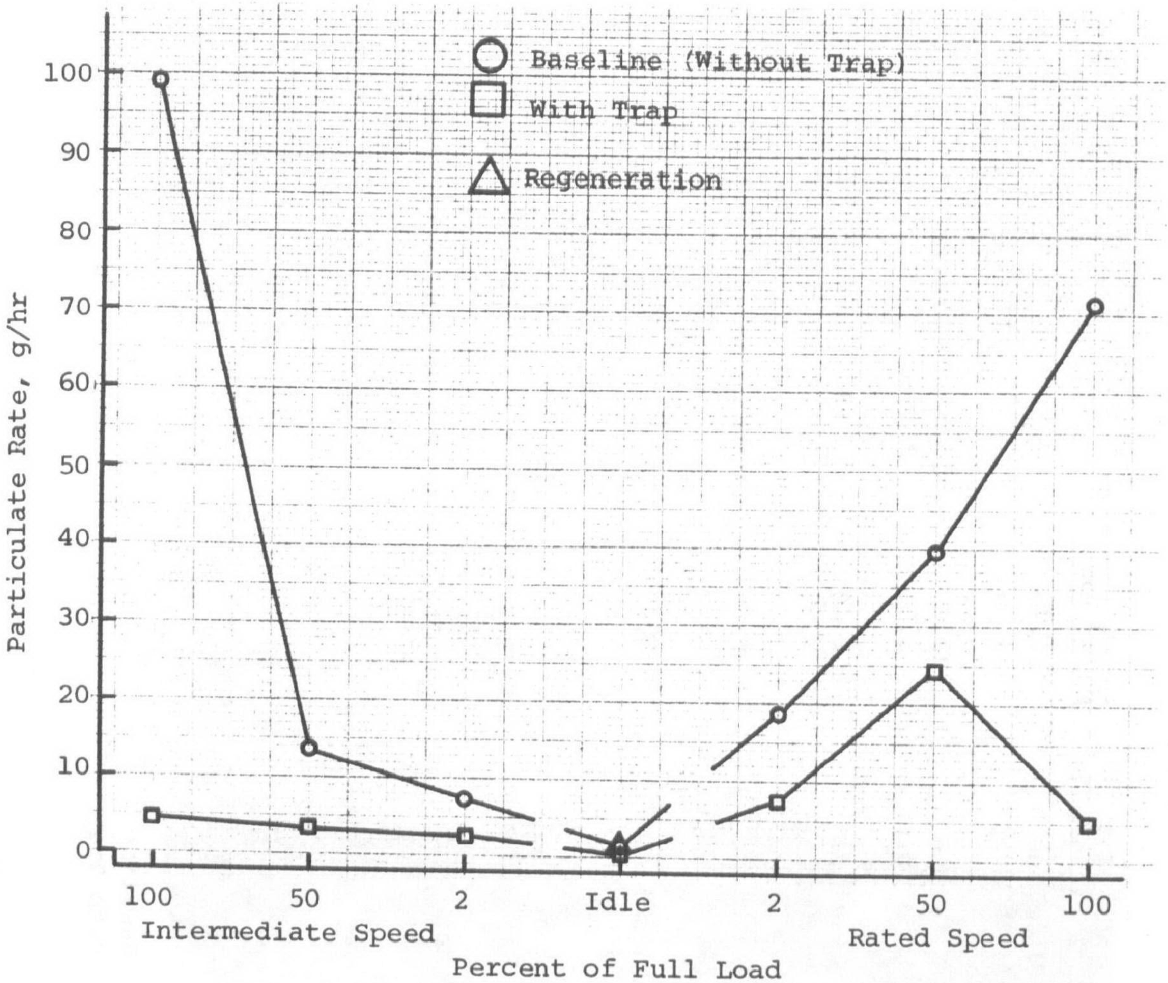


Figure 30. Modal particulate rates from the DDAD 6V71 coach engine

The 7-mode composite brake specific particulate was reduced from 0.70 to 0.15 g/kW-hr with the trap, a 78.5 percent reduction in total particulate emissions. Similarly, the 7-mode composite fuel specific particulate rate was reduced from 2.27 to 0.48 g/kg fuel with the use of the trap. During regeneration, the particulate emission rate was about 2.5 times that obtained during the idle condition with the trap. On a fuel specific basis, the particulate rate during regeneration was reduced from 0.58 to 0.28 g/kg fuel due to the increased fuel consumed by the burner.

Particulate emission results obtained during transient test work on the DDAD 6V71 coach engine were given (eariler in the report) in Table 14, along with gaseous emission results. The transient cycle composite particulate emissions were reduced 61 percent, from 0.75 to 0.29 g/kW-hr, by use of the trap. Over the bus cycle, total particulate was reduced 68 percent, from 0.78 to 0.25 g/kW-hr. On a fuel specific basis, transient cycle composite particulate values were reduced from 2.55 to 0.98 g/kg fuel and bus cycle values were reduced from 2.58 to 0.84 g/kg of fuel. Seven-mode composite fuel specific values obtained without the trap were similar to transient composite values, but with the trap, the 7-mode composite fuel specific value was much lower than obtained over the transient composite. This difference was likely due to the higher trap efficiencies for full load operation during the 7-mode steady-state test work.

Particulate emission results obtained during transient test work on the GMC RTS-II coach were given (earlier in the report) in Table 15, along with gaseous emission results. Recall that the bus was relatively smoky and that the trap Δp, indicating trap load, increased rather quickly. Fuel specific particulate emissions of the vehicle were 4.3 times those of the base engine. Over the cold- and hot-start truck chassis cycles, the composite particulate emissions were reduced 92 percent, from 4.42 to 0.35 g/km, with the trap. Total particulate emissions over the bus cycle were reduced 93 percent, from 6.62 to 0.43 g/km, with the trap. For comparative purposes, fuel specific particulate emissions were reduced from 10.9 to 0.88 g/kg of fuel over the transient composite of the truck chassis cycles. Fuel specific particulate was reduced from 12.3 to 0.90 g/kg of fuel over the chassis version of the bus cycle.

Comparing emission results from the DDAD 6V71 coach engine to those obtained from the GMC RTS-II coach show that with the trap in place, both had particulate emissions near 1.0 g/kg of fuel. If a BSFC of 0.300 kg fuel/kW-hr is assumed, then the particulate rate from the bus engine used in the coach would be 0.30 g/kW-hr or 0.22 g/hp-hr with the trap.

3. Sulfate

Total particulate samples were collected on Fluorpore filter media for analysis of sulfate emissions. Sulfate emission results over 7 modes of steady-state operation of the 1979 DDAD 6V71 coach engine with and without trap, along with emissions during regeneration are given in Table 29 and are illustrated in Figure 31. Sulfate mass emissions were reduced over all modes of steady-state operation with the trap. The trap

TABLE 29. SULFATE EMISSIONS SUMMARY FROM MODAL OPERATION OF THE DDAD 6V71 COACH ENGINE

Test Condition rpm/load, %	Test Configuration	Sulfate Emission Rates mg/m^3 Exhaust	mg/hr	mg/kW-hr	mg/kg fuel	$SO_4^=$ as % of Fuel S[a]
1260/2	Baseline[b]	0.40	240	130	63	1.2
	With Trap	0.10	58	29	15	0.29
1260/50	Baseline[b]	1.4	880	18	72	1.3
	With Trap	0.18	100	2.1	8.9	0.17
1260/100	Baseline[b]	2.4	1500	15	60	1.1
	With Trap	0.34	200	2.0	7.9	0.16
Idle	Baseline[b]	0.56	100	--	120	2.2
	With Trap	0.19	33	--	37	0.72
2100/100	Baseline[b]	2.8	2700	21	76	1.4
	With Trap	0.39	360	2.6	10	0.20
2100/50	Baseline[b]	2.5	2400	36	110	2.0
	With Trap	0.95	890	13	40	0.79
2100/2	Baseline[b]	0.70	630	230	69	1.3
	With Trap	0.08	70	26	8.4	0.17
(Regeneration of Trap)		1.6	290	--	64	1.2

	Composite of 7-modes: Brake Specific, mg/kW-hr	Fuel Specific, mg/kg fuel
Baseline[b]	24.8	80.6
With Trap	5.2	17.2

[a]No. 1 Diesel Fuel has 0.18 percent by weight sulfur.
[b]Baseline represents "without trap"

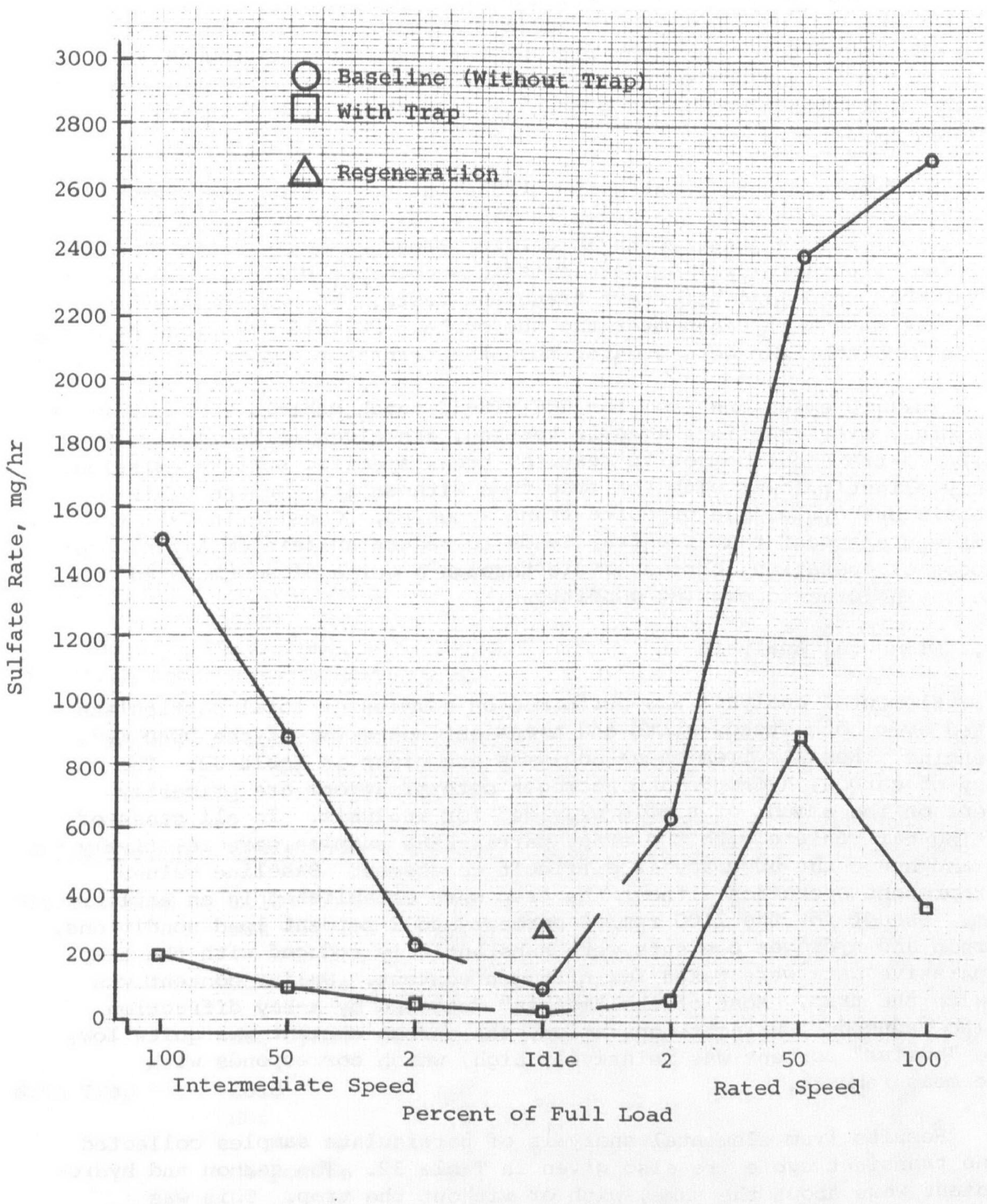


Figure 31. Modal sulfate rates from the DDAD 6V71 coach engine

generally reduced sulfate mass emissions by 85 percent except at the 50 percent load/rated speed condition and idle condition, which showed reductions of 63 and 67 percent, respectively. The trap reduced the 7-mode composite sulfate emissions by 79 percent from 24.8 to 5.2 mg/kW-hr. The percent of fuel sulfur converted to sulfate averaged about 0.35 percent with the trap, compared to 1.5 percent without the trap. During regeneration, the sulfate mass emissions were almost 9 times greater than those obtained during the idle condition with the trap, likely due to the purge of accumulated sulfates.

Sulfate emission results from transient testing of the DDAD 6V71 coach engine with the trap are given in Table 30, along with baseline (without trap) levels obtained in an earlier program. Comparison of these results indicate that lower sulfate emissions occurred with the use of the trap over both cold- and hot-start transient tests. No comparative baseline sulfate data were taken over the bus cycle. Sulfate emissions over the bus cycle with the trap were greater than the transient composite values.

Sulfate emissions from the GMC RTS-II coach vehicle with and without the trap, over transient chassis testing, are given in Table 31. On the basis of transient composite results, brake specific sulfate emissions were only slightly lower with the trap than without it. On the basis of the chassis bus cycle, the opposite trend appeared. Considering all the data, it would appear that the trap tends to reduce sulfate emissions over some modes of operation, but may cycle through a purge of accumulated sulfate during other operating conditions.

4. Elemental Analysis

Elemental analysis was performed on samples of total particulate collected over both steady-state and transient operation of the DDAD 6V71 coach engine. Results from these analyses are given in Table 32. The accuracy of carbon, hydrogen and nitrogen determinations are primarily dependent on the amount of sample provided for analysis. In all cases of collecting particulate with the trap, particulate samples were relatively small, and hence the accuracy is difficult to assess. Baseline values which represent operation without the trap were established in an earlier program. Except for the 2100 rpm/50 percent and 2 percent load conditions, the carbon and hydrogen contents were substantially reduced with the trap. No comparative data were taken for nitrogen content. Sulfur content was lower with the trap. Most of the "metals" detected by x-ray difraction were also reduced. During regeneration, the carbon content was quite low, but the "sulfur" content was relatively high, which corresponds with sulfate measurements.

Results from elemental analysis of particulate samples collected over the transient cycle are also given in Table 32. The carbon and hydrogen content were about the same, with or without the trap. This was surprising, considering the values obtained from steady-state derived particulate with the trap. The trap appears to reduce the sulfur content of the transient-derived particulate, but increases in iron content were noted.

TABLE 30. SULFATE EMISSION SUMMARY FROM TRANSIENT FTP OPERATION OF DDAD 6V71 COACH ENGINE WITH AND WITHOUT TRAP

Test Configuration	Cycle Type	Sulfate Rate mg/test	mg/kW-hr	mg/kg fuel	$SO_4^=$ as % of Fuel S[a]
Baseline[c]	Cold	190	28	75	1.4
	Hot	230	28	89	1.6
	Transient Composite	220	28	87	1.5
With Trap	Cold	100	13	40	0.79
	Hot	73	8.7	30	0.58
	Transient Composite	77	9.3	31	0.61
	Bus Cycle[b]	91	23	78	1.53

[a]No. 1 Diesel fuel had 0.17 percent by weight sulfur
[b]Results based on average of two runs. Sulfate results over bus cycle showed poor repeatability: (138 and 43.4 mg/test, 35.1 and 11.1 mg/kW-hr, 118 and 37.4 mg/kg fuel, and 2.32 and 0.73 % fuel S conversion).
[c]Baseline represents "without trap"

TABLE 31. SULFATE EMISSION SUMMARY FROM TRANSIENT TESTING OF THE GMC RTS-II COACH WITH AND WITHOUT TRAP

Test Configuration	Cycle Type	Sulfate Rate mg/test	mg/km	mg/kg fuel	$SO_4^=$ as % of Fuel S[a]
Without Trap	Cold	140	17	34	0.60
	Hot	110	12	32	0.56
	Composite	110	13	32	0.57
	Bus Cycle	77	16	33	0.57
With Trap	Cold	190	22	49	0.86
	Hot	78	8.9	23	0.40
	Composite	94	11	27	0.47
	Bus Cyclc	110	24	51	0.89

[a]No. 1 Diesel fuel (EM-455-F) had a 0.19 percent by weight sulfur
[b]Based on single run

TABLE 32. SUMMARY OF ELEMENTAL ANALYSIS OF TOTAL PARTICULATE FROM THE DDAD 6V71 COACH ENGINE

Condition rpm/load, %	DDAD 6V71 Test Configuration	C	H	S	N	Mg	K	Al	Si	P	Cl	Ca	Cr	Mn	Fe	Zn	Sn	Sb	Pb	"Total"[c]
		Element, Percent by Weight of Total Particulate																		
1260/2	Baseline	59.8	9.0	1.90	d	b	b	0.01	0.03	0.16	0.11	0.28	b	a	b	0.14	a	a	b	2.8
	With Trap	37.4	4.9	0.25	3.5	b	a	a	a	b	a	0.19	b	b	a	b	b	b	b	0.2
1260/50	Baseline	69.2	10.4	2.94	d	b	b	0.03	0.16	0.12	0.04	0.33	a	a	a	0.15	a	a	b	4.3
	With Trap	46.0	7.1	0.38	1.1	b	a	a	a	b	b	0.22	b	b	a	b	b	b	b	0.2
1260/100	Baseline	84.9	2.7	0.40	d	b	b	0.06	0.07	a	0.06	0.12	b	a	a	a	a	b	b	1.0
	With Trap	57.7	3.4	0.43	0.9	b	b	b	b	b	b	0.08	b	b	b	b	b	b	b	0.1
Idle	Baseline	68.9	9.9	3.45	d	b	b	0.03	0.08	a	a	0.36	a	0.84	b	b	a	a	b	5.7
	With Trap	20.3	3.3	0.83	2.3	b	a	b	a	b	a	0.49	b	a	b	a	b	b	b	0.5
2100/100	Baseline	67.2	3.5	1.58	d	b	b	0.52	0.56	0.12	0.03	0.36	b	a	0.26	0.19	a	a	b	5.0
	With Trap	46.9	4.7	1.89	2.3	b	b	b	b	a	b	a	b	b	a	b	b	b	b	0.0
2100/50	Baseline	60.4	7.5	2.45	d	b	b	0.68	0.75	0.11	a	0.26	b	b	0.31	0.13	b	b	b	4.9
	With Trap	78.7	11.3	1.09	0.6	b	a	b	a	b	b	0.05	b	b	b	b	b	b	b	0.0
2100/2	Baseline	65.3	9.6	1.15	d	a	b	0.03	0.13	0.09	0.05	0.51	a	a	0.31	0.11	a	a	b	2.9
	With Trap	67.9	10.2	0.14	1.9	b	b	b	a	b	b	0.08	b	b	0.39	b	b	b	b	0.1
Regeneration		34.7	5.4	7.22	1.2	a	a	a	a	b	b	0.38	b	a	b	b	b	b	b	0.4

Transient Cycle	DDAD 6V71 Test Configuration	C	H	"S"	N	Mg	K	Al	Si	P	Cl	Ca	Cr	Mn	Fe	Zn	Sn	Sb	Pb	"Total"[c]
Cold Start Transient	Baseline	77.0	10.1	1.80	0.77	b	b	0.03	0.04	0.12	a	0.24	b	a	a	a	a	b	b	2.6
	With Trap	77.9	10.3	0.23	1.1	a	0.06	a	a	b	b	0.15	b	b	0.67	b	b	b	b	0.9
Hot Start Transient	Baseline	67.7	8.4	1.44	0.70	b	b	0.03	0.05	0.11	a	0.25	a	a	b	a	a	a	b	2.9
	With Trap	72.2	10.5	0.35	1.1	b	0.28	a	0.30	b	b	0.14	b	b	1.33	b	b	b	b	2.1
Bus Cycle	Baseline	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d
	With Trap	61.6	9.1	a	1.8	a	0.13	0.07	0.48	b	a	0.51	b	b	1.26	b	b	b	b	2.5

[a]Element detected but was below the level of quantitation
[b]Element was not detected
[c]"Total" represents the percent of total mass detected by x-ray nad does not include Carbon, Hydrogen, Nitrogen or Oxygen
[d]No Data

Elemental analysis was also performed on samples of particulate generated by the GMC RTS-II coach vehicle over chassis testing with and without the trap, and the results are given in Table 33. No comparative carbon, hydrogen and nitrogen data were obtained without the trap. Carbon and hydrogen content of particulate with the trap were relatively low compared to transient tests of the DDAD 6V71 coach engine, but were more like the values obtained over steady-state test work of the test engine with the trap. Percents of sulfur were generally higher with the trap, as were the elements calcium and iron.

5. Soluble Organic Fraction

The soluble organic fraction (SOF) of the total particulate was obtained from soxhlet extraction of 20x20 inch Pallflex filters using methylene chloride as a solvent. Results from steady-state operation over 7 modes are given in Table 34 for the DDAD 6V71 coach engine run with and without the trap. Results from a 7-mode composite of these individual modes are given in Table 35, along with results obtained over cold- and hot-start and bus transient testing of the test engine. SOF emissions are presented in Table 35 on a brake specific and fuel specific basis, as well as a percent soluble basis. Table 36 gives results from transient chassis testing of the GMC RTS-II coach with and without the trap.

From Table 34, the percent of solubles in particulate collected during operation with the trap increased substantially over most of the 7 modes tested. However, the mass emission rate of SOF was substantially lower over most of the 7 modes. SOF emissions during the 2100 rpm/50 percent load condition increased from 14.1 to 20.5 g SOF/hr with the use of the trap. Recall that for this mode, the total particulate was reduced 38 percent with the trap. This was unexpected, and may be due to a SOF storage and purge phenomenon. Solubles are generally considered to be unburned fuel-like materials and/or lubricating oils which condense and are collected as particulate at or below 125°F. The trap was in the raw exhaust stream where temperatures range from about 250 to 932°F (120 to 500°C) from idle to maximum power operation, respectively. Hence, it is likely that the trap would have little ability to reduce SOF emissions or may purge previously collected solubles over load conditions where the trap temperature exceeds the boiling range of materials identified as SOF. It is interesting that SOF emissions during regeneration were noticeably greater than reported for the idle condition with the trap.

Referring to Table 35, the 7-mode composite brake specific emission of SOF was reduced 45 percent from 0.20 to 0.11 g SOF/kW-hr. Over cold- and hot-start transient testing of the engine alone, the transient composite SOF emissions were reduced by 38 percent from 0.40 to 0.25 g SOF/kW-hr with use of the trap. A greater reduction in brake specific SOF emissions (63 percent) was noted over the bus cycle.

Table 36 indicates relatively low values of SOF for the bus without the trap, when compared to levels obtained for the test engine. Over the transient composite of chassis testing, the trap reduced the specific SOF emissions by 87 percent, from 0.75 to 0.10 g SOF/kg fuel. Over the bus cycle, the fuel specific SOF emissions were reduced 88 percent, from 0.81 to 0.10 g SOF/kg fuel by use of the trap.

TABLE 33. SUMMARY OF ELEMENTAL ANALYSIS OF TOTAL PARTICULATE FROM THE GMC RTS-II COACH

Transient Cycle	GMC RTS-II Test Configuration	Element, Percent by Weight of Total Particulate[c]																		
		C	H	S	N	Mg	K	Al	Si	P	Cl	Ca	Cr	Mn	Fe	Zn	Sn	Sb	Pb	"Total"
Cold Start Transient	Without Trap	d	d	0.20	d	b	0.01	a	a	0.09	0.02	0.05	b	0.05	0.13	0.10	0.03	b	b	0.5
	With Trap	48.3	1.75	0.74	0.2	b	0.04	a	a	0.11	a	0.39	b	a	0.97	a	b	b	b	1.5
Hot Start Transient	Without Trap	d	d	0.19	d	0.04	a	b	b	0.06	0.02	0.03	b	a	0.11	0.08	0.03	b	b	0.3
	With Trap	32.9	1.0	0.90	a	a	0.10	0.12	0.47	a	0.14	1.80	a	b	1.42	b	b	b	b	4.0
Bus Cycle	Without Trap	d	d	0.16	d	0.02	a	b	a	0.04	0.02	0.02	b	b	a	a	b	b	b	0.1
	With Trap	48.8	1.2	0.38	a	b	0.11	a	a	a	a	0.95	b	b	0.71	b	a	b	b	1.8

[a] Element detected but was below the level of quantitation
[b] Element was not detected
[c] The element of Ti was also detected, but was below the level of quantitation
[d] No data

TABLE 34. SUMMARY OF SOLUBLE ORGANIC FARCTION FROM THE DDAD 6V71 COACH ENGINE

Test Condition rpm/load, %	Modal Soluble Organic Fraction			
	Baseline[a]		With Trap	
	% SOF	g SOF/hr	% SOF	g SOF/hr
1260/2	83.3	6.28	67.7	1.88
1260/50	53.0	7.20	80.8	2.63
1260/100	14.5	14.3	35.8	1.69
Idle	56.4	0.864	89.2	0.464
2100/100	20.9	14.9	35.7	1.80
2100/50	35.2	14.1	83.4	20.5
2100/2	69.5	12.9	87.1	6.57
Regeneration	NA	NA	51.8	0.653

NA = Not Applicable
[a]Baseline represents "without trap"

TABLE 35. SUMMARY OF CYCLE AND COMPOSITE SOLUBLE ORGANIC FRACTION FROM THE DDAD 6V71 COACH ENGINE

Test Cycle Composite	Cycle Composite Soluble Organic Fraction					
	Baseline			With Trap		
	% SOF	g SOF/kW-hr	g SOF/kg Fuel	% SOF	g SOF/kW-hr	g SOF/kg Fuel
7-mode Composite	28.9	0.20	0.65	75.0	0.11	0.36
Cold Start Cycle	56.8	0.49	1.3	84.4	0.24	0.74
Hot Start Cycle	56.1	0.39	1.2	82.7	0.25	0.86
Transient Composite	56.2	0.40	1.2	82.9	0.25	0.84
Bus Cycle	64.6	0.54	1.6	81.8	0.20	0.67

TABLE 36. SUMMARY OF SOLUBLE ORGANIC FRACTIONS FROM THE GMC-RTS-II COACH

	Without Trap			With Trap		
	% SOF	g SOF/km	g SOF/kg Fuel	% SOF	g SOF/km	g SOF/kg Fuel
Cold Start	8.4	0.46	0.93	12.4	0.073	0.16
Hot Start	6.6	0.28	0.72	11.2	0.035	0.09
Transient Composite	6.9	0.31	0.75	11.4	0.040	0.10
Bus Cycle	6.6	0.41	0.81	11.4	0.049	0.10

Benzo(a)pyrene (BaP) content of the SOF was determined for composite samples from 7-mode testing, cold- and hot-start transient testing, and operation over the bus cycle. Results from these analyses are given in Table 37. For the DDAD 6V71 coach engine without the trap (baseline configuration), no BaP concentrations above the minimum detectable level of 0.0002 µg BaP/mg SOF were found. When the trap was used, BaP levels appeared to increase, but the levels given in Table 37 are still quite small and are relatively close to the limits of detection. BaP levels from the GMC RTS-II coach with and without the trap were also very low.

TABLE 37. SUMMARY OF BENZO(a)PYRENE EMISSIONS

Cycle	DDAD 6V71 Coach Engine			GMC RTS-II Coach		
Composite	Rates	Baseline	With Trap	Rates	Without Trap	With Trap
7-mode Composite	µg BaP/mg SOF	<<0.0002[a]	0.0011	µg BaP/mg SOF	b	b
	µg BaP/kW-hr	<<0.04[a]	0.12	µg BaP/km		
	µg BaP/kg fuel	<<0.13[a]	0.38	µg BaP/kg fuel		
Transient Composite	µg BaP/mg SOF	<<0.0002[a]	0.0011	µg BaP/mg SOF	0.0002	0.0014
	µg BaP/kW-hr	<<0.08[a]	0.28	µg BaP/km	0.050	0.055
	µg BaP/kg fuel	<<0.24[a]	0.92	µg BaP/kg fuel	0.12	0.14
Bus Cycle	µg BaP/mg SOF	<<0.0002[a]	0.0006	µg BaP/mg SOF	<<0.0002[a]	0.0004
	µg BaP/kW-hr	<<0.11[a]	0.11	µg BaP/km	<<0.0080[a]	0.022
	µg BaP/kg fuel	<<0.32[a]	0.37	µg BaP/kg fuel	<<0.020[a]	0.044

[a]No BaP above the minimum detectable level of 0.0002 µg BaP/mg SOF
[b]No comparative data taken

High temperature boiling point distributions of the cold- and hot-start transient composite SOF from the DDAD 6V71 coach engine with and without the trap were run. In addition, SOF from the bus cycle was processed. These three samples were of sufficient quantity to allow the use of internal standard. Results from these boiling point distributions are tabulated in Table 38. Comparing results from transient operation with and without the trap, SOF from runs made with the trap appear to contain about the same portion of lower boiling range, but a lower portion of higher boiling range material. The bus cycle SOF also had a low portion of higher boiling range material.

TABLE 38. BOILING POINT DISTRIBUTION OF SOLUBLE ORGANIC FRACTION FROM THE DDAD 6V71 COACH ENGINE

Distillation Point	Boiling Temperature of Distillation Point, °C			
	Baseline		With Trap	
	Transient	Bus Cycle	Transient	Bus Cycle
IBP	307	a	340	325
10% point	391		396	397
20% point	412		418	422
30% point	432		435	442
40% point	452		450	461
50% point	474		465	479
60% point	503		480	503
70% point	542		499	622
80% point	607		530	---
90% point	---		---	---
EP point	---		---	---
Recovery, % @ 640°C	84		85	72

[a]No comparative data taken

Figures 32 and 33 represent the GC boiling point distributions for the DDAD 6V71 coach engine composite transient SOF and for bus cycle SOF with the trap (no comparative figure for the baseline configuration is available). These figures (run with internal standard C_9-C_{11} for quantitative purposes) show that the bulk of the material elutes at 20 to 28 minutes retention time, which indicates a boiling range similar to paraffinic materials with a range of 20 to 40 carbon atoms. Peaks at 4-6 minutes retention time coincide with the solvent used and peaks at 11-14 minutes retention time coincide with the internal standard. Peaks near 9 minutes retention time were attributed to column contaminant. Figures 34 and 35 represent the GC boiling range from the composite transient SOF and bus cycle SOF from the GMC RTS-II chassis test work with the trap. Quantities of SOF were too small to allow for the

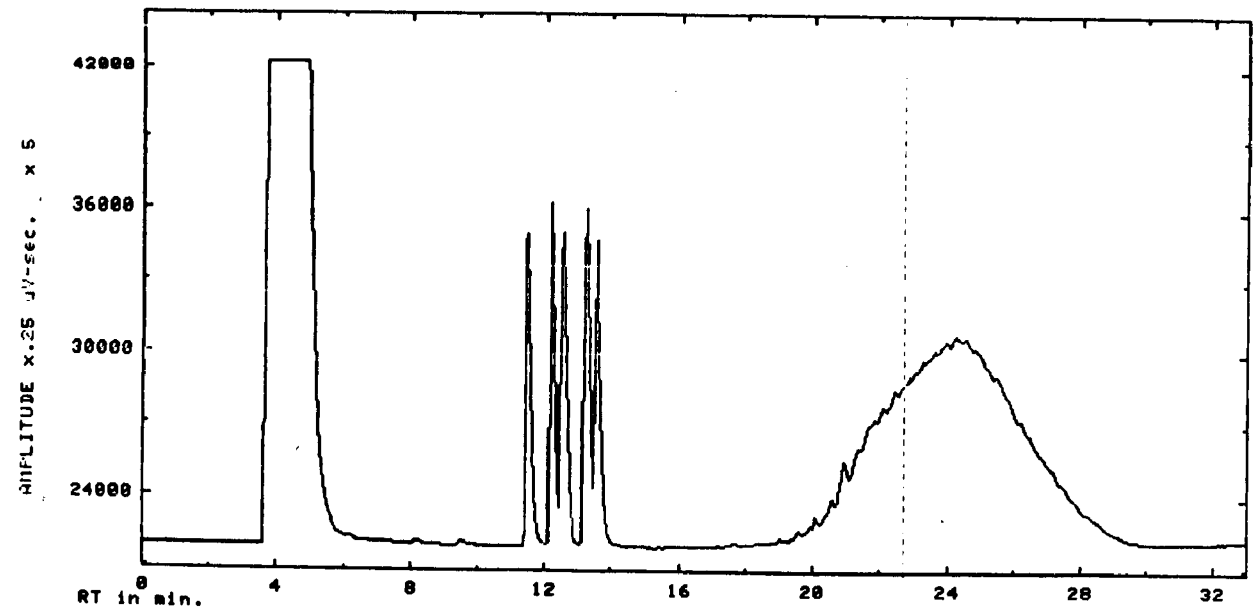


Figure 32. Boiling point distribution of SOF from cold- and hot-start transient test of DDAD 6V71 coach engine with trap with internal standard

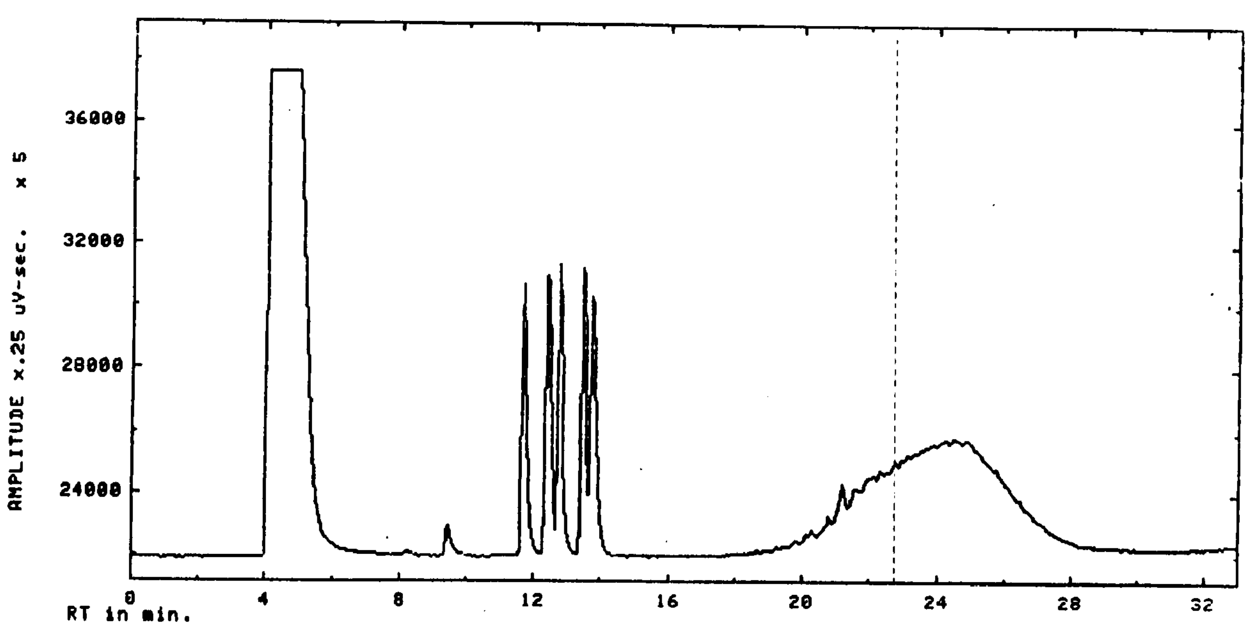


Figure 33. Boiling point distribution of SOF from bus cycle test of DDAD 6V71 coach engine with trap with internal standard

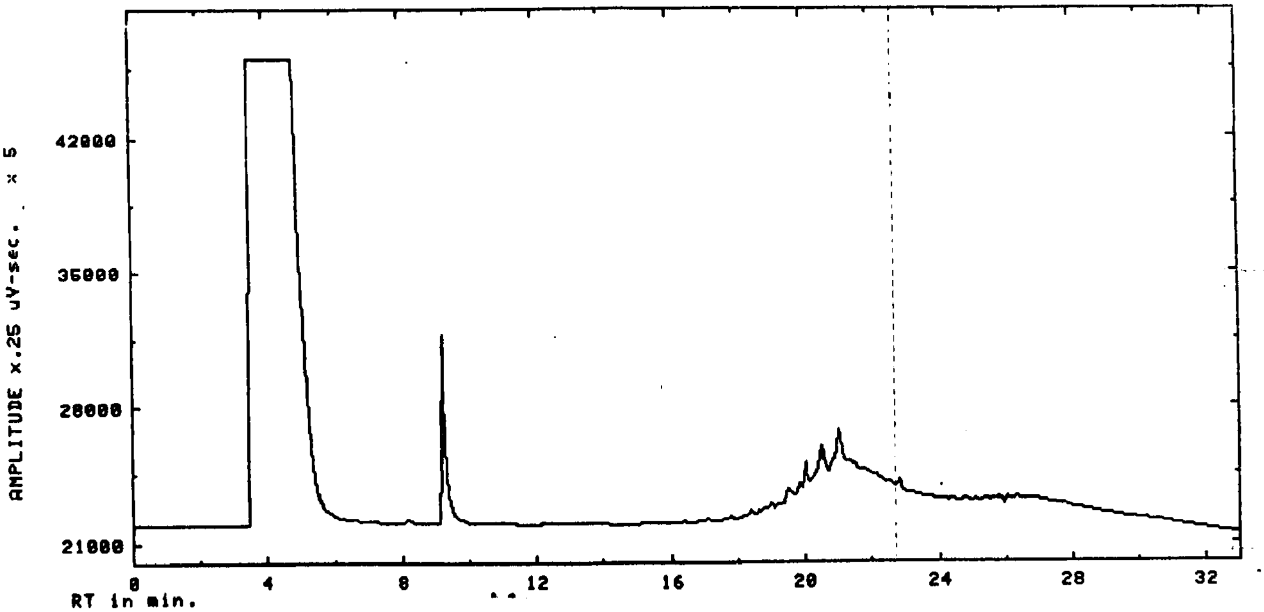


Figure 34. Boiling point distribution of SOF from cold- and hot-start transient test of GMC RTS-II coach with trap without internal standard

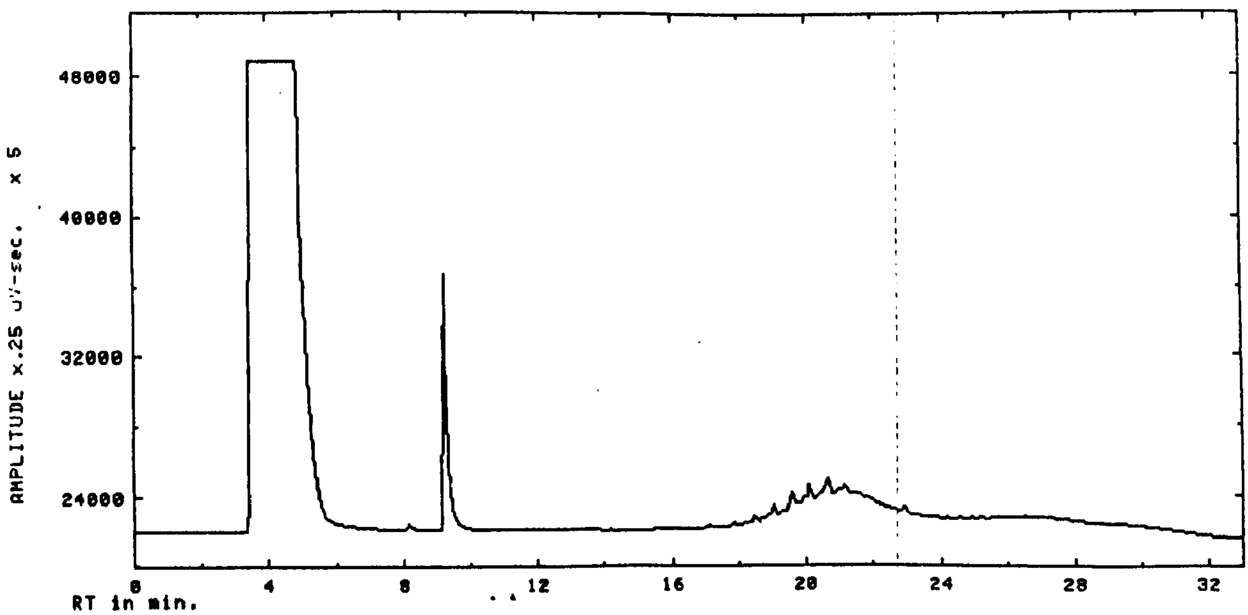


Figure 35. Boiling point distribution of SOF from bus cycle test of GMC RTS-II coach with trap without internal standard

use of internal standard in those latter cases, hence, no quantification data or boiling point distribution were tabulated as in Table 38. These figures indicate that the major portion of the SOF had a boiling range similar to a paraffinic material with about 20 to 24 carbon atoms. This apparent shift to the lighter boiling range is thought to be due to engine variability.

Elemental composition of some of the composite SOF samples were determined and are given in Table 39. With the exception of the sulfur, the percent of carbon, hydrogen and nitrogen content of the transient composite SOF with or without the trap was almost the same. For both the test engine and the coach vehicle, the nitrogen appears to be slightly greater over bus cycle operation than over cold- and hot-start transient operation.

TABLE 39. ELEMENTAL COMPOSITION OF SOLUBLE ORGANIC FRACTION

Element, Percent of SOF	DDAD 6V71 Coach Engine				DDAD 6V71 Coach	
	Baseline		With Trap		With Trap	
	Transient	Bus Cycle	Transient	Bus Cycle	Transient	Bus Cycle
C	84.68	a	85.96	85.28	79.81	82.41
H	13.15	a	13.04	12.93	11.78	12.49
N	0.24	a	0.24	0.49	0.59	1.04
S	0.49	a	0.31	0.40	0.38	0.46

[a]No data taken

V. QUALITY ASSURANCE

All work under this program was conducted in accordance with the Quality Assurance Project Plan submitted when the Work Assignment was initiated. Results obtained from the various sampling and analysis techniques used were checked and reviewed in order to eliminate potential errors in raw data, instrument reading, computer processing errors, or computations. System checks such as propane recovery checks, torquemeter verification, introduction of standard gases into instrumentation, and weight chamber control measures were carried out in order to provide quality measurements. Unregulated chemistry samples were processed as carefully as possible during the work-up stages of the procedure in order to verify proper operation of liquid and gas chromatographic instrumentation, respectively. No quality problems were apparent and the results reported herein are believed to be accurate relative to the specific procedures used in analysis. Details of procedures and computer programs used in this project are available through Reference 18.

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APPENDIX A

13-MODE RESULTS

TABLE A-1. 13-MODE FEDERAL DIESEL EMISSION CYCLE 1979

ENGINE: DDAD 6V-71 COACH   NO.1 DIESEL , BASELINE   BAROMETER 29.18
TEST NO. 01-01   FUEL: EM-400-F   PROJECT:11-5830-008   DATE: 05/12/81

MODE	POWER PCT	ENGINE SPEED COND / RPM	TORQUE OBS N X M	POWER OBS KW	FUEL FLOW KG/MIN	AIR FLOW KG/MIN	INTAKE HUMID G/KG	NOX CORR FACT	MEASURED HC PPM	MEASURED CO PPM	MEASURED CO2 PCT	MEASURED NOX PPM	CALCULATED GRAMS / HOUR HC	CALCULATED GRAMS / HOUR CO	CALCULATED GRAMS / HOUR NOX	MODE
1		IDLE / 400.	0.	.0	.014	3.48	7.1	.959	208.	101.	.73	130.	23.	22.	44.	1
2	2	INTER / 1260.	15.	2.0	.063	12.09	7.1	.959	272.	146.	1.05	100.	96.	103.	110.	2
3	25	INTER / 1260.	186.	24.5	.128	12.02	7.1	.959	248.	80.	2.18	215.	88.	56.	237.	3
4	50	INTER / 1260.	373.	49.2	.203	12.02	7.1	.959	248.	61.	3.67	380.	84.	40.	394.	4
5	75	INTER / 1260.	559.	73.7	.292	11.94	7.1	.958	264.	159.	5.34	565.	90.	104.	580.	5
6	100	INTER / 1260.	746.	98.4	.416	11.83	7.1	.958	216.	5775.	7.25	820.	74.	3703.	822.	6
7		IDLE / 400.	0.	.0	.014	3.46	7.1	.959	224.	101.	.73	135.	24.	22.	46.	7
8	100	RATED / 2100.	597.	131.2	.596	18.45	7.1	.958	316.	1139.	6.63	840.	177.	1212.	1397.	8
9	75	RATED / 2100.	448.	98.4	.471	18.50	7.1	.958	328.	173.	5.19	500.	186.	188.	850.	9
10	50	RATED / 2100.	298.	65.6	.349	18.53	7.1	.959	328.	90.	3.92	335.	180.	96.	559.	10
11	25	RATED / 2100.	149.	32.8	.242	18.61	7.1	.959	328.	93.	2.66	215.	181.	101.	365.	11
12	2	RATED / 2100.	12.	2.7	.153	18.75	7.1	.959	336.	103.	1.68	120.	183.	111.	202.	12
13		IDLE / 400.	0.	.0	.014	3.52	7.1	.959	232.	114.	.81	160.	23.	22.	49.	13

MODE	CALCULATED GRAMS/KG-FUEL HC	GRAMS/KG-FUEL CO	GRAMS/KG-FUEL NOX	GRAMS/KW-HR HC	GRAMS/KW-HR CO	GRAMS/KW-HR NOX	F/A DRY MEAS	F/A STOICH	"PHI"	WET HC CORR FACT	F/A CALC	F/A PCT MEAS	POWER CORR FACT	BSFC CORR KG/KW-HR	MODAL WEIGHT FACTOR	MODE
1	27.56	26.78	53.97	******	******	*****	.0039	.0687	.057	.992	.0036	-7.6	.991	*****	.067	1
2	25.20	26.98	28.93	48.75	52.21	55.98	.0053	.0687	.077	.989	.0052	-1.5	1.011	1.914	.080	2
3	11.45	7.29	30.68	3.60	2.29	9.65	.0108	.0687	.157	.979	.0105	-2.5	1.011	.311	.080	3
4	6.94	3.33	32.41	1.71	.82	8.00	.0170	.0687	.247	.965	.0174	2.8	1.011	.244	.080	4
5	5.16	5.96	33.12	1.22	1.42	7.86	.0246	.0687	.358	.951	.0252	2.3	1.010	.235	.080	5
6	2.95	*****	32.94	.75	37.62	8.35	.0354	.0687	.516	.932	.0365	3.1	1.011	.251	.080	6
7	29.62	26.73	55.93	******	******	*****	.0040	.0687	.058	.992	.0036	-8.0	.987	*****	.067	7
8	4.96	33.92	39.10	1.35	9.24	10.65	.0325	.0687	.474	.940	.0315	-3.1	1.048	.260	.080	8
9	6.57	6.66	30.10	1.89	1.91	8.64	.0256	.0687	.373	.952	.0245	-4.3	1.049	.274	.080	9
10	8.59	4.58	26.69	2.74	1.46	8.52	.0190	.0687	.276	.963	.0187	-1.7	1.049	.304	.080	10
11	12.46	6.94	25.12	5.51	3.07	11.11	.0131	.0687	.191	.974	.0128	-2.3	1.050	.421	.080	11
12	19.82	12.05	21.98	67.99	41.34	75.38	.0082	.0687	.120	.983	.0082	-.5	1.051	3.263	.080	12
13	29.72	27.23	59.84	******	******	*****	.0039	.0687	.057	.991	.0040	3.5	.988	*****	.067	13

CYCLE COMPOSITE USING 13-MODE WEIGHT FACTORS

BSHC ------- = 2.414 GRAM/KW-HR (1.801 GRAM/BHP-HR)
BSCO ------- = 9.971 GRAM/KW-HR (7.439 GRAM/BHP-HR)
BSNOX ------ = 9.732 GRAM/KW-HR (7.260 GRAM/BHP-HR)
BSHC + BSNOX = 12.146 GRAM/KW-HR (9.061 GRAM/BHP-HR)
CORR. BSFC - = .296 KG/KW-HR (.487 LBS/BHP-HR)

TABLE A-2. 13-MODE FEDERAL DIESEL EMISSION CYCLE 1979

ENGINE: DDAD 6V-71 COACH NO.1 DIESEL , BASELINE BAROMETER 29.18
TEST NO. 01-01 FUEL: EM-400-F PROJECT:11-5830-008 DATE: 06/12/81

MODE	POWER PCT	ENGINE SPEED COND / RPM	TORQUE OBS N X M	POWER OBS KW	FUEL FLOW KG/MIN	AIR FLOW KG/MIN	INTAKE HUMID G/KG	NOX CORR FACT	MEASURED HC PPM	MEASURED CO PPM	MEASURED CO2 PCT	MEASURED NOX PPM	CALCULATED GRAMS / HOUR HC	CALCULATED GRAMS / HOUR CO	CALCULATED GRAMS / HOUR NOX	MODE
1		IDLE / 400.	0.	.0	.014	3.55	6.1	.940	192.	119.	.81	160.	19.	23.	48.	1
2	2	INTER / 1260.	14.	1.8	.063	12.09	6.1	.940	260.	146.	1.18	130.	82.	92.	126.	2
3	25	INTER / 1260.	186.	24.5	.128	12.09	6.1	.941	236.	80.	2.23	235.	82.	55.	248.	3
4	50	INTER / 1260.	373.	49.2	.203	12.09	6.1	.942	236.	58.	3.60	390.	82.	39.	405.	4
5	75	INTER / 1260.	559.	73.7	.292	12.02	6.1	.943	252.	159.	5.34	575.	86.	104.	581.	5
6	100	INTER / 1260.	746.	98.4	.416	11.94	6.1	.944	216.	5735.	7.16	830.	74.	3722.	830.	6
7		IDLE / 400.	0.	.0	.014	3.54	6.1	.940	220.	98.	.69	130.	25.	22.	46.	7
8	100	RATED / 2100.	599.	131.8	.596	18.57	6.1	.944	312.	1126.	6.72	820.	173.	1183.	1327.	8
9	75	RATED / 2100.	449.	98.7	.471	18.61	6.1	.943	324.	159.	5.34	470.	179.	168.	765.	9
10	50	RATED / 2100.	300.	65.9	.349	18.65	6.1	.942	328.	88.	3.92	330.	180.	94.	541.	10
11	25	RATED / 2100.	149.	32.8	.242	18.63	6.1	.941	328.	93.	2.66	210.	181.	101.	360.	11
12	2	RATED / 2100.	12.	2.7	.153	18.74	6.1	.941	328.	101.	1.68	115.	178.	109.	190.	12
13		IDLE / 400.	0.	.0	.014	3.52	6.1	.940	236.	106.	.81	165.	23.	21.	49.	13

MODE	CALCULATED GRAMS/KG-FUEL HC	CALCULATED GRAMS/KG-FUEL CO	CALCULATED GRAMS/KG-FUEL NOX	CALCULATED GRAMS/KW-HR HC	CALCULATED GRAMS/KW-HR CO	CALCULATED GRAMS/KW-HR NOX	F/A DRY MEAS	F/A STOICH	"PHI"	WET HC CORR FACT	F/A CALC	F/A PCT MEAS	POWER CORR FACT	BSFC CORR KG/KW-HR	MODAL WEIGHT FACTOR	MODE
1	23.03	28.55	58.90	******	******	*****	.0039	.0687	.056	.991	.0040	4.1	.989	*****	.067	1
2	21.57	24.13	32.98	46.91	51.37	70.20	.0053	.0687	.077	.988	.0058	10.2	1.007	8.114	.080	2
3	10.67	7.14	32.20	3.35	2.24	10.12	.0107	.0687	.166	.978	.0107	.4	1.005	.313	.080	3
4	6.73	3.22	33.33	1.66	.80	8.23	.0169	.0687	.245	.966	.0171	1.5	1.005	.246	.080	4
5	4.92	5.96	33.17	1.17	1.42	7.88	.0244	.0687	.366	.951	.0252	3.0	1.006	.236	.080	5
6	2.98	*****	33.27	.76	37.81	8.43	.0350	.0687	.510	.933	.0361	2.9	1.004	.252	.080	6
7	30.71	27.40	55.76	******	******	*****	.0039	.0687	.056	.992	.0034	-10.9	.982	*****	.067	7
8	4.84	33.10	37.12	1.31	8.97	10.06	.0323	.0687	.470	.939	.0319	-1.1	1.044	.260	.080	8
9	6.32	5.95	27.08	1.81	1.70	7.75	.0255	.0687	.371	.951	.0252	-1.0	1.044	.274	.080	9
10	8.59	4.48	25.84	2.73	1.42	8.21	.0188	.0687	.274	.964	.0187	-1.0	1.044	.305	.080	10
11	12.45	6.94	24.09	5.51	3.07	10.65	.0131	.0687	.190	.975	.0128	-2.1	1.046	.423	.080	11
12	19.36	11.83	20.68	66.39	40.56	70.90	.0082	.0687	.120	.983	.0082	-.5	1.046	3.277	.080	12
13	28.21	25.34	60.51	******	******	*****	.0039	.0687	.057	.991	.0040	3.8	.986	*****	.067	13

CYCLE COMPOSITE USING 13-MODE WEIGHT FACTORS

BSHC ------- =	2.334	GRAM/KW-HR	(1.741	GRAM/BHP-HR)
BSCO ------- =	9.872	GRAM/KW-HR	(7.365	GRAM/BHP-HR)
BSNOX ------ =	9.458	GRAM/KW-HR	(7.055	GRAM/BHP-HR)
BSHC + BSNOX =	11.792	GRAM/KW-HR	(8.797	GRAM/BHP-HR)
CORR. BSFC - =	.297	KG/KW-HR	(.488	LBS/BHP-HR)

TABLE A-3. 13-MODE FEDERAL DIESEL EMISSION CYCLE 1979

ENGINE: DDAD 6V-71 COACH NO.1 DIESEL BASELINE REPEAT BAROMETER 29.34
TEST-1 FUEL: EM-400-F PROJECT: 05-6619-007 DATE: 3/10/83

MODE	POWER PCT	ENGINE SPEED COND / RPM	TORQUE OBS N X M	POWER OBS KW	FUEL FLOW KG/MIN	AIR FLOW KG/MIN	INTAKE HUMID G/KG	NOX CORR FACT	MEASURED HC PPM	MEASURED CO PPM	MEASURED CO2 PCT	MEASURED NOX PPM	CALCULATED GRAMS / HOUR HC	CALCULATED GRAMS / HOUR CO	CALCULATED GRAMS / HOUR NOX	MODE
1		IDLE / 401.	0.	.0	.014	3.86	37.	.905	152.	63.	.76	170.	17.	14.	56.	1
2	2	INTER / 1260.	19.	2.5	.063	12.26	37.	.910	196.	114.	1.08	120.	68.	79.	123.	2
3	25	INTER / 1260.	195.	25.8	.128	12.25	33.	.906	164.	68.	2.20	245.	58.	48.	253.	3
4	50	INTER / 1260.	381.	50.3	.204	12.25	34.	.912	164.	52.	3.48	415.	59.	37.	435.	4
5	75	INTER / 1260.	574.	75.7	.299	12.25	34.	.915	166.	138.	5.16	600.	60.	96.	623.	5
6	100	INTER / 1260.	758.	100.0	.417	12.02	29.	.910	120.	5838.	6.83	840.	43.	3966.	847.	6
7		IDLE / 400.	0.	.0	.014	3.78	29.	.865	158.	68.	.76	165.	18.	15.	52.	7
8	100	RATED / 2100.	613.	134.8	.596	19.06	34.	.917	204.	1014.	6.32	880.	120.	1135.	1474.	8
9	75	RATED / 2100.	457.	100.5	.475	19.06	34.	.911	224.	108.	5.08	505.	131.	121.	844.	9
10	50	RATED / 2100.	305.	67.1	.348	19.21	29.	.895	234.	52.	3.73	340.	135.	58.	556.	10
11	25	RATED / 2100.	152.	33.4	.227	18.86	34.	.902	230.	52.	2.46	205.	129.	57.	333.	11
12	2	RATED / 2100.	12.	2.7	.144	18.86	29.	.888	240.	68.	1.57	125.	131.	74.	196.	12
13		IDLE / 399.	0.	.0	.014	3.80	34.	.892	162.	68.	.76	170.	18.	15.	55.	13

MODE	CALCULATED GRAMS/KG-FUEL HC	CALCULATED GRAMS/KG-FUEL CO	CALCULATED GRAMS/KG-FUEL NOX	CALCULATED GRAMS/KW-HR HC	CALCULATED GRAMS/KW-HR CO	CALCULATED GRAMS/KW-HR NOX	F/A DRY MEAS	F/A STOICH	"PHI"	WET HC CORR FACT	F/A CALC	F/A PCT MEAS	POWER CORR FACT	BSFC CORR KG/KW-HR	MODAL WEIGHT FACTOR	MODE
1	19.62	16.24	64.73	************		******	.0037	.0685	.055	.991	.0037	-.0	.984	*****	.067	1
2	17.85	20.67	32.32	27.14	31.43	49.13	.0052	.0685	.076	.988	.0053	1.9	1.005	1.512	.080	2
3	7.54	6.16	32.81	2.26	1.84	9.82	.0105	.0685	.154	.978	.0106	.2	1.004	.298	.080	3
4	4.84	2.99	35.53	1.18	.73	8.65	.0167	.0685	.244	.967	.0165	-1.2	1.004	.242	.080	4
5	3.36	5.36	34.77	.79	1.27	8.23	.0245	.0685	.357	.952	.0243	-.6	1.006	.235	.080	5
6	1.73	158.42	33.83	.43	39.64	8.47	.0349	.0685	.509	.935	.0346	-.7	1.012	.247	.080	6
7	20.36	17.51	59.99	************		******	.0038	.0685	.056	.992	.0037	-1.9	.990	*****	.067	7
8	3.36	31.72	41.20	.89	8.42	10.93	.0314	.0685	.459	.942	.0300	-4.4	1.046	.254	.080	8
9	4.60	4.26	29.59	1.30	1.21	8.40	.0251	.0685	.366	.953	.0240	-4.4	1.046	.271	.080	9
10	6.45	2.79	26.62	2.01	.87	8.29	.0182	.0685	.266	.965	.0177	-2.7	1.047	.298	.080	10
11	9.47	4.21	24.44	3.86	1.71	9.95	.0121	.0685	.176	.976	.0118	-2.3	1.043	.390	.080	11
12	15.23	8.56	22.79	48.90	27.47	73.14	.0076	.0685	.112	.984	.0076	-.2	1.043	3.078	.080	12
13	20.87	17.50	63.66	************		******	.0038	.0685	.055	.991	.0037	-1.3	.986	*****	.067	13

CYCLE COMPOSITE USING 13-MODE WEIGHT FACTORS

BSHC ------- =	1.652	GRAM/KW-HR	(1.232	GRAM/BHP-HR)
BSCO ------- =	9.627	GRAM/KW-HR	(7.182	GRAM/BHP-HR (
BSNOX ------ =	9.817	GRAM/KW-HR	(7.324	GRAM/BHP-HR)
BSHC + BSNOX =	11.469	GRAM/KW-HR	(8.556	GRAM/BHP-HR)
CORR. BSFC - =	.289	KG/KW-HR	(.475	LBS/BHP-HR)

TABLE A-4. 13-MODE FEDERAL DIESEL EMISSION CYCLE 1979

ENGINE: DDAD 6V71 COACH BEFORE PARTICULATE TRAP BAROMETER 28.85
TEST-02-01 FUEL: EM-400-F PROJECT: 05-6619-007 DATE: 04/20/83

MODE	POWER PCT	ENGINE SPEED COND / RPM	TORQUE OBS N X M	POWER OBS KW	FUEL FLOW KG/MIN	AIR FLOW KG/MIN	INTAKE HUMID G/KG	NOX CORR FACT	MEASURED HC PPM	MEASURED CO PPM	MEASURED CO2 PCT	MEASURED NOX PPM	CALCULATED GRAMS / HOUR HC	CALCULATED GRAMS / HOUR CO	CALCULATED GRAMS / HOUR NOX	MODE
1		IDLE / 400.	0.	.0	.015	3.52	64.	.946	192.	68.	.80	158.	21.	15.	54.	1
2	2	INTER / 1260.	15.	2.0	.065	11.68	64.	.968	232.	114.	1.04	109.	85.	83.	126.	2
3	25	INTER / 1260.	184.	24.3	.119	11.72	64.	.970	180.	74.	1.95	218.	67.	54.	252.	3
4	50	INTER / 1260.	368.	48.5	.195	11.65	64.	.972	174.	63.	3.36	367.	62.	44.	406.	4
5	75	INTER / 1260.	552.	72.8	.294	11.57	64.	.975	166.	157.	5.08	550.	60.	109.	608.	5
6	100	INTER / 1260.	735.	97.0	.420	11.49	61.	.971	132.	2405.	6.92	753.	50.	1700.	844.	6
7		IDLE / 400.	0.	.0	.017	3.45	64.	.951	166.	74.	.80	163.	20.	18.	62.	7
8	100	RATED / 2100.	624.	137.2	.605	18.27	64.	.977	204.	1199.	6.49	847.	119.	1322.	1490.	8
9	75	RATED / 2100.	468.	102.9	.495	18.28	64.	.973	224.	183.	5.53	525.	126.	197.	896.	9
10	50	RATED / 2100.	312.	68.6	.366	18.45	69.	.986	252.	68.	3.79	308.	150.	79.	574.	10
11	25	RATED / 2100.	156.	34.3	.240	18.30	71.	.990	256.	63.	2.62	188.	143.	69.	333.	11
12	2	RATED / 2100.	12.	2.7	.139	18.38	71.	.990	276.	68.	1.61	109.	143.	70.	180.	12
13		IDLE / 400.	0.	.0	.015	3.58	71.	.985	196.	74.	.88	163.	20.	15.	53.	13

MODE	CALCULATED GRAMS/KG-FUEL HC	CO	NOX	CALCULATED GRAMS/KW-HR HC	CO	NOX	F/A DRY MEAS	F/A STOICH	"PHI"	WET HC CORR FACT	F/A CALC	F/A PCT MEAS	POWER CORR FACT	BSFC CORR KG/KW-HR	MODAL WEIGHT FACTOR	MODE
1	23.48	16.59	59.49	************		******	.0043	.0685	.063	.990	.0039	-8.8	1.016	*****	.067	1
2	21.86	21.37	32.29	43.31	42.34	63.97	.0056	.0685	.082	.988	.0051	-8.6	1.034	1.916	.080	2
3	9.30	7.55	35.19	2.74	2.22	10.36	.0103	.0685	.150	.979	.0094	-8.6	1.034	.285	.080	3
4	5.32	3.75	34.66	1.28	.91	8.36	.0169	.0685	.247	.967	.0160	-5.4	1.034	.233	.080	4
5	3.41	6.19	34.49	.83	1.50	8.35	.0257	.0685	.374	.952	.0240	-6.6	1.033	.234	.080	5
6	1.97	67.56	33.52	.51	17.53	8.70	.0368	.0685	.538	.935	.0334	-9.4	1.034	.251	.080	6
7	20.35	18.09	61.83	************		******	.0049	.0685	.071	.990	.0039	-19.0	1.014	*****	.067	7
8	3.27	36.44	41.05	.87	9.63	10.86	.0334	.0685	.487	.939	.0309	-7.5	1.073	.246	.080	8
9	4.24	6.62	30.16	1.22	1.91	8.71	.0273	.0685	.399	.948	.0261	-4.6	1.075	.269	.080	9
10	6.85	3.58	26.13	2.19	1.15	8.36	.0200	.0685	.292	.963	.0180	-10.0	1.072	.298	.080	10
11	9.92	4.79	23.07	4.17	2.01	9.70	.0133	.0685	.194	.973	.0126	-5.2	1.072	.392	.080	11
12	17.09	8.33	21.56	53.13	25.90	67.03	.0076	.0685	.112	.982	.0078	2.5	1.068	2.911	.080	12
13	21.86	16.44	58.18	************		******	.0043	.0685	.062	.988	.0043	1.7	1.006	*****	.067	13

CYCLE COMPOSITE USING 13-MODE WEIGHT FACTORS

BSHC ------- =	1.789	GRAM/KW-HR	(1.335	GRAM/BHP-HR	)
BSCO ------- =	6.381	GRAM/KW-HR	(4.760	GRAM/BHP-HR	(
BSNOX ------ =	9.907	GRAM/KW-HR	(7.390	GRAM/BHP-HR	)
BSHC + BSNOX =	11.696	GRAM/KW-HR	(8.725	GRAM/BHP-HR	)
CORR. BSFC - =	.286	KG/KW-HR	(.471	LBS/BHP-HR	)

TABLE A-5. 13-MODE FEDERAL DIESEL EMISSION CYCLE 1979

ENGINE:DDAD 6V71 COACH AFTER PARTICULATE TRAP BAROMETER 28.85
TEST-02-01 FUEL:EM-400-F PROJECT:05-6619-007 DATE:04/20/83

MODE	POWER PCT	ENGINE SPEED COND / RPM	TORQUE OBS N X M	POWER OBS KW	FUEL FLOW KG/MIN	AIR FLOW KG/MIN	INTAKE HUMID G/KG	NOX CORR FACT	MEASURED HC PPM	MEASURED CO PPM	MEASURED CO2 PCT	MEASURED NOX PPM	CALCULATED GRAMS / HOUR HC	CALCULATED GRAMS / HOUR CO	CALCULATED GRAMS / HOUR NOX	MODE
1		IDLE / 400.	0.	.0	.015	3.52	64.	.946	140.	74.	.80	163.	16.	16.	56.	1
2	2	INTER / 1260.	15.	2.0	.065	11.68	64.	.968	222.	120.	1.04	109.	82.	88.	126.	2
3	25	INTER / 1260.	184.	24.3	.119	11.72	64.	.970	182.	74.	1.96	218.	67.	54.	251.	3
4	50	INTER / 1260.	368.	48.5	.195	11.65	64.	.972	174.	63.	3.36	367.	62.	44.	406.	4
5	75	INTER / 1260.	552.	72.8	.294	11.57	64.	.975	156.	170.	5.08	545.	57.	118.	603.	5
6	100	INTER / 1260.	735.	97.0	.420	11.49	61.	.971	110.	2329.	6.92	758.	41.	1649.	850.	6
7		IDLE / 400.	0.	.0	.017	3.45	64.	.951	108.	74.	.80	169.	13.	18.	64.	7
8	100	RATED / 2100.	624.	137.2	.605	18.27	64.	.977	168.	1166.	6.49	867.	98.	1287.	1526.	8
9	75	RATED / 2100.	468.	102.9	.495	18.28	64.	.973	196.	170.	5.30	510.	115.	191.	909.	9
10	50	RATED / 2100.	312.	68.6	.366	18.45	69.	.986	248.	68.	3.79	308.	148.	79.	574.	10
11	25	RATED / 2100.	156.	34.3	.240	18.30	71.	.990	252.	63.	2.51	188.	147.	72.	347.	11
12	2	RATED / 2100.	12.	2.7	.139	18.38	71.	.990	276.	68.	1.71	109.	135.	66.	170.	12
13		IDLE / 400.	0.	.0	.015	3.58	71.	.985	184.	68.	.88	163.	19.	14.	53.	13

MODE	CALCULATED GRAMS/KG-FUEL HC	CALCULATED GRAMS/KG-FUEL CO	CALCULATED GRAMS/KG-FUEL NOX	GRAMS/KW-HR HC	GRAMS/KW-HR CO	GRAMS/KW-HR NOX	F/A DRY MEAS	F/A STOICH	"PHI"	WET HC CORR FACT	F/A CALC	F/A PCT MEAS	POWER CORR FACT	BSFC CORR KG/KW-HR	MODAL WEIGHT FACTOR	MODE
1	17.22	18.15	61.72	************		******	.0043	.0685	.063	.990	.0039	-9.3	1.016	*****	.067	1
2	20.93	22.51	32.30	41.46	44.59	64.00	.0056	.0685	.082	.988	.0051	-8.6	1.034	1.916	.080	2
3	9.36	7.51	35.01	2.76	2.21	10.31	.0103	.0685	.150	.979	.0094	-8.2	1.034	.285	.080	3
4	5.32	3.75	34.66	1.28	.91	8.36	.0169	.0685	.247	.967	.0160	-5.4	1.034	.233	.080	4
5	3.21	6.70	34.17	.78	1.62	8.28	.0257	.0685	.374	.952	.0240	-6.6	1.033	.234	.080	5
6	1.64	65.51	33.79	.43	17.00	8.77	.0368	.0685	.538	.935	.0333	-9.5	1.034	.251	.080	6
7	13.33	18.22	64.56	************		******	.0049	.0685	.071	.990	.0039	-19.5	1.014	*****	.067	7
8	2.70	35.47	42.07	.71	9.38	11.12	.0334	.0685	.487	.940	.0309	-7.6	1.073	.246	.080	8
9	3.87	6.42	30.59	1.12	1.85	8.83	.0273	.0685	.399	.950	.0250	-8.5	1.075	.269	.080	9
10	6.74	3.59	26.13	2.16	1.15	8.36	.0200	.0685	.292	.963	.0180	-10.0	1.072	.298	.080	10
11	10.18	4.99	24.08	4.28	2.10	10.12	.0133	.0685	.194	.974	.0121	-9.1	1.072	.392	.080	11
12	16.13	7.85	20.33	50.15	24.41	63.19	.0076	.0685	.112	.981	.0083	8.7	1.068	2.911	.080	12
13	20.56	15.14	58.29	************		******	.0043	.0685	.062	.988	.0043	1.5	1.006	*****	.067	13

CYCLE COMPOSITE USING 13-MODE WEIGHT FACTORS

BSHC ------- = 1.678 GRAM/KW-HR (1.252 GRAM/BHP-HR)
BSCO ------- = 6.245 GRAM/KW-HR (4.659 GRAM/BHP-HR (
BSNOX ------ = 10.004 GRAM/KW-HR (7.463 GRAM/BHP-HR)
BSHC + BSNOX = 11.682 GRAM/KW-HR (8.715 GRAM/BHP-HR)
CORR. BSFC - = .286 KG/KW-HR (.471 LBS/BHP-HR)

APPENDIX B

TRANSIENT TEST RESULTS FROM DDAD 6V71 COACH ENGINE WITHOUT TRAP

TABLE B-1. ENGINE EMISSION RESULTS
C-TRANS.

PROJECT NO. 05-6619-007

ENGINE NO.D1
ENGINE MODEL 78 DDA 6V-71N
ENGINE 7.0 L(426. CID) V-6
CVS NO. 19

TEST NO.D1-2 RUN1
DATE 4/ 5/83
TIME
DYNO NO. 3

DIESEL EM-400-F
BAG CART NO. 1

BAROMETER 735.84 MM HG(28.97 IN HG)
DRY BULB TEMP. 24.4 DEG C(76.0 DEG F)

RELATIVE HUMIDITY , ENGINE-40. PCT , CVS-34. PCT
ABSOLUTE HUMIDITY 7.9 GM/KG(55.3 GRAINS/LB) NOX HUMIDITY C.F. 1.0000

BAG RESULTS

BAG NUMBER	1	2	3	4
DESCRIPTION	NYNF	LANF	LAF	NYNF
TIME SECONDS	296.0	299.9	305.0	297.9
TOT. BLOWER RATE SCMM (SCFM)	32.23 (1137.9)	32.24 (1138.3)	32.24 (1138.6)	32.23 (1138.1)
TOT. 20X20 RATE SCMM (SCFM)	0.00 (0.0)	0.00 (0.0)	0.00 (0.0)	0.00 (0.00)
TOT. 90MM RATE SCMM (SCFM)	.05 (1.66)	.05 (1.66)	.05 (1.66)	.05 (1.66)
TOT. AUX. SAMPLE RATE SCMM (SCFM)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
TOTAL FLOW STD. CU. METRES(SCF)	159.2 (5622.)	161.4 (5698.)	164.1 (5796.)	160.3 (5659.)
HC SAMPLE METER/RANGE/PPM	14.6/12/ 29.	20.0/12/ 40.	44.2/12/ 88.	19.3/12/ 39.
HC BCKGRD METER/RANGE/PPM	6.2/ 1/ 6.	7.8/ 1/ 8.	8.4/ 1/ 8.	8.0/ 1/ 8.
CO SAMPLE METER/RANGE/PPM	33.9/13/ 31.	27.8/13/ 25.	58.0/12/ 126.	43.2/13/ 40.
CO BCKGRD METER/RANGE/PPM	.1/13/ 0.	.5/13/ 0.	.1/12/ 0.	.4/13/ 0.
CO2 SAMPLE METER/RANGE/PCT	55.5/11/ .45	68.7/11/ .60	82.9/ 3/ 1.53	52.2/11/ .41
CO2 BCKGRD METER/RANGE/PCT	6.9/11/ .04	6.8/11/ .04	3.0/ 3/ .05	7.7/11/ .05
NOX SAMPLE METER/RANGE/PPM	40.6/ 2/ 41.	43.8/ 2/ 44.	37.3/ 3/ 112.	37.5/ 2/ 38.
NOX BCKGRD METER/RANGE/PPM	.5/ 2/ 1.	.6/ 2/ 1.	.2/ 3/ 1.	1.0/ 2/ 1.
DILUTION FACTOR	29.61	22.23	8.64	31.91
HC CONCENTRATION PPM	23.	33.	81.	31.
CO CONCENTRATION PPM	31.	24.	121.	39.
CO2 CONCENTRATION PCT	.41	.56	1.49	.37
NOX CONCENTRATION PPM	40.1	43.2	111.4	36.5
HC MASS GRAMS	2.14	3.02	7.66	2.86
CO MASS GRAMS	5.67	4.60	23.12	7.32
CO2 MASS GRAMS	1185.6	1647.5	4475.8	1077.8
NOX MASS GRAMS	12.21	13.34	34.96	11.20
FUEL KG (LB)	.380 (.84)	.526 (1.16)	1.433 (3.16)	.347 (.77)
KW HR (HP HR)	.87 (1.17)	1.34 (1.80)	5.11 (6.85)	1.11 (1.49)
BSHC G/KW HR (G/HP HR)	2.45 (1.83)	2.25 (1.68)	1.50 (1.12)	2.57 (1.92)
BSCO G/KW HR (G/HP HR)	6.50 (4.85)	3.43 (2.56)	4.53 (3.38)	6.59 (4.92)
BSCO2 G/KW HR (G/HP HR)	1358.95 (1013.37)	1227.41 (915.28)	876.23 (653.40)	970.05 (723.37)
BSNOX G/KW HR (G/HP HR)	14.00 (10.44)	9.94 (7.41)	6.84 (5.10)	10.08 (7.51)
BSFC KG/KW HR (LB/HP HR)	.435 (.715)	.392 (.644)	.281 (.461)	.312 (.513)

TOTAL TEST RESULTS 4 BAGS

TOTAL KW HR (HP HR)	8.43 (11.31)
BSHC G/KW HR (G/HP HR)	1.86 (1.39)
BSCO G/KW HR (G/HP HR)	4.83 (3.60)
BSCO2 G/KW HR (G/HP HR)	994. (742.)
BSNOX G/KW HR (G/HP HR)	8.50 (6.34)
BSFC KG/KW HR (LB/HP HR)	.318 (.524)

PARTICULATE RESULTS, TOTAL FOR 4 BAGS

90MM PARTICULATE RATES	GRAMS/TEST	4.83
	G/KWHR(G/HPHR)	.57 (.43)
	G/KG FUEL (G/LB FUEL)	1.80 (.81)
	FILTER EFF.	90.9

TABLE B-2. ENGINE EMISSION RESULTS
C-TRANS.

PROJECT NO. 05-6619-007

ENGINE NO.D1
ENGINE MODEL 78 DDA 6V-71N
ENGINE 7.0 L(426. CID) V-6
CVS NO. 19

TEST NO.D1-2- RUN1
DATE 4/15/83
TIME
DYNO NO. 3

DIESEL EM-400-F
BAG CART NO. 1

BAROMETER 747.27 MM HG(29.42 IN HG)
DRY BULB TEMP. 22.8 DEG C(73.0 DEG F)

RELATIVE HUMIDITY , ENGINE-51. PCT , CVS-22. PCT
ABSOLUTE HUMIDITY 9.0 GM/KG(62.9 GRAINS/LB) NOX HUMIDITY C.F. 1.0000

BAG RESULTS

BAG NUMBER	1	2	3	4
DESCRIPTION	NYNF	LANF	LAF	NYNF
TIME SECONDS	296.0	300.0	304.9	298.0
TOT. BLOWER RATE SCMM (SCFM)	32.62 (1151.7)	32.63 (1152.1)	32.62 (1151.8)	32.63 (1152.3)
TOT. 20X20 RATE SCMM (SCFM)	0.00 (0.0)	0.00 (0.0)	0.00 (0.0)	0.00 (0.00)
TOT. 90MM RATE SCMM (SCFM)	.04 (1.52)	.04 (1.52)	.04 (1.52)	.04 (1.52)
TOT. AUX. SAMPLE RATE SCMM (SCFM)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
TOTAL FLOW STD. CU. METRES(SCF)	161.1 (5689.)	163.4 (5768.)	166.0 (5861.)	162.3 (5731.)
HC SAMPLE METER/RANGE/PPM	13.5/12/ 27.	18.8/12/ 38.	41.4/12/ 83.	16.1/12/ 32.
HC BCKGRD METER/RANGE/PPM	7.6/ 1/ 8.	8.0/ 1/ 8.	8.4/ 1/ 8.	8.0/ 1/ 8.
CO SAMPLE METER/RANGE/PPM	39.4/13/ 37.	26.9/13/ 25.	96.5/13/ 98.	36.1/13/ 33.
CO BCKGRD METER/RANGE/PPM	.8/13/ 1.	1.5/13/ 1.	22.0/13/ 20.	1.5/13/ 1.
CO2 SAMPLE METER/RANGE/PCT	75.5/12/ .32	68.1/11/ .59	81.4/ 3/ 1.50	87.0/12/ .38
CO2 BCKGRD METER/RANGE/PCT	12.2/12/ .04	7.2/11/ .04	4.0/ 3/ .06	13.6/12/ .05
NOX SAMPLE METER/RANGE/PPM	39.8/ 2/ 40.	43.9/ 2/ 44.	36.5/ 3/ 110.	36.7/ 2/ 37.
NOX BCKGRD METER/RANGE/PPM	.3/ 2/ 0.	.6/ 2/ 1.	.4/ 3/ 1.	.6/ 2/ 1.
DILUTION FACTOR	41.02	22.51	8.84	34.24
HC CONCENTRATION PPM	20.	30.	75.	25.
CO CONCENTRATION PPM	35.	23.	77.	32.
CO2 CONCENTRATION PCT	.28	.55	1.44	.34
NOX CONCENTRATION PPM	39.5	43.3	108.4	36.1
HC MASS GRAMS	1.82	2.82	7.22	2.29
CO MASS GRAMS	6.65	4.36	14.85	5.98
CO2 MASS GRAMS	825.7	1638.9	4388.8	1009.6
NOX MASS GRAMS	12.17	13.54	34.42	11.21
FUEL KG (LB)	.266 (.59)	.523 (1.15)	1.401 (3.09)	.324 (.71)
KW HR (HP HR)	.87 (1.16)	1.30 (1.75)	4.90 (6.57)	1.06 (1.42)
BSHC G/KW HR (G/HP HR)	2.11 (1.57)	2.16 (1.61)	1.47 (1.10)	2.17 (1.62)
BSCO G/KW HR (G/HP HR)	7.69 (5.73)	3.34 (2.49)	3.03 (2.26)	5.64 (4.21)
BSCO2 G/KW HR (G/HP HR)	954.61 (711.85)	1255.92 (936.54)	895.82 (668.01)	953.42 (710.97)
BSNOX G/KW HR (G/HP HR)	14.07 (10.49)	10.37 (7.73)	7.03 (5.24)	10.59 (7.89)
BSFC KG/KW HR (LB/HP HR)	.308 (.506)	.401 (.659)	.286 (.470)	.306 (.503)

TOTAL TEST RESULTS 4 BAGS

TOTAL KW HR (HP HR)	8.13 (10.90)
BSHC G/KW HR (G/HP HR)	1.74 (1.30)
BSCO G/KW HR (G/HP HR)	3.92 (2.92)
BSCO2 G/KW HR (G/HP HR)	967. (721.)
BSNOX G/KW HR (G/HP HR)	8.78 (6.54)
BSFC KG/KW HR (LB/HP HR)	.309 (.509)

PARTICULATE RESULTS, TOTAL FOR 4 BAGS

90MM PARTICULATE RATES

GRAMS/TEST	4.59
G/KWHR(G/HPHR)	.56 (.42)
G/KG FUEL (G/LB FUEL)	1.82 (.83)
FILTER EFF.	90.4

TABLE B-3. ENGINE EMISSION RESULTS
C-TRANS

PROJECT NO. 05-6619-007

ENGINE NO.D1
ENGINE MODEL 78 DDA 6V-71N
ENGINE 7.0 L(426. CID) V-6
CVS NO. 19

TEST NO.D1-2- RUN1
DATE 4/18/83
TIME
DYNO NO. 3

DIESEL EM-400-F
BAG CART NO. 1

BAROMETER 735.33 MM HG(28.95 IN HG)
DRY BULB TEMP. 26.1 DEG C(79.0 DEG F)

RELATIVE HUMIDITY , ENGINE-27. PCT , CVS-26. PCT
ABSOLUTE HUMIDITY 5.9 GM/KG(41.1 GRAINS/LB) NOX HUMIDITY C.F. 1.0000

BAG RESULTS

BAG NUMBER	1	2	3	4
DESCRIPTION	NYNF	LANF	LAF	NYNF
TIME SECONDS	295.9	299.9	304.9	297.9
TOT. BLOWER RATE SCMM (SCFM)	32.28 (1139.8)	32.28 (1139.8)	32.28 (1139.7)	32.27 (1139.6)
TOT. 20X20 RATE SCMM (SCFM)	0.00 (0.0)	0.00 (0.0)	0.00 (0.0)	0.00 (0.00)
TOT. 90MM RATE SCMM (SCFM)	.04 (1.47)	.04 (1.47)	.04 (1.47)	.04 (1.47)
TOT. AUX. SAMPLE RATE SCMM (SCFM)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
TOTAL FLOW STD. CU. METRES(SCF)	159.4 (5628.)	161.6 (5704.)	164.2 (5799.)	160.4 (5665.)
HC SAMPLE METER/RANGE/PPM	13.6/12/ 27.	19.9/12/ 40.	45.0/12/ 90.	17.8/12/ 36.
HC BCKGRD METER/RANGE/PPM	6.0/ 1/ 6.	6.0/ 1/ 6.	6.0/ 1/ 6.	6.0/ 1/ 6.
CO SAMPLE METER/RANGE/PPM	38.4/13/ 36.	27.4/13/ 25.	65.1/12/ 145.	39.9/13/ 37.
CO BCKGRD METER/RANGE/PPM	.1/13/ 0.	.1/13/ 0.	.3/12/ 1.	.2/12/ 0.
CO2 SAMPLE METER/RANGE/PCT	92.5/12/ .42	68.8/11/ .60	82.3/ 3/ 1.52	87.7/12/ .39
CO2 BCKGRD METER/RANGE/PCT	11.3/12/ .04	6.9/11/ .04	2.8/ 3/ .04	12.2/12/ .04
NOX SAMPLE METER/RANGE/PPM	36.5/ 2/ 37.	43.2/ 2/ 43.	37.1/ 3/ 111.	35.7/ 2/ 36.
NOX BCKGRD METER/RANGE/PPM	.3/ 2/ 0.	.4/ 2/ 0.	.2/ 3/ 1.	.6/ 2/ 1.
DILUTION FACTOR	31.59	22.18	8.70	33.82
HC CONCENTRATION PPM	21.	34.	85.	30.
CO CONCENTRATION PPM	35.	25.	139.	36.
CO2 CONCENTRATION PCT	.38	.56	1.48	.35
NOX CONCENTRATION PPM	36.2	42.8	110.8	35.1
HC MASS GRAMS	1.96	3.18	8.02	2.76
CO MASS GRAMS	6.49	4.61	26.66	6.76
CO2 MASS GRAMS	1111.9	1651.2	4448.8	1024.5
NOX MASS GRAMS	11.04	13.23	34.79	10.78
FUEL KG (LB)	.357 (.79)	.527 (1.16)	1.427 (3.15)	.330 (.73)
KW HR (HP HR)	.91 (1.22)	1.36 (1.82)	4.87 (6.53)	1.03 (1.38)
BSHC G/KW HR (G/HP HR)	2.16 (1.61)	2.34 (1.75)	1.65 (1.23)	2.68 (2.00)
BSCO G/KW HR (G/HP HR)	7.14 (5.32)	3.40 (2.53)	5.48 (4.08)	6.57 (4.90)
BSCO2 G/KW HR (G/HP HR)	1222.16 (911.37)	1216.67 (907.27)	913.63 (681.29)	995.61 (742.42)
BSNOX G/KW HR (G/HP HR)	12.13 (9.05)	9.75 (7.27)	7.14 (5.33)	10.47 (7.81)
BSFC KG/KW HR (LB/HP HR)	.392 (.644)	.388 (.639)	.293 (.482)	.321 (.527)

TOTAL TEST RESULTS 4 BAGS

TOTAL KW HR (HP HR)	8.17 (10.95)
BSHC G/KW HR (G/HP HR)	1.95 (1.45)
BSCO G/KW HR (G/HP HR)	5.45 (4.07)
BSCO2 G/KW HR (G/HP HR)	1009. (752.)
BSNOX G/KW HR (G/HP HR)	8.55 (6.38)
BSFC KG/KW HR (LB/HP HR)	.323 (.532)

PARTICULATE RESULTS, TOTAL FOR 4 BAGS

90MM PARTICULATE RATES	GRAMS/TEST	6.70
	G/KWHR(G/HPHR)	.82 (.61)
	G/KG FUEL (G/LB FUEL)	2.54 (1.15)
	FILTER EFF.	90.1

TABLE B-4. ENGINE EMISSION RESULTS
H-TRANS.

PROJECT NO. 05-6619-007

ENGINE NO.D1
ENGINE MODEL 78 DDA 6V-71N
ENGINE 7.0 L(426. CID) V-6
CVS NO. 19

TEST NO.D1-2 RUN1
DATE 4/ 5/83
TIME
DYNO NO. 3

DIESEL EM-400-F
BAG CART NO. 1

BAROMETER 735.33 MM HG(28.95 IN HG)
DRY BULB TEMP. 25.6 DEG C(78.0 DEG F)

RELATIVE HUMIDITY , ENGINE-39. PCT , CVS-31. PCT
ABSOLUTE HUMIDITY 8.2 GM/KG(57.7 GRAINS/LB) NOX HUMIDITY C.F. 1.0000

BAG RESULTS

BAG NUMBER	1	2	3	4
DESCRIPTION	NYNF	LANF	LAF	NYNF
TIME SECONDS	296.0	300.0	305.0	297.9
TOT. BLOWER RATE SCMM (SCFM)	32.35 (1142.1)	32.36 (1142.5)	32.37 (1142.8)	32.34 (1142.0)
TOT. 20X20 RATE SCMM (SCFM)	0.00 (0.0)	0.00 (0.0)	0.00 (0.0)	0.00 (0.00)
TOT. 90MM RATE SCMM (SCFM)	.04 (1.31)	.04 (1.31)	.04 (1.31)	.04 (1.31)
TOT. AUX. SAMPLE RATE SCMM (SCFM)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
TOTAL FLOW STD. CU. METRES(SCF)	159.8 (5641.)	162.0 (5719.)	164.7 (5816.)	160.8 (5677.)
HC SAMPLE METER/RANGE/PPM	18.3/12/ 37.	24.3/12/ 49.	45.4/12/ 91.	18.5/12/ 37.
HC BCKGRD METER/RANGE/PPM	6.9/ 1/ 7.	7.0/ 1/ 7.	7.8/ 1/ 8.	7.9/ 1/ 8.
CO SAMPLE METER/RANGE/PPM	48.1/13/ 45.	61.5/13/ 59.	60.1/12/ 132.	45.9/13/ 43.
CO BCKGRD METER/RANGE/PPM	2.8/13/ 3.	3.4/13/ 3.	.2/12/ 0.	1.1/13/ 1.
CO2 SAMPLE METER/RANGE/PCT	52.9/11/ .42	72.2/11/ .64	82.8/ 3/ 1.53	51.3/11/ .40
CO2 BCKGRD METER/RANGE/PCT	8.4/11/ .05	8.3/11/ .05	3.8/ 3/ .06	7.8/11/ .05
NOX SAMPLE METER/RANGE/PPM	37.3/ 2/ 37.	50.7/ 2/ 51.	39.5/ 3/ 119.	38.7/ 2/ 39.
NOX BCKGRD METER/RANGE/PPM	.8/ 2/ 1.	.9/ 2/ 1.	.2/ 3/ 1.	.9/ 2/ 1.
DILUTION FACTOR	31.35	20.60	8.65	32.61
HC CONCENTRATION PPM	30.	42.	84.	29.
CO CONCENTRATION PPM	42.	55.	126.	41.
CO2 CONCENTRATION PCT	.37	.59	1.48	.36
NOX CONCENTRATION PPM	36.5	49.8	118.0	37.8
HC MASS GRAMS	2.76	3.92	7.97	2.72
CO MASS GRAMS	7.82	10.34	24.22	7.74
CO2 MASS GRAMS	1083.0	1755.7	4451.9	1052.2
NOX MASS GRAMS	11.16	15.44	37.16	11.63
FUEL KG (LB)	.349 (.77)	.564 (1.24)	1.427 (3.15)	.339 (.75)
KW HR (HP HR)	1.10 (1.47)	1.77 (2.37)	5.17 (6.93)	1.23 (1.65)
BSHC G/KW HR (G/HP HR)	2.52 (1.88)	2.22 (1.66)	1.54 (1.15)	2.21 (1.65)
BSCO G/KW HR (G/HP HR)	7.13 (5.32)	5.85 (4.36)	4.69 (3.50)	6.29 (4.69)
BSCO2 G/KW HR (G/HP HR)	987.98 (736.73)	993.43 (740.80)	861.48 (642.40)	855.15 (637.69)
BSNOX G/KW HR (G/HP HR)	10.18 (7.59)	8.74 (6.51)	7.19 (5.36)	9.45 (7.05)
BSFC KG/KW HR (LB/HP HR)	.318 (.523)	.319 (.524)	.276 (.454)	.276 (.453)

TOTAL TEST RESULTS 4 BAGS

TOTAL KW HR (HP HR)	9.26 (12.42)
BSHC G/KW HR (G/HP HR)	1.88 (1.40)
BSCO G/KW HR (G/HP HR)	5.41 (4.04)
BSCO2 G/KW HR (G/HP HR)	901. (672.)
BSNOX G/KW HR (G/HP HR)	8.14 (6.07)
BSFC KG/KW HR (LB/HP HR)	.289 (.475)

PARTICULATE RESULTS, TOTAL FOR 4 BAGS

90MM PARTICULATE RATES	GRAMS/TEST	7.03
	G/KWHR(G/HPHR)	.76 (.57)
	G/KG FUEL (G/LB FUEL)	2.62 (1.19)
	FILTER EFF.	90.0

TABLE B-5. ENGINE EMISSION RESULTS
H-TRANS

PROJECT NO. 05-6619-007

ENGINE NO.D1
ENGINE MODEL 78 DDA 6V-71N
ENGINE 7.0 L(426. CID) V-6
CVS NO. 19

TEST NO.D1-2- RUN1
DATE 4/18/83
TIME
DYNO NO. 3

DIESEL EM-400-F
BAG CART NO. 1

BAROMETER 734.57 MM HG(28.92 IN HG)
DRY BULB TEMP. 23.9 DEG C(75.0 DEG F)

RELATIVE HUMIDITY , ENGINE-32. PCT , CVS-26. PCT
ABSOLUTE HUMIDITY 6.0 GM/KG(42.1 GRAINS/LB) NOX HUMIDITY C.F. 1.0000

BAG RESULTS

BAG NUMBER	1	2	3	4
DESCRIPTION	NYNF	LANF	LAF	NYNF
TIME SECONDS	296.0	300.0	305.0	298.0
TOT. BLOWER RATE SCMM (SCFM)	32.34 (1141.9)	32.34 (1141.9)	32.34 (1141.8)	32.32 (1141.3)
TOT. 20X20 RATE SCMM (SCFM)	0.00 (0.0)	0.00 (0.0)	0.00 (0.0)	0.00 (0.00)
TOT. 90MM RATE SCMM (SCFM)	.04 (1.40)	.04 (1.40)	.04 (1.40)	.04 (1.40)
TOT. AUX. SAMPLE RATE SCMM (SCFM)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
TOTAL FLOW STD. CU. METRES(SCF)	159.7 (5640.)	161.9 (5716.)	164.6 (5811.)	160.7 (5676.)
HC SAMPLE METER/RANGE/PPM	16.3/12/ 33.	23.7/12/ 47.	45.9/12/ 92.	18.1/12/ 36.
HC BCKGRD METER/RANGE/PPM	7.4/ 1/ 7.	7.2/ 1/ 7.	7.8/ 1/ 8.	7.4/ 1/ 7.
CO SAMPLE METER/RANGE/PPM	42.1/13/ 39.	57.0/13/ 54.	54.2/12/ 116.	38.0/13/ 35.
CO BCKGRD METER/RANGE/PPM	1.4/13/ 1.	2.2/13/ 2.	.9/12/ 2.	1.6/13/ 1.
CO2 SAMPLE METER/RANGE/PCT	88.0/12/ .39	68.8/11/ .60	77.6/ 3/ 1.42	82.7/12/ .36
CO2 BCKGRD METER/RANGE/PCT	11.8/12/ .04	6.8/11/ .04	2.8/ 3/ .04	11.4/12/ .04
NOX SAMPLE METER/RANGE/PPM	36.4/ 2/ 36.	47.7/ 2/ 48.	35.8/ 3/ 107.	34.7/ 2/ 35.
NOX BCKGRD METER/RANGE/PPM	.5/ 2/ 1.	.6/ 2/ 1.	.3/ 3/ 1.	.7/ 2/ 1.
DILUTION FACTOR	33.68	22.05	9.30	36.50
HC CONCENTRATION PPM	25.	40.	85.	29.
CO CONCENTRATION PPM	37.	51.	111.	33.
CO2 CONCENTRATION PCT	.35	.56	1.38	.32
NOX CONCENTRATION PPM	35.9	47.1	106.6	34.0
HC MASS GRAMS	2.34	3.78	8.05	2.69
CO MASS GRAMS	6.96	9.69	21.23	6.24
CO2 MASS GRAMS	1029.2	1656.5	4163.8	949.0
NOX MASS GRAMS	10.97	14.59	33.55	10.46
FUEL KG (LB)	.331 (.73)	.532 (1.17)	1.334 (2.94)	.306 (.67)
KW HR (HP HR)	1.04 (1.39)	1.67 (2.24)	4.91 (6.58)	1.03 (1.38)
BSHC G/KW HR (G/HP HR)	2.26 (1.68)	2.26 (1.69)	1.64 (1.22)	2.62 (1.95)
BSCO G/KW HR (G/HP HR)	6.72 (5.01)	5.80 (4.32)	4.33 (3.23)	6.06 (4.52)
BSCO2 G/KW HR (G/HP HR)	992.96 (740.45)	991.71 (739.51)	848.59 (632.79)	922.21 (687.69)
BSNOX G/KW HR (G/HP HR)	10.58 (7.89)	8.74 (6.51)	6.84 (5.10)	10.16 (7.58)
BSFC KG/KW HR (LB/HP HR)	.319 (.525)	.318 (.524)	.272 (.447)	.297 (.488)

TOTAL TEST RESULTS 4 BAGS

TOTAL KW HR (HP HR)	8.64 (11.59)
BSHC G/KW HR (G/HP HR)	1.95 (1.45)
BSCO G/KW HR (G/HP HR)	5.10 (3.81)
BSCO2 G/KW HR (G/HP HR)	902. (673.)
BSNOX G/KW HR (G/HP HR)	8.05 (6.00)
BSFC KG/KW HR (LB/HP HR)	.290 (.476)

PARTICULATE RESULTS, TOTAL FOR 4 BAGS

90MM PARTICULATE RATES	GRAMS/TEST	6.75
	G/KWHR(G/HPHR)	.78 (.58)
	G/KG FUEL (G/LB FUEL)	2.69 (1.22)
	FILTER EFF.	90.0

TABLE B-6. ENGINE EMISSION RESULTS
BUS CYCLE

PROJECT NO. 05-6619-007

ENGINE NO.D1
ENGINE MODEL 78 DDA 6V-71N
ENGINE 7.0 L(426. CID) V-6
CVS NO. 19

TEST NO.D1-1 RUN1
DATE 4/ 5/83
TIME
DYNO NO. 3

DIESEL EM-400-F
BAG CART NO. 1

BAROMETER 734.57 MM HG(28.92 IN HG)
DRY BULB TEMP. 26.1 DEG C(79.0 DEG F)

RELATIVE HUMIDITY , ENGINE-38. PCT , CVS-31. PCT
ABSOLUTE HUMIDITY 8.2 GM/KG(57.4 GRAINS/LB) NOX HUMIDITY C.F. 1.0000

BAG RESULTS

BAG NUMBER	1	2	3
TIME SECONDS	273.9	287.9	272.9
TOT. BLOWER RATE SCMM (SCFM)	32.18 (1136.3)	32.18 (1136.2)	32.17 (1136.0)
TOT. 20X20 RATE SCMM (SCFM)	0.00 (0.0)	0.00 (0.0)	0.00 (0.0)
TOT. 90MM RATE SCMM (SCFM)	.04 (1.38)	.04 (1.38)	.04 (1.38)
TOT. AUX. SAMPLE RATE SCMM (SCFM)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
TOTAL FLOW STD. CU. METRES(SCF)	147.1 (5193.)	154.6 (5458.)	146.5 (5173.)
HC SAMPLE METER/RANGE/PPM	19.6/12/ 39.	19.0/12/ 38.	18.8/12/ 38.
HC BCKGRD METER/RANGE/PPM	6.4/ 1/ 6.	7.6/ 1/ 8.	8.2/ 1/ 8.
CO SAMPLE METER/RANGE/PPM	25.2/13/ 23.	61.6/13/ 59.	21.3/13/ 19.
CO BCKGRD METER/RANGE/PPM	.1/13/ 0.	.1/13/ 0.	.1/13/ 0.
CO2 SAMPLE METER/RANGE/PCT	58.8/11/ .48	71.1/11/ .63	58.2/11/ .48
CO2 BCKGRD METER/RANGE/PCT	7.2/11/ .04	7.4/11/ .04	7.3/11/ .04
NOX SAMPLE METER/RANGE/PPM	40.2/ 2/ 40.	52.9/ 2/ 53.	40.3/ 2/ 40.
NOX BCKGRD METER/RANGE/PPM	.8/ 2/ 1.	.9/ 2/ 1.	1.0/ 2/ 1.
DILUTION FACTOR	27.44	21.09	27.84
HC CONCENTRATION PPM	33.	31.	30.
CO CONCENTRATION PPM	23.	58.	19.
CO2 CONCENTRATION PCT	.44	.58	.43
NOX CONCENTRATION PPM	39.4	52.0	39.3
HC MASS GRAMS	2.80	2.73	2.51
CO MASS GRAMS	3.86	10.40	3.23
CO2 MASS GRAMS	1186.6	1651.8	1162.7
NOX MASS GRAMS	11.09	15.38	11.02
FUEL KG (LB)	.380 (.84)	.530 (1.17)	.371 (.82)
KW HR (HP HR)	1.13 (1.51)	1.84 (2.47)	1.19 (1.60)
BSHC G/KW HR (G/HP HR)	2.49 (1.86)	1.48 (1.11)	2.10 (1.57)
BSCO G/KW HR (G/HP HR)	3.42 (2.55)	5.64 (4.21)	2.71 (2.02)
BSCO2 G/KW HR (G/HP HR)	1053.84 (785.85)	896.82 (668.76)	974.50 (726.69)
BSNOX G/KW HR (G/HP HR)	9.85 (7.34)	8.35 (6.23)	9.24 (6.89)
BSFC KG/KW HR (LB/HP HR)	.337 (.554)	.288 (.473)	.311 (.512)

TOTAL TEST RESULTS 3 BAGS

TOTAL KW HR (HP HR)	4.16 (5.58)
BSHC G/KW HR (G/HP HR)	1.93 (1.44)
BSCO G/KW HR (G/HP HR)	4.20 (3.13)
BSCO2 G/KW HR (G/HP HR)	962. (717.)
BSNOX G/KW HR (G/HP HR)	9.01 (6.72)
BSFC KG/KW HR (LB/HP HR)	.308 (.506)

PARTICULATE RESULTS, TOTAL FOR 3 BAGS

90MM PARTICULATE RATES

GRAMS/TEST	3.56
G/KWHR(G/HPHR)	.86 (.64)
G/KG FUEL (G/LB FUEL)	2.78 (1.26)
FILTER EFF.	86.0

TABLE B-7. ENGINE EMISSION RESULTS
B-TRANS

PROJECT NO. 05-6619-007

ENGINE NO.D1
ENGINE MODEL 78 DDA 6V-71N
ENGINE 7.0 L(426. CID) V-6
CVS NO. 19

TEST NO.D1-2- RUN1
DATE 4/18/83
TIME
DYNO NO. 3

DIESEL EM-400-F
BAG CART NO. 1

BAROMETER 733.55 MM HG(28.88 IN HG)
DRY BULB TEMP. 25.0 DEG C(77.0 DEG F)

RELATIVE HUMIDITY , ENGINE-28. PCT , CVS-25. PCT
ABSOLUTE HUMIDITY 5.7 GM/KG(40.0 GRAINS/LB) NOX HUMIDITY C.F. 1.0000

BAG RESULTS

BAG NUMBER	1	2	3
TIME SECONDS	274.0	288.0	272.9
TOT. BLOWER RATE SCMM (SCFM)	32.28 (1139.9)	32.29 (1140.2)	32.30 (1140.4)
TOT. 20X20 RATE SCMM (SCFM)	0.00 (0.0)	0.00 (0.0)	0.00 (0.0)
TOT. 90MM RATE SCMM (SCFM)	.04 (1.43)	.04 (1.43)	.04 (1.43)
TOT. AUX. SAMPLE RATE SCMM (SCFM)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
TOTAL FLOW STD. CU. METRES(SCF)	147.6 (5212.)	155.2 (5480.)	147.1 (5194.)
HC SAMPLE METER/RANGE/PPM	16.9/12/ 34.	17.6/12/ 35.	18.6/12/ 37.
HC BCKGRD METER/RANGE/PPM	5.6/ 1/ 6.	5.8/ 1/ 6.	6.0/ 1/ 6.
CO SAMPLE METER/RANGE/PPM	23.3/13/ 21.	55.0/13/ 52.	23.2/13/ 21.
CO BCKGRD METER/RANGE/PPM	.4/13/ 0.	.4/13/ 0.	.2/13/ 0.
CO2 SAMPLE METER/RANGE/PCT	95.0/12/ .43	67.2/11/ .58	96.2/12/ .44
CO2 BCKGRD METER/RANGE/PCT	11.2/12/ .04	6.4/11/ .04	11.5/12/ .04
NOX SAMPLE METER/RANGE/PPM	38.8/ 2/ 39.	49.8/ 2/ 50.	39.0/ 2/ 39.
NOX BCKGRD METER/RANGE/PPM	.7/ 2/ 1.	.6/ 2/ 1.	.7/ 2/ 1.
DILUTION FACTOR	30.51	22.83	29.97
HC CONCENTRATION PPM	28.	30.	31.
CO CONCENTRATION PPM	21.	51.	21.
CO2 CONCENTRATION PCT	.40	.54	.40
NOX CONCENTRATION PPM	38.1	49.2	38.3
HC MASS GRAMS	2.42	2.65	2.67
CO MASS GRAMS	3.54	9.20	3.54
CO2 MASS GRAMS	1073.0	1539.7	1087.1
NOX MASS GRAMS	10.76	14.61	10.78
FUEL KG (LB)	.343 (.76)	.494 (1.09)	.348 (.77)
KW HR (HP HR)	1.10 (1.48)	1.77 (2.38)	1.13 (1.51)
BSHC G/KW HR (G/HP HR)	2.19 (1.63)	1.50 (1.11)	2.37 (1.77)
BSCO G/KW HR (G/HP HR)	3.20 (2.39)	5.18 (3.87)	3.14 (2.34)
BSCO2 G/KW HR (G/HP HR)	972.25 (725.01)	867.56 (646.94)	965.48 (719.96)
BSNOX G/KW HR (G/HP HR)	9.75 (7.27)	8.23 (6.14)	9.57 (7.14)
BSFC KG/KW HR (LB/HP HR)	.311 (.511)	.278 (.457)	.309 (.508)

TOTAL TEST RESULTS 3 BAGS

TOTAL KW HR (HP HR)	4.00 (5.37)
BSHC G/KW HR (G/HP HR)	1.93 (1.44)
BSCO G/KW HR (G/HP HR)	4.06 (3.03)
BSCO2 G/KW HR (G/HP HR)	924. (689.)
BSNOX G/KW HR (G/HP HR)	9.03 (6.73)
BSFC KG/KW HR (LB/HP HR)	.296 (.486)

PARTICULATE RESULTS, TOTAL FOR 3 BAGS

90MM PARTICULATE RATES

GRAMS/TEST	2.79
G/KWHR(G/HPHR)	.70 (.52)
G/KG FUEL (G/LB FUEL)	2.36 (1.07)
FILTER EFF.	84.0

APPENDIX C

TRANSIENT TEST RESULTS FROM DDAD 6V71 COACH ENGINE WITH TRAP

TABLE C-2. ENGINE EMISSION RESULTS
C-TRANS.

PROJECT NO. 05-6619-007

ENGINE NO.D1
ENGINE MODEL 78 DDA 6V-71N
ENGINE 7.0 L(426. CID) V-6
CVS NO. 19

TEST NO.D1-2 RUN1
DATE 4/21/83
TIME
DYNO NO. 3

DIESEL EM-400-F
BAG CART NO. 1

BAROMETER 733.55 MM HG(28.88 IN HG)
DRY BULB TEMP. 25.6 DEG C(78.0 DEG F)

RELATIVE HUMIDITY , ENGINE-54. PCT , CVS-53. PCT
ABSOLUTE HUMIDITY 11.5 GM/KG(80.5 GRAINS/LB) NOX HUMIDITY C.F. 1.0000

BAG RESULTS

BAG NUMBER	1	2	3	4
DESCRIPTION	NYNF	LANF	LAF	NYNF
TIME SECONDS	296.0	300.1	305.0	298.0
TOT. BLOWER RATE SCMM (SCFM)	32.14 (1134.9)	32.12 (1134.1)	32.14 (1134.8)	32.12 (1134.3)
TOT. 20X20 RATE SCMM (SCFM)	0.00 (0.0)	0.00 (0.0)	0.00 (0.0)	0.00 (0.00)
TOT. 90MM RATE SCMM (SCFM)	.04 (1.44)	.04 (1.44)	.04 (1.44)	.04 (1.44)
TOT. AUX. SAMPLE RATE SCMM (SCFM)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
TOTAL FLOW STD. CU. METRES(SCF)	158.8 (5606.)	160.8 (5680.)	163.6 (5776.)	159.8 (5641.)
HC SAMPLE METER/RANGE/PPM	13.6/12/ 27.	20.8/12/ 42.	48.3/12/ 97.	18.1/12/ 36.
HC BCKGRD METER/RANGE/PPM	8.6/ 1/ 9.	9.6/ 1/ 10.	10.0/ 1/ 10.	10.0/ 1/ 10.
CO SAMPLE METER/RANGE/PPM	30.6/13/ 28.	30.1/13/ 28.	48.1/12/ 101.	37.1/13/ 34.
CO BCKGRD METER/RANGE/PPM	2.0/13/ 2.	2.2/13/ 2.	1.2/12/ 2.	1.4/13/ 1.
CO2 SAMPLE METER/RANGE/PCT	90.5/12/ .41	67.2/11/ .58	79.0/ 3/ 1.45	86.4/12/ .38
CO2 BCKGRD METER/RANGE/PCT	11.9/12/ .04	7.2/11/ .04	3.7/ 3/ .06	13.6/12/ .05
NOX SAMPLE METER/RANGE/PPM	33.6/ 2/ 34.	39.9/ 2/ 40.	33.9/ 3/ 102.	33.6/ 2/ 34.
NOX BCKGRD METER/RANGE/PPM	.5/ 2/ 1.	.7/ 2/ 1.	.4/ 3/ 1.	.9/ 2/ 1.
DILUTION FACTOR	32.59	22.90	9.13	34.51
HC CONCENTRATION PPM	19.	32.	88.	26.
CO CONCENTRATION PPM	26.	25.	95.	32.
CO2 CONCENTRATION PCT	.37	.54	1.40	.34
NOX CONCENTRATION PPM	33.1	39.2	100.6	32.7
HC MASS GRAMS	1.73	3.01	8.26	2.44
CO MASS GRAMS	4.76	4.69	18.04	6.02
CO2 MASS GRAMS	1065.7	1581.8	4188.1	983.4
NOX MASS GRAMS	10.05	12.07	31.48	10.00
FUEL KG (LB)	.341 (.75)	.505 (1.11)	1.341 (2.96)	.316 (.70)
KW HR (HP HR)	.82 (1.10)	1.29 (1.73)	4.77 (6.40)	1.01 (1.36)
BSHC G/KW HR (G/HP HR)	2.11 (1.57)	2.33 (1.74)	1.73 (1.29)	2.40 (1.79)
BSCO G/KW HR (G/HP HR)	5.80 (4.32)	3.63 (2.71)	3.78 (2.82)	5.93 (4.42)
BSCO2 G/KW HR (G/HP HR)	1299.17 (968.79)	1226.15 (914.34)	877.56 (654.39)	969.69 (723.10)
BSNOX G/KW HR (G/HP HR)	12.26 (9.14)	9.35 (6.98)	6.60 (4.92)	9.86 (7.35)
BSFC KG/KW HR (LB/HP HR)	.415 (.683)	.392 (.644)	.281 (.462)	.312 (.512)

TOTAL TEST RESULTS 4 BAGS

TOTAL KW HR (HP HR)	7.90 (10.59)
BSHC G/KW HR (G/HP HR)	1.96 (1.46)
BSCO G/KW HR (G/HP HR)	4.24 (3.16)
BSCO2 G/KW HR (G/HP HR)	990. (738.)
BSNOX G/KW HR (G/HP HR)	8.05 (6.01)
BSFC KG/KW HR (LB/HP HR)	.317 (.521)

PARTICULATE RESULTS, TOTAL FOR 4 BAGS

90MM PARTICULATE RATES	GRAMS/TEST	3.45
	G/KWHR(G/HPHR)	.44 (.33)
	G/KG FUEL (G/LB FUEL)	1.38 (.63)
	FILTER EFF.	84.7

TABLE C-3. ENGINE EMISSION RESULTS
H-TRANS.

PROJECT NO. 05-6619-007

ENGINE NO.D1
ENGINE MODEL 78 DDA 6V-71N
ENGINE 7.0 L(426. CID) V-6
CVS NO. 19

TEST NO.D1-1 RUN1
DATE 4/21/83
TIME
DYNO NO. 3

DIESEL EM-400-F
BAG CART NO. 1

BAROMETER 736.35 MM HG(28.99 IN HG)
DRY BULB TEMP. 26.1 DEG C(79.0 DEG F)

RELATIVE HUMIDITY , ENGINE-62. PCT , CVS-49. PCT
ABSOLUTE HUMIDITY 13.5 GM/KG(94.6 GRAINS/LB) NOX HUMIDITY C.F. 1.0000

BAG RESULTS

BAG NUMBER	1	2	3	4
DESCRIPTION	NYNF	LANF	LAF	NYNF
TIME SECONDS	295.9	300.0	305.0	297.9
TOT. BLOWER RATE SCMM (SCFM)	32.39 (1143.9)	32.40 (1144.2)	32.39 (1143.8)	32.41 (1144.4)
TOT. 20X20 RATE SCMM (SCFM)	0.00 (0.0)	0.00 (0.0)	0.00 (0.0)	0.00 (0.00)
TOT. 90MM RATE SCMM (SCFM)	.04 (1.42)	.04 (1.42)	.04 (1.42)	.04 (1.42)
TOT. AUX. SAMPLE RATE SCMM (SCFM)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
TOTAL FLOW STD. CU. METRES(SCF)	160.0 (5648.)	162.2 (5728.)	164.9 (5821.)	161.1 (5689.)
HC SAMPLE METER/RANGE/PPM	15.8/12/ 32.	22.5/12/ 45.	46.4/12/ 93.	18.1/12/ 36.
HC BCKGRD METER/RANGE/PPM	10.1/ 1/ 10.	10.0/ 1/ 10.	10.0/ 1/ 10.	10.4/ 1/ 10.
CO SAMPLE METER/RANGE/PPM	35.4/13/ 33.	48.2/13/ 45.	47.6/12/ 100.	40.7/13/ 38.
CO BCKGRD METER/RANGE/PPM	.5/13/ 0.	9.1/13/ 8.	1.1/12/ 2.	.4/13/ 0.
CO2 SAMPLE METER/RANGE/PCT	85.8/12/ .38	67.0/11/ .58	77.7/ 3/ 1.42	83.8/12/ .37
CO2 BCKGRD METER/RANGE/PCT	12.8/12/ .04	7.4/11/ .04	3.1/ 3/ .05	12.6/12/ .04
NOX SAMPLE METER/RANGE/PPM	33.4/ 2/ 33.	43.8/ 2/ 44.	34.9/ 3/ 105.	33.0/ 2/ 33.
NOX BCKGRD METER/RANGE/PPM	.5/ 2/ 1.	.6/ 2/ 1.	.1/ 3/ 0.	.4/ 2/ 0.
DILUTION FACTOR	34.88	22.91	9.30	35.87
HC CONCENTRATION PPM	22.	35.	84.	26.
CO CONCENTRATION PPM	32.	36.	94.	37.
CO2 CONCENTRATION PCT	.34	.53	1.38	.32
NOX CONCENTRATION PPM	32.9	43.2	104.4	32.6
HC MASS GRAMS	2.00	3.32	7.98	2.42
CO MASS GRAMS	5.88	6.87	18.02	6.88
CO2 MASS GRAMS	982.5	1584.7	4164.7	957.6
NOX MASS GRAMS	10.07	13.41	32.93	10.05
FUEL KG (LB)	.315 (.70)	.507 (1.12)	1.333 (2.94)	.308 (.68)
KW HR (HP HR)	1.01 (1.35)	1.62 (2.17)	4.85 (6.51)	1.01 (1.35)
BSHC G/KW HR (G/HP HR)	1.99 (1.48)	2.05 (1.53)	1.64 (1.23)	2.40 (1.79)
BSCO G/KW HR (G/HP HR)	5.84 (4.35)	4.25 (3.17)	3.71 (2.77)	6.84 (5.10)
BSCO2 G/KW HR (G/HP HR)	976.01 (727.81)	979.29 (730.26)	857.90 (639.73)	951.21 (709.31)
BSNOX G/KW HR (G/HP HR)	10.00 (7.46)	8.29 (6.18)	6.78 (5.06)	9.98 (7.44)
BSFC KG/KW HR (LB/HP HR)	.313 (.515)	.314 (.516)	.275 (.451)	.306 (.504)

TOTAL TEST RESULTS 4 BAGS

TOTAL KW HR (HP HR)	8.49 (11.38)
BSHC G/KW HR (G/HP HR)	1.85 (1.38)
BSCO G/KW HR (G/HP HR)	4.44 (3.31)
BSCO2 G/KW HR (G/HP HR)	906. (676.)
BSNOX G/KW HR (G/HP HR)	7.83 (5.84)
BSFC KG/KW HR (LB/HP HR)	.290 (.477)

PARTICULATE RESULTS, TOTAL FOR 4 BAGS

90MM PARTICULATE RATES		
	GRAMS/TEST	2.10
	G/KWHR(G/HPHR)	.25 (.18)
	G/KG FUEL (G/LB FUEL)	.85 (.39)
	FILTER EFF.	81.7

TABLE C-4. ENGINE EMISSION RESULTS
H-TRANS.

PROJECT NO. 05-6619-007

ENGINE NO.D1
ENGINE MODEL 78 DDA 6V-71N
ENGINE 7.0 L(426. CID) V-6
CVS NO. 19

TEST NO.D1-2 RUN1
DATE 4/21/83
TIME
DYNO NO. 3

DIESEL EM-400-F
BAG CART NO. 1

BAROMETER 733.04 MM HG(28.86 IN HG)
DRY BULB TEMP. 26.1 DEG C(79.0 DEG F)

RELATIVE HUMIDITY , ENGINE-64. PCT , CVS-50. PCT
ABSOLUTE HUMIDITY 14.1 GM/KG(99.0 GRAINS/LB) NOX HUMIDITY C.F. 1.0000

BAG RESULTS

BAG NUMBER	1	2	3	4
DESCRIPTION	NYNF	LANF	LAF	NYNF
TIME SECONDS	296.1	300.1	305.0	298.0
TOT. BLOWER RATE SCMM (SCFM)	32.09 (1133.2)	32.10 (1133.6)	32.09 (1133.2)	32.10 (1133.5)
TOT. 20X20 RATE SCMM (SCFM)	0.00 (0.0)	0.00 (0.0)	0.00 (0.0)	0.00 (0.00)
TOT. 90MM RATE SCMM (SCFM)	.04 (1.40)	.04 (1.40)	.04 (1.40)	.04 (1.40)
TOT. AUX. SAMPLE RATE SCMM (SCFM)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
TOTAL FLOW STD. CU. METRES(SCF)	158.6 (5599.)	160.8 (5677.)	163.3 (5768.)	159.6 (5637.)
HC SAMPLE METER/RANGE/PPM	16.8/12/ 34.	23.7/12/ 47.	48.0/12/ 96.	18.5/12/ 37.
HC BCKGRD METER/RANGE/PPM	9.0/ 1/ 9.	10.0/ 1/ 10.	10.2/ 1/ 10.	11.8/ 1/ 12.
CO SAMPLE METER/RANGE/PPM	36.7/13/ 34.	50.7/13/ 48.	50.5/12/ 107.	37.2/13/ 34.
CO BCKGRD METER/RANGE/PPM	1.3/13/ 1.	1.1/13/ 1.	1.4/12/ 3.	5.3/13/ 5.
CO2 SAMPLE METER/RANGE/PCT	84.9/12/ .37	67.7/11/ .58	78.6/ 3/ 1.44	84.7/12/ .37
CO2 BCKGRD METER/RANGE/PCT	11.9/12/ .04	7.1/11/ .04	3.1/ 3/ .05	14.0/12/ .05
NOX SAMPLE METER/RANGE/PPM	32.6/ 2/ 33.	44.0/ 2/ 44.	33.5/ 3/ 101.	32.6/ 2/ 33.
NOX BCKGRD METER/RANGE/PPM	.6/ 2/ 1.	.7/ 2/ 1.	.3/ 3/ 1.	1.2/ 2/ 1.
DILUTION FACTOR	35.33	22.57	9.17	35.40
HC CONCENTRATION PPM	25.	38.	87.	25.
CO CONCENTRATION PPM	32.	46.	100.	29.
CO2 CONCENTRATION PCT	.33	.54	1.40	.32
NOX CONCENTRATION PPM	32.0	43.3	99.7	31.4
HC MASS GRAMS	2.28	3.51	8.19	2.34
CO MASS GRAMS	5.92	8.54	19.05	5.41
CO2 MASS GRAMS	967.9	1600.6	4182.2	949.6
NOX MASS GRAMS	9.71	13.32	31.14	9.60
FUEL KG (LB)	.311 (.69)	.513 (1.13)	1.339 (2.95)	.305 (.67)
KW HR (HP HR)	.96 (1.29)	1.63 (2.18)	4.87 (6.53)	1.01 (1.36)
BSHC G/KW HR (G/HP HR)	2.37 (1.77)	2.16 (1.61)	1.68 (1.25)	2.31 (1.72)
BSCO G/KW HR (G/HP HR)	6.16 (4.59)	5.25 (3.92)	3.91 (2.92)	5.34 (3.98)
BSCO2 G/KW HR (G/HP HR)	1006.22 (750.34)	984.59 (734.21)	858.86 (640.45)	936.35 (698.24)
BSNOX G/KW HR (G/HP HR)	10.09 (7.53)	8.20 (6.11)	6.40 (4.77)	9.46 (7.06)
BSFC KG/KW HR (LB/HP HR)	.323 (.532)	.316 (.519)	.275 (.452)	.301 (.495)

TOTAL TEST RESULTS 4 BAGS

TOTAL KW HR (HP HR)	8.47 (11.36)
BSHC G/KW HR (G/HP HR)	1.93 (1.44)
BSCO G/KW HR (G/HP HR)	4.59 (3.43)
BSCO2 G/KW HR (G/HP HR)	909. (678.)
BSNOX G/KW HR (G/HP HR)	7.53 (5.61)
BSFC KG/KW HR (LB/HP HR)	.291 (.479)

PARTICULATE RESULTS, TOTAL FOR 4 BAGS

90MM PARTICULATE RATES	GRAMS/TEST	2.80
	G/KWHR(G/HPHR)	.33 (.25)
	G/KG FUEL (G/LB FUEL)	1.13 (.51)
	FILTER EFF.	84.0

TABLE C-5. ENGINE EMISSION RESULTS
BUS CYCLE

PROJECT NO. 05-6619-007

ENGINE NO.D1
ENGINE MODEL 78 DDA 6V-71N
ENGINE 7.0 L(426. CID) V-6
CVS NO. 19

TEST NO.D1-1 RUN1
DATE 4/21/83
TIME
DYNO NO. 3

DIESEL EM-400-F
BAG CART NO. 1

BAROMETER 735.84 MM HG(28.97 IN HG)
DRY BULB TEMP. 25.6 DEG C(78.0 DEG F)

RELATIVE HUMIDITY , ENGINE-66. PCT , CVS-49. PCT
ABSOLUTE HUMIDITY 14.0 GM/KG(97.7 GRAINS/LB) NOX HUMIDITY C.F. 1.0000

BAG RESULTS

BAG NUMBER	1	2	3
TIME SECONDS	274.0	288.0	273.0
TOT. BLOWER RATE SCMM (SCFM)	32.50 (1147.5)	32.48 (1147.0)	32.50 (1147.6)
TOT. 20X20 RATE SCMM (SCFM)	0.00 (0.0)	0.00 (0.0)	0.00 (0.0)
TOT. 90MM RATE SCMM (SCFM)	.04 (1.44)	.04 (1.44)	.04 (1.44)
TOT. AUX. SAMPLE RATE SCMM (SCFM)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
TOTAL FLOW STD. CU. METRES(SCF)	148.6 (5247.)	156.1 (5512.)	148.1 (5228.)
HC SAMPLE METER/RANGE/PPM	16.7/12/ 33.	17.6/12/ 35.	17.5/12/ 35.
HC BCKGRD METER/RANGE/PPM	7.8/ 1/ 8.	8.0/ 1/ 8.	8.0/ 1/ 8.
CO SAMPLE METER/RANGE/PPM	24.2/13/ 22.	57.4/13/ 55.	23.4/13/ 21.
CO BCKGRD METER/RANGE/PPM	.9/13/ 1.	2.3/13/ 2.	1.6/13/ 1.
CO2 SAMPLE METER/RANGE/PCT	95.4/12/ .44	66.7/11/ .57	94.7/12/ .43
CO2 BCKGRD METER/RANGE/PCT	12.9/12/ .04	7.8/11/ .05	12.1/12/ .04
NOX SAMPLE METER/RANGE/PPM	35.7/ 2/ 36.	47.5/ 2/ 48.	35.9/ 2/ 36.
NOX BCKGRD METER/RANGE/PPM	.5/ 2/ 1.	.6/ 2/ 1.	.6/ 2/ 1.
DILUTION FACTOR	30.34	23.05	30.64
HC CONCENTRATION PPM	26.	27.	27.
CO CONCENTRATION PPM	21.	51.	19.
CO2 CONCENTRATION PCT	.39	.53	.39
NOX CONCENTRATION PPM	35.2	46.9	35.3
HC MASS GRAMS	2.21	2.47	2.32
CO MASS GRAMS	3.60	9.33	3.36
CO2 MASS GRAMS	1071.2	1507.8	1062.8
NOX MASS GRAMS	10.01	14.01	10.00
FUEL KG (LB)	.342 (.75)	.484 (1.07)	.340 (.75)
KW HR (HP HR)	1.09 (1.46)	1.74 (2.34)	1.10 (1.47)
BSHC G/KW HR (G/HP HR)	2.03 (1.51)	1.42 (1.06)	2.12 (1.58)
BSCO G/KW HR (G/HP HR)	3.31 (2.46)	5.35 (3.99)	3.06 (2.28)
BSCO2 G/KW HR (G/HP HR)	983.87 (733.67)	864.12 (644.37)	969.51 (722.96)
BSNOX G/KW HR (G/HP HR)	9.19 (6.85)	8.03 (5.99)	9.12 (6.80)
BSFC KG/KW HR (LB/HP HR)	.315 (.517)	.277 (.456)	.310 (.510)

TOTAL TEST RESULTS 3 BAGS

TOTAL KW HR (HP HR)	3.93 (5.27)
BSHC G/KW HR (G/HP HR)	1.78 (1.33)
BSCO G/KW HR (G/HP HR)	4.14 (3.09)
BSCO2 G/KW HR (G/HP HR)	927. (691.)
BSNOX G/KW HR (G/HP HR)	8.66 (6.45)
BSFC KG/KW HR (LB/HP HR)	.297 (.488)

PARTICULATE RESULTS, TOTAL FOR 3 BAGS

90MM PARTICULATE RATES		
	GRAMS/TEST	.81
	G/KWHR(G/HPHR)	.21 (.15)
	G/KG FUEL (G/LB FUEL)	.70 (.32)
	FILTER EFF.	72.8

TABLE C-6. ENGINE EMISSION RESULTS
BUS CYCLE

PROJECT NO. 05-6619-007

ENGINE NO.D1
ENGINE MODEL 78 DDA 6V-71N
ENGINE 7.0 L(426. CID) V-6
CVS NO. 19

TEST NO.D1-2 RUN1
DATE 4/21/83
TIME
DYNO NO. 3

DIESEL EM-400-F
BAG CART NO. 1

BAROMETER 732.54 MM HG(28.84 IN HG)
DRY BULB TEMP. 26.7 DEG C(80.0 DEG F)

RELATIVE HUMIDITY , ENGINE-60. PCT , CVS-54. PCT
ABSOLUTE HUMIDITY 13.7 GM/KG(95.9 GRAINS/LB) NOX HUMIDITY C.F. 1.0000

BAG RESULTS

BAG NUMBER	1	2	3
TIME SECONDS	274.0	288.0	273.0
TOT. BLOWER RATE SCMM (SCFM)	32.16 (1135.5)	32.18 (1136.2)	32.16 (1135.6)
TOT. 20X20 RATE SCMM (SCFM)	0.00 (0.0)	0.00 (0.0)	0.00 (0.0)
TOT. 90MM RATE SCMM (SCFM)	.04 (1.43)	.04 (1.43)	.04 (1.43)
TOT. AUX. SAMPLE RATE SCMM (SCFM)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
TOTAL FLOW STD. CU. METRES(SCF)	147.0 (5192.)	154.6 (5460.)	146.5 (5173.)
HC SAMPLE METER/RANGE/PPM	18.6/12/ 37.	18.9/12/ 38.	18.8/12/ 38.
HC BCKGRD METER/RANGE/PPM	9.4/ 1/ 9.	9.6/ 1/ 10.	9.6/ 1/ 10.
CO SAMPLE METER/RANGE/PPM	23.5/13/ 21.	58.2/13/ 56.	22.6/13/ 21.
CO BCKGRD METER/RANGE/PPM	.4/13/ 0.	.6/13/ 1.	3.9/13/ 4.
CO2 SAMPLE METER/RANGE/PCT	94.8/12/ .43	66.7/11/ .57	94.5/12/ .43
CO2 BCKGRD METER/RANGE/PCT	11.7/12/ .04	7.0/11/ .04	12.1/12/ .04
NOX SAMPLE METER/RANGE/PPM	35.6/ 2/ 36.	47.5/ 2/ 48.	35.8/ 2/ 36.
NOX BCKGRD METER/RANGE/PPM	.7/ 2/ 1.	.9/ 2/ 1.	1.2/ 2/ 1.
DILUTION FACTOR	30.58	23.04	30.71
HC CONCENTRATION PPM	28.	29.	28.
CO CONCENTRATION PPM	21.	54.	17.
CO2 CONCENTRATION PCT	.39	.53	.39
NOX CONCENTRATION PPM	34.9	46.6	34.6
HC MASS GRAMS	2.37	2.54	2.39
CO MASS GRAMS	3.52	9.63	2.86
CO2 MASS GRAMS	1060.8	1507.3	1048.3
NOX MASS GRAMS	9.82	13.79	9.71
FUEL KG (LB)	.339 (.75)	.484 (1.07)	.335 (.74)
KW HR (HP HR)	1.08 (1.45)	1.74 (2.33)	1.08 (1.45)
BSHC G/KW HR (G/HP HR)	2.20 (1.64)	1.46 (1.09)	2.21 (1.65)
BSCO G/KW HR (G/HP HR)	3.26 (2.43)	5.54 (4.13)	2.64 (1.97)
BSCO2 G/KW HR (G/HP HR)	981.10 (731.61)	867.50 (646.89)	969.47 (722.93)
BSNOX G/KW HR (G/HP HR)	9.08 (6.77)	7.94 (5.92)	8.98 (6.69)
BSFC KG/KW HR (LB/HP HR)	.314 (.516)	.278 (.458)	.310 (.509)

TOTAL TEST RESULTS 3 BAGS

TOTAL KW HR (HP HR)	3.90 (5.23)
BSHC G/KW HR (G/HP HR)	1.87 (1.40)
BSCO G/KW HR (G/HP HR)	4.11 (3.06)
BSCO2 G/KW HR (G/HP HR)	927. (691.)
BSNOX G/KW HR (G/HP HR)	8.54 (6.37)
BSFC KG/KW HR (LB/HP HR)	.297 (.488)

PARTICULATE RESULTS, TOTAL FOR 3 BAGS

90MM PARTICULATE RATES

GRAMS/TEST	.83
G/KWHR(G/HPHR)	.21 (.16)
G/KG FUEL (G/LB FUEL)	.71 (.32)
FILTER EFF.	72.2

APPENDIX D

CHASSIS TEST RESULTS FROM GMC RTS-II COACH WITHOUT TRAP

TABLE D-1. CFTP VEHICLE EMISSIONS RESULTS
PROJECT 05-6855-001

TEST NO. 3831 RUN 1
VEHICLE MODEL 80 DDAD 6V71
ENGINE 7.0 L(426. CID) V-6
TRANSMISSION A-3
GVW16329. KG(36000. LBS)

VEHICLE NO. 3-8
DATE 5/19/83
BAG CART NO. 1
DYNO NO. 4
CVS NO. 11

TEST WEIGHT 12837. KG(28300. LBS)
ACTUAL ROAD LOAD
DIESEL EM-455-F
ODOMETER 259722. KM(161384. MILES)

BAROMETER 738.12 MM HG(29.06 IN HG)
RELATIVE HUMIDITY 45. PCT

DRY BULB TEMP. 24.4 DEG C(76.0 DEG F)
ABS. HUMIDITY 8.9 GM/KG

NOX HUMIDITY CORRECTION FACTOR .94

BAG RESULTS

BAG NUMBER	1	2	3	4
DESCRIPTION	NYNF	LANF	LAF	NYNF
RUN TIME SECONDS	254.0	285.0	267.0	254.0
TOT. BLOWER RATE SCMM (SCFM)	193.14 (6819.8)	193.14 (6819.8)	193.19 (6821.4)	193.10 (6818.2)
TOT. 20X20 RATE SCMM (SCFM)	10.81 (381.6)	10.81 (381.6)	10.81 (381.6)	10.81 (381.6)
TOT. AUX. SAMPLE RATE SCMM (SCFM)	.07 (2.30)	.07 (2.30)	.07 (2.30)	.07 (2.30)
TOT FLOW STD. CU. METRES(SCF)	863.7 (30496.)	969.1 (34218.)	908.1 (32064.)	863.5 (30489.)
HC SAMPLE METER/RANGE/PPM	16.3/21/ 8.	19.1/21/ 10.	36.6/21/ 18.	14.4/21/ 7.
HC BCKGRD METER/RANGE/PPM	8.8/ 1/ 4.	8.4/ 1/ 4.	8.0/ 1/ 4.	7.5/ 1/ 4.
CO SAMPLE METER/RANGE/PPM	51.8/12/ 110.	56.1/12/ 121.	90.2/12/ 222.	73.0/13/ 71.
CO BCKGRD METER/RANGE/PPM	.5/12/ 1.	.7/12/ 1.	1.0/12/ 2.	.7/13/ 1.
CO2 SAMPLE METER/RANGE/PCT	72.2/13/ .15	84.7/13/ .18	89.8/12/ .40	61.6/13/ .12
CO2 BCKGRD METER/RANGE/PCT	20.2/13/ .04	20.3/13/ .04	11.4/12/ .04	20.2/13/ .04
NOX SAMPLE METER/RANGE/PPM	31.3/ 1/ 9.	39.2/ 1/ 12.	97.0/ 1/ 29.	26.8/ 1/ 8.
NOX BCKGRD METER/RANGE/PPM	.9/ 1/ 0.	1.0/ 1/ 0.	1.4/ 1/ 0.	1.0/ 1/ 0.
DILUTION FACTOR	83.94	69.92	31.53	101.81
HC CONCENTRATION PPM	4.	5.	14.	3.
CO CONCENTRATION PPM	108.	118.	215.	70.
CO2 CONCENTRATION PCT	.11	.14	.36	.09
NOX CONCENTRATION PPM	9.0	11.4	28.5	7.7
HC MASS GRAMS	1.90	3.02	7.55	1.74
CO MASS GRAMS	108.14	132.98	227.52	69.95
CO2 MASS GRAMS	1761.7	2521.4	6054.3	1379.1
NOX MASS GRAMS	14.10	19.88	46.63	11.97
MASS OF FUEL BURNED GRAMS	612.3	865.7	2033.5	472.2
MEASURED DISTANCE KM (MILES)	.77 (.48)	1.84 (1.14)	4.36 (2.71)	.86 (.54)
FUEL ECONOMY L/100KM (MPG)	98.46 (2.39)	58.11 (4.05)	57.67 (4.08)	67.70 (3.47)
HC GRAMS/KM (GRAMS/MILE)	2.47 (3.98)	1.64 (2.64)	1.73 (2.79)	2.01 (3.24)
CO GRAMS/KM (GRAMS/MILE)	140.70 (226.38)	72.22 (116.20)	52.20 (83.99)	81.13 (130.54)
CO2 GRAMS/KM (GRAMS/MILE)	2292.1 (3688.0)	1369.3 (2203.2)	1389.1 (2235.1)	1599.5 (2573.6)
NOX GRAMS/KM (GRAMS/MILE)	18.35 (29.52)	10.80 (17.37)	10.70 (17.21)	13.88 (22.33)

CFTP COMPOSITE RESULTS

HC GRAMS/KM (GRAMS/MILE)	1.81 (2.92)
CO GRAMS/KM (GRAMS/MILE)	68.78 (110.67)
CO2 GRAMS/KM (GRAMS/MILE)	1496.25 (2407.47)
NOX GRAMS/KM (GRAMS/MILE)	11.82 (19.02)
TOTAL DISTANCE KM (MILES)	7.831 (4.87)
FUEL CONSUMPTION KG (LB)	3.984 (8.784)
FUEL ECONOMY L/100KM (MPG)	62.88 (3.74)

PARTICULATE RATE

GRAMS/TEST	45.223
GRAMS/KG FUEL	11.35
GRAMS/KM	5.78
GRAMS/MILE	9.29
FILTER EFF.	98.83

TABLE D-2. CFTP VEHICLE EMISSIONS RESULTS
PROJECT 05-6855-001

TEST NO. 3832 RUN 1
VEHICLE MODEL 80 DDAD 6V71
ENGINE 7.0 L(426. CID) V-6
TRANSMISSION A-3
GVW16329. KG(36000. LBS)

VEHICLE NO. 3-8
DATE 5/20/83
BAG CART NO. 1
DYNO NO. 4
CVS NO. 11

TEST WEIGHT 12837. KG(28300. LBS)
ACTUAL ROAD LOAD
DIESEL EM-455-F
ODOMETER 259722. KM(161384. MILES)

BAROMETER 735.58 MM HG(28.96 IN HG)
RELATIVE HUMIDITY 67. PCT

DRY BULB TEMP. 24.4 DEG C(76.0 DEG F)
ABS. HUMIDITY 13.3 GM/KG

NOX HUMIDITY CORRECTION FACTOR 1.09

BAG RESULTS

BAG NUMBER	1	2	3	4
DESCRIPTION	NYNF	LANF	LAF	NYNF
RUN TIME SECONDS	254.0	285.0	267.0	254.0
TOT. BLOWER RATE SCMM (SCFM)	191.31 (6755.1)	191.25 (6753.0)	191.32 (6755.5)	191.24 (6752.8)
TOT. 20X20 RATE SCMM (SCFM)	9.59 (338.5)	9.59 (338.5)	9.59 (338.5)	9.59 (338.5)
TOT. AUX. SAMPLE RATE SCMM (SCFM)	.03 (.99)	.03 (.99)	.03 (.99)	.03 (.99)
TOT FLOW STD. CU. METRES(SCF)	850.6 (30034.)	954.1 (33689.)	894.1 (31572.)	850.3 (30024.)
HC SAMPLE METER/RANGE/PPM	19.7/21/ 10.	22.1/21/ 11.	40.1/21/ 20.	18.7/21/ 9.
HC BCKGRD METER/RANGE/PPM	10.5/ 1/ 5.	10.6/ 1/ 5.	10.8/ 1/ 5.	11.0/ 1/ 6.
CO SAMPLE METER/RANGE/PPM	62.9/12/ 139.	60.9/12/ 134.	94.7/12/ 237.	83.2/13/ 83.
CO BCKGRD METER/RANGE/PPM	1.1/12/ 2.	1.2/12/ 2.	1.8/12/ 3.	2.1/13/ 2.
CO2 SAMPLE METER/RANGE/PCT	79.4/13/ .17	90.4/13/ .19	92.2/12/ .42	67.9/13/ .14
CO2 BCKGRD METER/RANGE/PCT	24.2/13/ .04	24.1/13/ .04	13.5/12/ .05	24.3/13/ .05
NOX SAMPLE METER/RANGE/PPM	33.4/ 1/ 10.	40.2/ 1/ 12.	92.9/ 1/ 28.	28.9/ 1/ 9.
NOX BCKGRD METER/RANGE/PPM	2.0/ 1/ 1.	2.3/ 1/ 1.	2.9/ 1/ 1.	2.6/ 1/ 1.
DILUTION FACTOR	74.49	64.30	30.37	91.12
HC CONCENTRATION PPM	5.	6.	15.	4.
CO CONCENTRATION PPM	134.	128.	227.	79.
CO2 CONCENTRATION PCT	.12	.15	.37	.09
NOX CONCENTRATION PPM	9.3	11.3	26.8	7.8
HC MASS GRAMS	2.30	3.20	7.65	1.92
CO MASS GRAMS	132.63	142.64	236.37	78.13
CO2 MASS GRAMS	1883.7	2623.4	6083.3	1454.0
NOX MASS GRAMS	16.62	22.50	50.08	13.92
MASS OF FUEL BURNED GRAMS	663.4	902.9	2047.2	500.1
MEASURED DISTANCE KM (MILES)	.76 (.47)	1.85 (1.15)	5.20 (3.23)	.86 (.53)
FUEL ECONOMY L/100KM (MPG)	107.64 (2.19)	60.18 (3.91)	48.69 (4.83)	71.99 (3.27)
HC GRAMS/KM (GRAMS/MILE)	3.02 (4.85)	1.73 (2.78)	1.47 (2.37)	2.24 (3.60)
CO GRAMS/KM (GRAMS/MILE)	174.12 (280.15)	76.92 (123.76)	45.48 (73.18)	90.99 (146.40)
CO2 GRAMS/KM (GRAMS/MILE)	2473.0 (3979.1)	1414.7 (2276.2)	1170.5 (1883.3)	1693.2 (2724.3)
NOX GRAMS/KM (GRAMS/MILE)	21.82 (35.10)	12.13 (19.52)	9.64 (15.50)	16.21 (26.08)

CFTP COMPOSITE RESULTS

HC GRAMS/KM (GRAMS/MILE)	1.74 (2.80)
CO GRAMS/KM (GRAMS/MILE)	68.01 (109.43)
CO2 GRAMS/KM (GRAMS/MILE)	1388.87 (2234.69)
NOX GRAMS/KM (GRAMS/MILE)	11.89 (19.13)
TOTAL DISTANCE KM (MILES)	8.672 (5.39)
FUEL CONSUMPTION KG (LB)	4.114 (9.071)
FUEL ECONOMY L/100KM (MPG)	58.63 (4.01)

PARTICULATE RATE

GRAMS/TEST	44.478
GRAMS/KG FUEL	10.81
GRAMS/KM	5.13
GRAMS/MILE	8.25
FILTER EFF.	99.54

TABLE D-3. HFTP VEHICLE EMISSIONS RESULTS
PROJECT 05-6855-001

TEST NO. 3831 RUN 1	VEHICLE NO. 3-8	TEST WEIGHT 12837. KG(28300. LBS)
VEHICLE MODEL 80 DDAD 6V71	DATE 5/19/83	ACTUAL ROAD LOAD
ENGINE 7.0 L(426. CID) V-6	BAG CART NO. 1	DIESEL EM-455-F
TRANSMISSION A-3	DYNO NO. 4	ODOMETER 259722. KM(161384. MILES)
GVW16329. KG(36000. LBS)	CVS NO. 11	
BAROMETER 737.87 MM HG(29.05 IN HG)	DRY BULB TEMP. 25.0 DEG C(77.0 DEG F)	
RELATIVE HUMIDITY 49. PCT	ABS. HUMIDITY 10.0 GM/KG	NOX HUMIDITY CORRECTION FACTOR .98

BAG RESULTS

BAG NUMBER	1	2	3	4
DESCRIPTION	NYNF	LANF	LAF	NYNF
RUN TIME SECONDS	254.0	285.0	267.0	254.0
TOT. BLOWER RATE SCMM (SCFM)	191.63 (6766.5)	191.61 (6765.8)	191.65 (6767.3)	191.59 (6764.9)
TOT. 20X20 RATE SCMM (SCFM)	9.62 (339.8)	9.62 (339.8)	9.62 (339.8)	9.62 (339.8)
TOT. AUX. SAMPLE RATE SCMM (SCFM)	.06 (2.29)	.06 (2.29)	.06 (2.29)	.06 (2.29)
TOT FLOW STD. CU. METRES(SCF)	852.2 (30093.)	956.2 (33762.)	896.0 (31637.)	852.1 (30086.)
HC SAMPLE METER/RANGE/PPM	15.4/21/ 8.	17.6/21/ 9.	33.4/21/ 17.	14.5/21/ 7.
HC BCKGRD METER/RANGE/PPM	7.5/ 1/ 4.	7.8/ 1/ 4.	8.1/ 1/ 4.	8.5/ 1/ 4.
CO SAMPLE METER/RANGE/PPM	85.1/13/ 85.	47.6/12/ 100.	81.8/12/ 195.	69.5/13/ 68.
CO BCKGRD METER/RANGE/PPM	2.5/13/ 2.	.5/12/ 1.	1.0/12/ 2.	1.5/13/ 1.
CO2 SAMPLE METER/RANGE/PCT	66.3/13/ .13	80.7/13/ .17	80.0/12/ .34	59.9/13/ .12
CO2 BCKGRD METER/RANGE/PCT	20.6/13/ .04	20.6/13/ .04	11.3/12/ .04	20.2/13/ .04
NOX SAMPLE METER/RANGE/PPM	29.7/ 1/ 9.	36.6/ 1/ 11.	85.5/ 1/ 25.	25.5/ 1/ 8.
NOX BCKGRD METER/RANGE/PPM	1.2/ 1/ 0.	1.2/ 1/ 0.	1.7/ 1/ 0.	1.4/ 1/ 0.
DILUTION FACTOR	93.37	74.76	36.66	105.11
HC CONCENTRATION PPM	4.	5.	13.	3.
CO CONCENTRATION PPM	81.	97.	189.	65.
CO2 CONCENTRATION PCT	.10	.13	.31	.08
NOX CONCENTRATION PPM	8.5	10.5	24.9	7.2
HC MASS GRAMS	1.95	2.73	6.60	1.50
CO MASS GRAMS	80.52	108.21	196.64	64.53
CO2 MASS GRAMS	1513.8	2297.7	5047.1	1302.1
NOX MASS GRAMS	13.53	18.85	41.82	11.44
MASS OF FUEL BURNED GRAMS	520.3	782.5	1699.0	445.0
MEASURED DISTANCE KM (MILES)	.86 (.54)	1.87 (1.16)	5.21 (3.24)	.85 (.53)
FUEL ECONOMY L/100KM (MPG)	74.58 (3.15)	51.73 (4.55)	40.32 (5.83)	64.88 (3.63)
HC GRAMS/KM (GRAMS/MILE)	2.26 (3.64)	1.46 (2.35)	1.27 (2.04)	1.77 (2.84)
CO GRAMS/KM (GRAMS/MILE)	93.39 (150.27)	57.88 (93.13)	37.76 (60.75)	76.12 (122.48)
CO2 GRAMS/KM (GRAMS/MILE)	1755.8 (2825.1)	1229.0 (1977.5)	969.1 (1559.2)	1535.9 (2471.3)
NOX GRAMS/KM (GRAMS/MILE)	15.69 (25.24)	10.08 (16.22)	8.03 (12.92)	13.49 (21.71)

HFTP COMPOSITE RESULTS

HC GRAMS/KM (GRAMS/MILE)	1.45 (2.34)
CO GRAMS/KM (GRAMS/MILE)	51.20 (82.37)
CO2 GRAMS/KM (GRAMS/MILE)	1156.25 (1860.40)
NOX GRAMS/KM (GRAMS/MILE)	9.75 (15.68)
TOTAL DISTANCE KM (MILES)	8.788 (5.46)
FUEL CONSUMPTION KG (LB)	3.447 (7.600)
FUEL ECONOMY L/100KM (MPG)	48.48 (4.85)

PARTICULATE RATE

GRAMS/TEST	36.988
GRAMS/KG FUEL	10.73
GRAMS/KM	4.21
GRAMS/MILE	6.77
FILTER EFF.	97.72

TABLE D-4.HFTP VEHICLE EMISSIONS RESULTS
PROJECT 05-6855-001

TEST NO. 3832 RUN 1
VEHICLE MODEL 80 DDAD 6V71
ENGINE 7.0 L(426. CID) V-6
TRANSMISSION A3
GVW16329. KG(36000. LBS)

VEHICLE NO. 3-8
DATE 5/20/83
BAG CART NO. 1
DYNO NO. 4
CVS NO. 11

TEST WEIGHT 12837. KG(28300. LBS)
ACTUAL ROAD LOAD
DIESEL EM-455-F
ODOMETER 259722. KM(161384. MILES)

BAROMETER 735.08 MM HG(28.94 IN HG)
RELATIVE HUMIDITY 70. PCT

DRY BULB TEMP. 23.9 DEG C(75.0 DEG F)
ABS. HUMIDITY 13.5 GM/KG

NOX HUMIDITY CORRECTION FACTOR 1.10

BAG RESULTS

BAG NUMBER	1	2	3	4
DESCRIPTION	NYNF	LANF	LAF	NYNF
RUN TIME SECONDS	254.0	285.0	267.0	254.0
TOT. BLOWER RATE SCMM (SCFM)	191.51 (6762.0)	191.49 (6761.5)	191.53 (6762.8)	191.47 (6760.8)
TOT. 20X20 RATE SCMM (SCFM)	9.60 (338.8)	9.60 (338.8)	9.60 (338.8)	9.60 (338.8)
TOT. AUX. SAMPLE RATE SCMM (SCFM)	.03 (1.01)	.03 (1.01)	.03 (1.01)	.03 (1.01)
TOT FLOW STD. CU. METRES(SCF)	851.4 (30065.)	955.3 (33731.)	895.1 (31607.)	851.3 (30059.)
HC SAMPLE METER/RANGE/PPM	18.9/21/ 9.	21.8/21/ 11.	38.1/21/ 19.	19.8/21/ 10.
HC BCKGRD METER/RANGE/PPM	11.0/ 1/ 6.	11.1/ 1/ 6.	11.3/ 1/ 6.	11.4/ 1/ 6.
CO SAMPLE METER/RANGE/PPM	86.6/13/ 87.	50.7/12/ 108.	81.8/12/ 195.	67.1/13/ 65.
CO BCKGRD METER/RANGE/PPM	1.5/13/ 1.	.9/12/ 2.	1.4/12/ 3.	1.7/13/ 2.
CO2 SAMPLE METER/RANGE/PCT	70.1/13/ .14	84.1/13/ .18	84.8/12/ .37	54.5/13/ .11
CO2 BCKGRD METER/RANGE/PCT	25.3/13/ .05	25.1/13/ .05	13.8/12/ .05	23.6/13/ .04
NOX SAMPLE METER/RANGE/PPM	29.4/ 1/ 9.	37.1/ 1/ 11.	81.2/ 1/ 24.	22.2/ 1/ 7.
NOX BCKGRD METER/RANGE/PPM	2.4/ 1/ 1.	2.4/ 1/ 1.	3.1/ 1/ 1.	2.9/ 1/ 1.
DILUTION FACTOR	87.88	70.98	34.11	115.86
HC CONCENTRATION PPM	4.	5.	14.	4.
CO CONCENTRATION PPM	83.	103.	186.	62.
CO2 CONCENTRATION PCT	.10	.13	.33	.06
NOX CONCENTRATION PPM	8.0	10.3	23.3	5.7
HC MASS GRAMS	1.98	2.98	7.00	2.10
CO MASS GRAMS	82.39	114.79	194.25	61.36
CO2 MASS GRAMS	1504.1	2293.5	5346.6	1012.4
NOX MASS GRAMS	14.44	20.82	43.91	10.32
MASS OF FUEL BURNED GRAMS	518.1	784.7	1792.8	352.5
MEASURED DISTANCE KM (MILES)	.84 (.52)	1.90 (1.18)	5.26 (3.27)	.87 (.54)
FUEL ECONOMY L/100KM (MPG)	76.23 (3.09)	50.98 (4.61)	42.12 (5.59)	49.89 (4.72)
HC GRAMS/KM (GRAMS/MILE)	2.36 (3.79)	1.57 (2.52)	1.33 (2.14)	2.40 (3.86)
CO GRAMS/KM (GRAMS/MILE)	98.06 (157.78)	60.33 (97.08)	36.92 (59.41)	70.28 (113.07)
CO2 GRAMS/KM (GRAMS/MILE)	1790.2 (2880.5)	1205.5 (1939.6)	1016.2 (1635.1)	1159.4 (1865.5)
NOX GRAMS/KM (GRAMS/MILE)	17.18 (27.65)	10.94 (17.61)	8.35 (13.43)	11.82 (19.02)

HFTP COMPOSITE RESULTS

HC GRAMS/KM (GRAMS/MILE)	1.58 (2.55)
CO GRAMS/KM (GRAMS/MILE)	51.01 (82.07)
CO2 GRAMS/KM (GRAMS/MILE)	1144.13 (1840.91)
NOX GRAMS/KM (GRAMS/MILE)	10.08 (16.22)
TOTAL DISTANCE KM (MILES)	8.877 (5.52)
FUEL CONSUMPTION KG (LB)	3.448 (7.603)
FUEL ECONOMY L/100KM (MPG)	48.01 (4.90)

PARTICULATE RATE

GRAMS/TEST	38.077
GRAMS/KG FUEL	11.04
GRAMS/KM	4.29
GRAMS/MILE	6.90
FILTER EFF.	96.30

TABLE D-5. BUS VEHICLE EMISSIONS RESULTS
PROJECT 05-6855-001

TEST NO. 3831 RUN 1
VEHICLE MODEL 80 DDAD 6V71
ENGINE 7.0 L(426. CID) V-6
TRANSMISSION A-3
GVW16329. KG(36000. LBS)

VEHICLE NO. 3-8
DATE 5/19/83
BAG CART NO. 1
DYNO NO. 4
CVS NO. 11

TEST WEIGHT 12837. KG(28300. LBS)
ACTUAL ROAD LOAD
DIESEL EM-455-F
ODOMETER 259722. KM(161384. MILES)

BAROMETER 737.11 MM HG(29.02 IN HG)
RELATIVE HUMIDITY 52. PCT

DRY BULB TEMP. 24.4 DEG C(76.0 DEG F)
ABS. HUMIDITY 10.3 GM/KG

NOX HUMIDITY CORRECTION FACTOR .99

BAG RESULTS

TEST CYCLE	BUS
RUN TIME SECONDS	1193.0
TOT. BLOWER RATE SCMM (SCFM)	191.26 (6753.5)
TOT. 20X20 RATE SCMM (SCFM)	9.63 (340.1)
TOT. AUX. SAMPLE RATE SCMM (SCFM)	.07 (2.39)
TOT FLOW STD. CU. METRES(SCF)	3995.8 (141093.)
HC SAMPLE METER/RANGE/PPM	17.6/21/ 9.
HC BCKGRD METER/RANGE/PPM	8.0/ 1/ 4.
CO SAMPLE METER/RANGE/PPM	83.2/13/ 83.
CO BCKGRD METER/RANGE/PPM	.9/13/ 1.
CO2 SAMPLE METER/RANGE/PCT	64.3/13/ .13
CO2 BCKGRD METER/RANGE/PCT	20.2/13/ .04
NOX SAMPLE METER/RANGE/PPM	26.8/ 1/ 8.
NOX BCKGRD METER/RANGE/PPM	1.0/ 1/ 0.
DILUTION FACTOR	96.47
HC CONCENTRATION PPM	5.
CO CONCENTRATION PPM	80.
CO2 CONCENTRATION PCT	.09
NOX CONCENTRATION PPM	7.7
HC MASS GRAMS	11.18
CO MASS GRAMS	373.90
CO2 MASS GRAMS	6823.9
NOX MASS GRAMS	57.89
MASS OF FUEL BURNED GRAMS	2353.0
MEASURED DISTANCE KM (MILES)	4.81 (2.99)
FUEL ECONOMY L/100KM (MPG)	60.51 (3.89)
HC GRAMS/KM (GRAMS/MILE)	2.33 (3.74)
CO GRAMS/KM (GRAMS/MILE)	77.79 (125.17)
CO2 GRAMS/KM (GRAMS/MILE)	1419.8 (2284.4)
NOX GRAMS/KM (GRAMS/MILE)	12.04 (19.38)

	BUS COMPOSITE RESULTS
HC GRAMS/KM (GRAMS/MILE)	2.33 (3.74)
CO GRAMS/KM (GRAMS/MILE)	77.79 (125.17)
CO2 GRAMS/KM (GRAMS/MILE)	1419.77 (2284.41)
NOX GRAMS/KM (GRAMS/MILE)	12.04 (19.38)

PARTICULATE RATE	
GRAMS/TEST	29.261
GRAMS/KG FUEL	12.44
GRAMS/KM	6.09
GRAMS/MILE	9.80

TOTAL DISTANCE KM (MILES)	4.806 (2.99)
FUEL CONSUMPTION KG (LB)	2.353 (5.188)
FUEL ECONOMY L/100KM (MPG)	60.51 (3.89)

FILTER EFF. 98.07

TABLE D-6. BUS VEHICLE EMISSIONS RESULTS
PROJECT 05-6855-001

TEST NO. 3832 RUN 1	VEHICLE NO. 3-8	TEST WEIGHT 12837. KG(28300. LBS)
VEHICLE MODEL 80 DDAD 6V71	DATE 5/20/83	ACTUAL ROAD LOAD
ENGINE 7.0 L(426. CID) V-6	BAG CART NO. 1	DIESEL EM-455-F
TRANSMISSION A-3	DYNO NO. 4	ODOMETER 259722. KM(161384. MILES)
GVW16329. KG(36000. LBS)	CVS NO. 11	

BAROMETER 733.55 MM HG(28.88 IN HG)	DRY BULB TEMP. 23.9 DEG C(75.0 DEG F)	
RELATIVE HUMIDITY 74. PCT	ABS. HUMIDITY 14.4 GM/KG	NOX HUMIDITY CORRECTION FACTOR 1.14

BAG RESULTS

TEST CYCLE	BUS
RUN TIME SECONDS	1189.8
TOT. BLOWER RATE SCMM (SCFM)	191.08 (6747.1)
TOT. 20X20 RATE SCMM (SCFM)	9.54 (336.8)
TOT. AUX. SAMPLE RATE SCMM (SCFM)	.03 (1.03)
TOT FLOW STD. CU. METRES(SCF)	3978.8 (140493.)
HC SAMPLE METER/RANGE/PPM	19.9/21/ 10.
HC BCKGRD METER/RANGE/PPM	11.0/ 1/ 6.
CO SAMPLE METER/RANGE/PPM	87.4/13/ 88.
CO BCKGRD METER/RANGE/PPM	1.7/13/ 2.
CO2 SAMPLE METER/RANGE/PCT	69.5/13/ .14
CO2 BCKGRD METER/RANGE/PCT	23.5/13/ .04
NOX SAMPLE METER/RANGE/PPM	27.7/ 1/ 8.
NOX BCKGRD METER/RANGE/PPM	2.1/ 1/ 1.
DILUTION FACTOR	88.61
HC CONCENTRATION PPM	5.
CO CONCENTRATION PPM	84.
CO2 CONCENTRATION PCT	.10
NOX CONCENTRATION PPM	7.6
HC MASS GRAMS	10.39
CO MASS GRAMS	387.81
CO2 MASS GRAMS	7187.2
NOX MASS GRAMS	65.93
MASS OF FUEL BURNED GRAMS	2473.9
MEASURED DISTANCE KM (MILES)	4.77 (2.96)
FUEL ECONOMY L/100KM (MPG)	64.17 (3.67)
HC GRAMS/KM (GRAMS/MILE)	2.18 (3.51)
CO GRAMS/KM (GRAMS/MILE)	81.39 (130.95)
CO2 GRAMS/KM (GRAMS/MILE)	1508.3 (2426.9)
NOX GRAMS/KM (GRAMS/MILE)	13.84 (22.26)

	BUS COMPOSITE RESULTS		
HC GRAMS/KM (GRAMS/MILE)	2.18 (3.51)	PARTICULATE RATE	
CO GRAMS/KM (GRAMS/MILE)	81.39 (130.95)	GRAMS/TEST	30.197
CO2 GRAMS/KM (GRAMS/MILE)	1508.32 (2426.88)	GRAMS/KG FUEL	12.21
NOX GRAMS/KM (GRAMS/MILE)	13.84 (22.26)	GRAMS/KM	6.34
		GRAMS/MILE	10.20

TOTAL DISTANCE KM (MILES)	4.765 (2.96)		
FUEL CONSUMPTION KG (LB)	2.474 (5.455)	FILTER EFF.	98.76
FUEL ECONOMY L/100KM (MPG)	64.17 (3.67)		

APPENDIX E

CHASSIS TEST RESULTS FROM GMC RTS-II COACH WITH TRAP

TABLE E-1. CFTP VEHICLE EMISSIONS RESULTS
PROJECT 05-6855-001

TEST NO. 1 RUN 1
VEHICLE MODEL 80 DDAD 6V71
ENGINE 7.0 L(426. CID) V-6
TRANSMISSION A-3
GVW16329. KG(36000. LBS)

VEHICLE NO. 356
DATE 5/16/83
BAG CART NO. 1
DYNO NO. 4
CVS NO. 11

TEST WEIGHT 12837. KG(28300. LBS)
ACTUAL ROAD LOAD
DIESEL EM-455-F

BAROMETER 742.19 MM HG(29.22 IN HG)
RELATIVE HUMIDITY 46. PCT
DRY BULB TEMP. 22.8 DEG C(73.0 DEG F)
ABS. HUMIDITY 8.2 GM/KG
NOX HUMIDITY CORRECTION FACTOR .92

BAG RESULTS

BAG NUMBER	1	2	3	4
DESCRIPTION	NYNF	LANF	LAF	NYNF
RUN TIME SECONDS	254.0	285.0	267.0	254.0
TOT. BLOWER RATE SCMM (SCFM)	195.99 (6920.3)	195.94 (6918.6)	195.90 (6917.3)	195.87 (6916.2)
TOT. 20X20 RATE SCMM (SCFM)	10.95 (386.6)	10.95 (386.6)	10.95 (386.6)	10.95 (386.6)
TOT. AUX. SAMPLE RATE SCMM (SCFM)	.12 (4.40)	.12 (4.40)	.12 (4.40)	.12 (4.40)
TOT FLOW STD. CU. METRES(SCF)	876.6 (30951.)	983.3 (34721.)	921.0 (32522.)	876.1 (30934.)
HC SAMPLE METER/RANGE/PPM	14.8/21/ 7.	18.4/21/ 9.	29.7/21/ 15.	15.4/21/ 8.
HC BCKGRD METER/RANGE/PPM	11.0/ 1/ 6.	11.0/ 1/ 6.	11.0/ 1/ 6.	11.0/ 1/ 6.
CO SAMPLE METER/RANGE/PPM	54.1/12/ 116.	59.3/12/ 130.	89.3/12/ 219.	72.8/13/ 71.
CO BCKGRD METER/RANGE/PPM	5.0/12/ 9.	5.7/12/ 11.	10.2/12/ 19.	14.7/13/ 13.
CO2 SAMPLE METER/RANGE/PCT	78.1/13/ .16	89.0/13/ .19	91.2/12/ .41	68.0/13/ .14
CO2 BCKGRD METER/RANGE/PCT	25.4/13/ .05	27.3/13/ .05	19.6/12/ .07	30.6/13/ .06
NOX SAMPLE METER/RANGE/PPM	33.1/ 1/ 10.	41.9/ 1/ 12.	32.0/ 2/ 32.	29.3/ 1/ 9.
NOX BCKGRD METER/RANGE/PPM	3.6/ 1/ 1.	4.6/ 1/ 1.	2.7/ 2/ 3.	5.8/ 1/ 2.
DILUTION FACTOR	76.90	65.69	30.95	91.76
HC CONCENTRATION PPM	2.	4.	10.	2.
CO CONCENTRATION PPM	105.	117.	195.	57.
CO2 CONCENTRATION PCT	.12	.14	.34	.08
NOX CONCENTRATION PPM	8.8	11.1	29.4	7.0
HC MASS GRAMS	1.00	2.14	5.06	1.15
CO MASS GRAMS	107.11	133.81	209.62	58.09
CO2 MASS GRAMS	1851.5	2519.0	5796.0	1299.1
NOX MASS GRAMS	13.62	19.33	47.86	10.86
MASS OF FUEL BURNED GRAMS	639.2	864.5	1940.5	440.5
MEASURED DISTANCE KM (MILES)	.74 (.46)	1.83 (1.13)	5.10 (3.17)	.87 (.54)
FUEL ECONOMY L/100KM (MPG)	107.11 (2.20)	58.51 (4.02)	47.04 (5.00)	62.85 (3.74)
HC GRAMS/KM (GRAMS/MILE)	1.35 (2.17)	1.17 (1.89)	.99 (1.60)	1.32 (2.13)
CO GRAMS/KM (GRAMS/MILE)	145.21 (233.65)	73.27 (117.89)	41.11 (66.15)	67.05 (107.89)
CO2 GRAMS/KM (GRAMS/MILE)	2510.0 (4038.5)	1379.4 (2219.4)	1136.7 (1829.0)	1499.6 (2412.9)
NOX GRAMS/KM (GRAMS/MILE)	18.47 (29.72)	10.58 (17.03)	9.39 (15.10)	12.53 (20.17)

CFTP COMPOSITE RESULTS

HC GRAMS/KM (GRAMS/MILE)	1.10 (1.76)
CO GRAMS/KM (GRAMS/MILE)	59.64 (95.95)
CO2 GRAMS/KM (GRAMS/MILE)	1344.32 (2163.01)
NOX GRAMS/KM (GRAMS/MILE)	10.75 (17.29)
TOTAL DISTANCE KM (MILES)	8.529 (5.30)
FUEL CONSUMPTION KG (LB)	3.885 (8.566)
FUEL ECONOMY L/100KM (MPG)	56.30 (4.18)

PARTICULATE RATE

GRAMS/TEST	5.002
GRAMS/KG FUEL	1.29
GRAMS/KM	.59
GRAMS/MILE	.94

FILTER EFF. 79.94

TABLE E-2. HFTP VEHICLE EMISSIONS RESULTS
PROJECT 05-6855-001

TEST NO. 1 RUN 1
VEHICLE MODEL 80 DDAD 6V71
ENGINE 7.0 L(426. CID) V-6
TRANSMISSION A-3
GVW16329. KG(36000. LBS)

VEHICLE NO. 356
DATE 5/16/83
BAG CART NO. 1
DYNO NO. 4
CVS NO. 11

TEST WEIGHT 12837. KG(28300. LBS)
ACTUAL ROAD LOAD
DIESEL EM-455-F

BAROMETER 741.68 MM HG(29.20 IN HG)
RELATIVE HUMIDITY 56. PCT
DRY BULB TEMP. 25.0 DEG C(77.0 DEG F)
ABS. HUMIDITY 11.4 GM/KG
NOX HUMIDITY CORRECTION FACTOR 1.02

BAG RESULTS

BAG NUMBER	1	2	3	4
DESCRIPTION	NYNF	LANF	LAF	NYNF
RUN TIME SECONDS	254.0	285.0	267.0	254.0
TOT. BLOWER RATE SCMM (SCFM)	195.82 (6914.4)	195.80 (6913.7)	195.81 (6914.2)	195.73 (6911.2)
TOT. 20X20 RATE SCMM (SCFM)	10.93 (385.8)	10.93 (385.8)	10.93 (385.8)	10.93 (385.8)
TOT. AUX. SAMPLE RATE SCMM (SCFM)	.12 (4.27)	.12 (4.27)	.12 (4.27)	.12 (4.27)
TOT FLOW STD. CU. METRES(SCF)	875.7 (30922.)	982.5 (34693.)	920.5 (32504.)	875.4 (30909.)
HC SAMPLE METER/RANGE/PPM	14.5/21/ 7.	18.2/21/ 9.	28.7/21/ 14.	14.8/21/ 7.
HC BCKGRD METER/RANGE/PPM	11.0/ 1/ 6.	11.0/ 1/ 6.	11.0/ 1/ 6.	11.0/ 1/ 6.
CO SAMPLE METER/RANGE/PPM	73.4/13/ 72.	89.3/13/ 90.	73.6/12/ 170.	63.5/13/ 61.
CO BCKGRD METER/RANGE/PPM	8.1/13/ 7.	9.6/13/ 9.	8.4/12/ 16.	10.6/13/ 10.
CO2 SAMPLE METER/RANGE/PCT	65.3/13/ .13	80.3/13/ .17	87.1/12/ .39	63.6/13/ .13
CO2 BCKGRD METER/RANGE/PCT	25.1/13/ .05	27.3/13/ .05	19.4/12/ .07	27.9/13/ .05
NOX SAMPLE METER/RANGE/PPM	28.7/ 1/ 9.	37.1/ 1/ 11.	30.7/ 2/ 31.	28.4/ 1/ 8.
NOX BCKGRD METER/RANGE/PPM	3.4/ 1/ 1.	4.3/ 1/ 1.	2.7/ 2/ 3.	4.9/ 1/ 1.
DILUTION FACTOR	95.77	75.61	33.22	99.21
HC CONCENTRATION PPM	2.	4.	9.	2.
CO CONCENTRATION PPM	63.	79.	150.	51.
CO2 CONCENTRATION PCT	.09	.12	.32	.08
NOX CONCENTRATION PPM	7.5	9.8	28.1	7.0
HC MASS GRAMS	.92	2.09	4.80	.99
CO MASS GRAMS	64.50	90.82	161.02	51.56
CO2 MASS GRAMS	1377.2	2105.3	5388.0	1225.4
NOX MASS GRAMS	12.92	18.80	50.60	12.00
MASS OF FUEL BURNED GRAMS	468.1	712.4	1787.2	413.8
MEASURED DISTANCE KM (MILES)	.82 (.51)	1.83 (1.14)	5.19 (3.23)	.86 (.53)
FUEL ECONOMY L/100KM (MPG)	70.60 (3.33)	48.13 (4.89)	42.57 (5.53)	59.75 (3.94)
HC GRAMS/KM (GRAMS/MILE)	1.12 (1.80)	1.14 (1.84)	.92 (1.49)	1.15 (1.85)
CO GRAMS/KM (GRAMS/MILE)	78.70 (126.63)	49.64 (79.86)	31.03 (49.92)	60.24 (96.92)
CO2 GRAMS/KM (GRAMS/MILE)	1680.4 (2703.8)	1150.6 (1851.4)	1038.2 (1670.5)	1431.6 (2303.4)
NOX GRAMS/KM (GRAMS/MILE)	15.77 (25.37)	10.28 (16.53)	9.75 (15.69)	14.02 (22.57)

HFTP COMPOSITE RESULTS

HC GRAMS/KM (GRAMS/MILE)	1.01 (1.63)
CO GRAMS/KM (GRAMS/MILE)	42.31 (68.08)
CO2 GRAMS/KM (GRAMS/MILE)	1161.14 (1868.27)
NOX GRAMS/KM (GRAMS/MILE)	10.85 (17.46)
TOTAL DISTANCE KM (MILES)	8.695 (5.40)
FUEL CONSUMPTION KG (LB)	3.381 (7.456)
FUEL ECONOMY L/100KM (MPG)	48.07 (4.89)

PARTICULATE RATE

GRAMS/TEST	2.671
GRAMS/KG FUEL	.79
GRAMS/KM	.31
GRAMS/MILE	.49

FILTER EFF. 76.72

TABLE E-3. NY BUS VEHICLE EMISSIONS RESULTS
PROJECT 05-6855-001

TEST NO. 1 RUN 1	VEHICLE NO. 356	TEST WEIGHT 12837. KG(28300. LBS)
VEHICLE MODEL 80 DDAD 6V71	DATE 5/16/83	ACTUAL ROAD LOAD
ENGINE 7.0 L(426. CID) V-6	BAG CART NO. 1	DIESEL EM-455-F
TRANSMISSION A-3	DYNO NO. 4	
GVW16329. KG(36000. LBS)	CVS NO. 11	
BAROMETER 740.41 MM HG(29.15 IN HG)	DRY BULB TEMP. 25.6 DEG C(78.0 DEG F)	
RELATIVE HUMIDITY 40. PCT	ABS. HUMIDITY 8.4 GM/KG	NOX HUMIDITY CORRECTION FACTOR .93

BAG RESULTS

TEST CYCLE	NY BUS
RUN TIME SECONDS	1193.8
TOT. BLOWER RATE SCMM (SCFM)	194.79 (6878.2)
TOT. 20X20 RATE SCMM (SCFM)	10.82 (381.9)
TOT. AUX. SAMPLE RATE SCMM (SCFM)	.12 (4.34)
TOT FLOW STD. CU. METRES(SCF)	4093.4 (144538.)
HC SAMPLE METER/RANGE/PPM	13.3/21/ 7.
HC BCKGRD METER/RANGE/PPM	7.5/ 1/ 4.
CO SAMPLE METER/RANGE/PPM	71.3/13/ 70.
CO BCKGRD METER/RANGE/PPM	3.9/13/ 4.
CO2 SAMPLE METER/RANGE/PCT	63.4/13/ .13
CO2 BCKGRD METER/RANGE/PCT	22.1/13/ .04
NOX SAMPLE METER/RANGE/PPM	26.8/ 1/ 8.
NOX BCKGRD METER/RANGE/PPM	2.2/ 1/ 1.
DILUTION FACTOR	98.97
HC CONCENTRATION PPM	3.
CO CONCENTRATION PPM	65.
CO2 CONCENTRATION PCT	.09
NOX CONCENTRATION PPM	7.3
HC MASS GRAMS	6.91
CO MASS GRAMS	310.01
CO2 MASS GRAMS	6560.7
NOX MASS GRAMS	53.26
MASS OF FUEL BURNED GRAMS	2233.8
MEASURED DISTANCE KM (MILES)	4.69 (2.92)
FUEL ECONOMY L/100KM (MPG)	58.83 (4.00)
HC GRAMS/KM (GRAMS/MILE)	1.47 (2.37)
CO GRAMS/KM (GRAMS/MILE)	66.05 (106.27)
CO2 GRAMS/KM (GRAMS/MILE)	1397.8 (2249.1)
NOX GRAMS/KM (GRAMS/MILE)	11.35 (18.26)

NY BUS COMPOSITE RESULTS

HC GRAMS/KM (GRAMS/MILE)	1.47 (2.37)	PARTICULATE RATE	
CO GRAMS/KM (GRAMS/MILE)	66.05 (106.27)	GRAMS/TEST	2.039
CO2 GRAMS/KM (GRAMS/MILE)	1397.82 (2249.09)	GRAMS/KG FUEL	.91
NOX GRAMS/KM (GRAMS/MILE)	11.35 (18.26)	GRAMS/KM	.43
		GRAMS/MILE	.70
TOTAL DISTANCE KM (MILES)	4.694 (2.92)		
FUEL CONSUMPTION KG (LB)	2.234 (4.926)	FILTER EFF.	78.35
FUEL ECONOMY L/100KM (MPG)	58.83 (4.00)		

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16. ABSTRACT

Diesel soot or smoke has been regarded as a nuisance pollutant and potential health hazard, especially in congested urban areas where diesel buses operate. Exhaust emissions from a DDAD 6V-71 coach engine and a similarly-powered 1980 GMC RTS-II coach, fitted with a non-catalyzed particulate trap, were characterized over various Federal Test Procedures for heavy-duty engines, including an experimental test cycle for buses. Regeneration was accomplished using an in-line burner in the exhaust to raise the engines' idle exhaust gas temperature from 120 to 700°C. Trap testing included approximately 15 hours of engine operation and 100 miles of bus operation. Particulate emissions were reduced by an average of 79 percent and smoke emissions were nil using the trap. The effect of the trap on regulated and other unregulated emissions was generally minimal.

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a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
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