Exhaust Emissions Testing Performed for Air Products Corporation on Transit Buses Fueled by Air Products Brand Methanol Fuel

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August 21, 1998

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1 Introduction

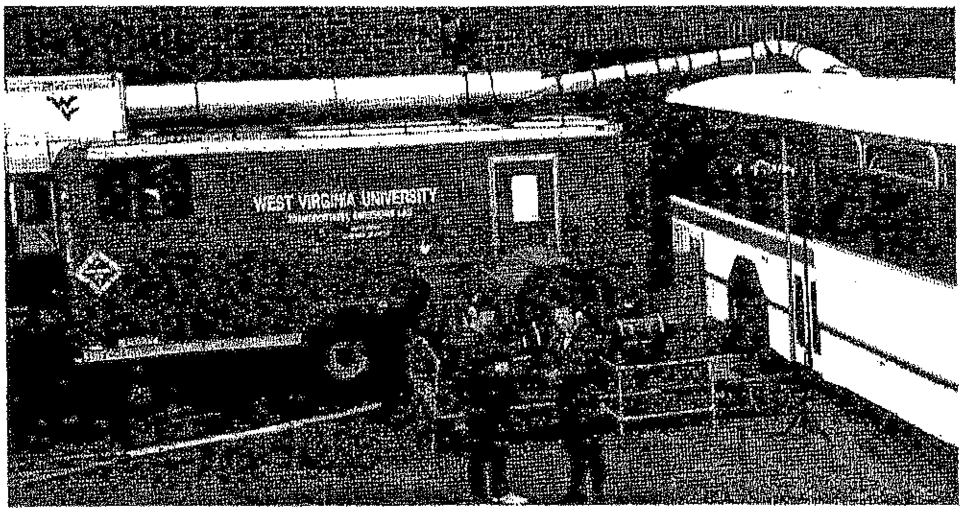

Figure 1 -- Laboratory #1

1.1 Overview

The emissions testing reviewed in this report was performed for Air Products Corporation who are currently developing a "fuel grade" methanol (FGM) product for use in heavy duty vehicles. The subject vehicles, transit buses, were equipped with Detroit Diesel Corporation 6V92 compression ignition engines designed to operate on alcohol fuels. At the time of this research, the only fuel commonly used in methanol vehicles is a high purity chemical grade methanol (CGM). The FGM is being developed as a replacement for the CGM which is expensive when compared to diesel fuel.

West Virginia University (WVU), through funding from Air Products Corporation, performed emissions measurements on a sample of three Methanol fueled transit busses in New York City in April, 1998. The vehicles were tested on both FGM and CGM. The vehicles were operated through commonly used, pre-determined vehicle speed vs. time schedules while vehicle emission, torque and speed were monitored and recorded. Emissions monitored during the testing included hydrocarbons (HC), carbon monoxide (CO), carbon dioxide (CO2), oxides of nitrogen (NOx), particulate matter (PM), methanol (CH3OH), and formaldehyde (HCHO).

1.2 Emissions Laboratory Description and General Approach

The WVU Transportable Heavy Duty Emissions Testing Laboratory (Figure 1) evaluates emissions from alternatively fueled vehicles across North America. The usual objective of the research performed is to build an emissions database that can be used to ascertain emissions performance and fuel efficiency of alternatively fueled vehicles. West Virginia University designed, constructed and now operates two Transportable Heavy Duty Vehicle Emissions Testing Laboratories which travel to transit agencies and trucking facilities where the laboratory is stationed to test vehicle emissions.

Several technical papers (SAE 961082, SAE 951016, and SAE 952746) have been presented on the design of the two laboratories and on emissions data collected from both conventional and alternatively fueled vehicles.

The transportable laboratory used in this research consisted of a dynamometer test bed, instrumentation trailer and support trailer. The test bed (Figure 2 and Figure 3) was designed to be transported to the test site by a tractor truck where it is then lowered to the ground. Once lowered, subject vehicles were then driven on to the test bed where the outer drive wheels of the vehicle are removed and replaced by special adapters (Figure 4), which provided a connection between the drive axle of the vehicle and the inertial flywheels and power absorbers of the dynamometer. Speed-increasing gearboxes transmitted the bus drive axle power to flywheel sets. The flywheel sets consisted of a series of selectable discs used to simulate vehicle inertia. During the test cycle, torque cells and speed transducers at the vehicle hubs monitored wheel torque and hub speed.

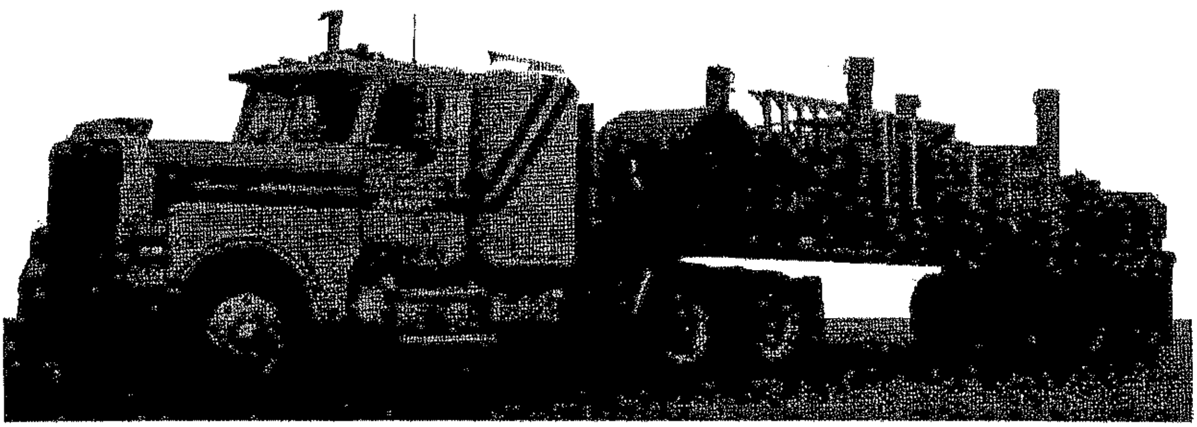

Figure 2 -- Dynamometer test bed packed for transport

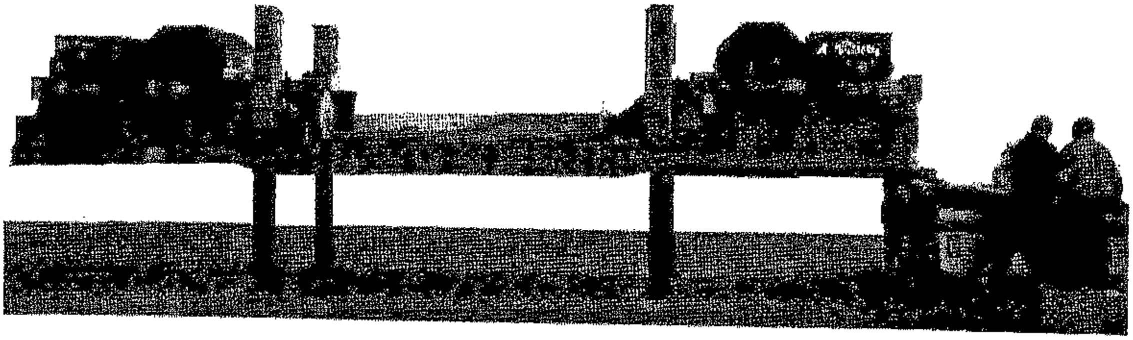

Figure 3 -- Test bed ready for lowering in preparation for testing

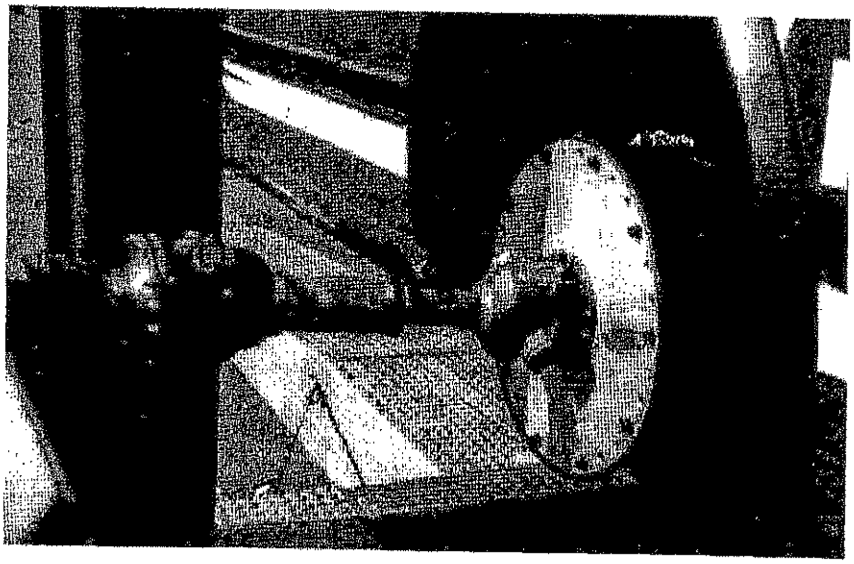

Figure 4 -- Close-up of adapter connecting the vehicle hub to the dynamometer drivetrain

The instrumentation trailer (Figure 5) held both the emissions measurement system for the laboratory and the data acquisition and control hardware necessary for the operation of the test bed. Exhaust emissions from the bus were piped to a 45cm dilution tunnel at the instrumentation trailer. The tunnel mixed the exhaust with ambient air which both cooled and diluted the exhaust. The use of dilution tunnels has been discussed in detail by Kittelson and Johnson (1991). Dilution tunnel flow control was realized using a critical flow venturi system (CVS). A two-stage blower system maintained critical flow through the venturi throat restrictions to maintain a known, and nearly constant mass flow of dilute exhaust during testing flow of dilute exhaust during testing. The flow used in the research was approximately 1000 scfm, including both vehicle exhaust and dilution air.

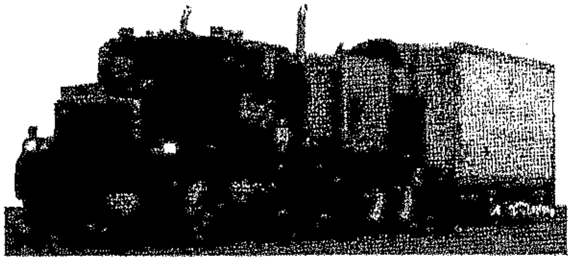

Figure 5 -- Instrumentation trailer and transport vehicle

Dilute exhaust samples were drawn from sample probes located 15 feet from the mouth of the dilution tunnel. The samples were routed to the respective analyzers using heated sampling lines. Levels of carbon dioxide (CO_2), carbon monoxide (CO), oxides of nitrogen (NO_x) and hydrocarbons (HC) were measured continuously, then integrated over the complete test cycle. A sample of the ambient (dilution) air was collected in a Tedlar bag and analyzed at the end of each test. These measurements were then subtracted from the continuous measurements. Detail of the analyzers used in this research are given in Table 1

Hydrocarbons	Flame ionization detector	Rosemount Analytical Model 402
Carbon Monoxide	Non-dispersive infrared	Rosemount Analytical Model 880A
Carbon Dioxide	Non-dispersive infrared	Rosemount Analytical Model 880A
Oxides of Nitrogen	Chemiluminescent	Rosemount Analytical Model 955

Table 1-- Analyzers used for emissions measurement

A gravimetric measurement of particulate matter (PM) was obtained using 70mm filters, weighed before and after testing. The filters were conditioned for temperature and humidity in an environmental chamber before each weighing to reduce error due to variation in water content. It was known from prior research that the PM levels from methanol fueled buses were likely to be low.

The researchers also measured the amount of formaldehyde and methanol present in the engine exhaust. Formaldehyde measurement was accomplished using DNPH coated silica beads in sample cartridges prepared by Atmospheric Analysis & Consulting (AA&C). During the test, a continuous exhaust sample from the dilution tunnel was passed through the cartridge where any formaldehyde present depleted a quantity of DNPH from the cartridge proportional to the amount of formaldehyde in the sample. The amount of methanol in the exhaust was determined by passing a continuous sample through a series of two impingers containing 25 ml of distilled water. Any methanol present in the sample was dissolved in the water, which was then analyzed using gas chromatography with a Varian 3600 gas chromatograph. The continuous reading from the hydrocarbon analyzer was known to be affected by the level of methanol in the exhaust because the flame ionization detector's response to the methanol, as compared to its calibration gas (propane), is slightly lower.

2 Specific Test Procedures

2.1 Pre-Test

Prior to testing each methanol bus, a visual inspection was performed to locate lift points, look for damage, and examine exhaust connections. Also vehicle information was gathered such as mileage, identification numbers (chassis and engine), type of muffler and catalyst, and seating capacity.

To minimize variation in emissions due to air-cleaner quality, a clean air filter was used for all the vehicles tested. The original air cleaner was reinstalled in each bus before it was returned to the owner.

Proper operation of the gas sampling system, associated analyzers, and test bed instrumentation was checked following a comprehensive calibration schedule after setup of the laboratory. In particular, the gas analysis instrumentation was calibrated and checked using "zero" air (air free of any contaminants) and "span" gas (air containing a known quantity of the gas under consideration) as well as evenly spaced concentration levels of the gas. The integrity of the dilution tunnel and associated plumbing was verified using a propane injection. This procedure involved introducing a known amount of propane into the dilution tunnel using a critical flow orifice injection rig. The hydrocarbon concentration measured using the hydrocarbon analyzer was then compared to that calculated from the injection rig to verify propane mass recovery. A difference of less than 2% indicated that there were no leaks and that the analysis system was operating satisfactorily. The 2% valve is customarily used because it follows the requirements for emissions testing presented in the Code of Federal Regulations Title 40, Part 86, Subpart N.

Since this emissions research involved vehicles (buses) with a single rear axles, additional load on the inner rear tires was introduced when the outside tires were removed. This additional load was removed by placing jacks on calibrated scales beneath the bus. The vehicle was lifted until each scale read one quarter of the vehicle's rear curb weight.

Prior to performing a test, the vehicle was operated on the dynamometer to bring the vehicle's engine and transmission as well as associated dynamometer equipment up to operating temperature. This provided a uniform starting point for all testing when considering the vehicle/dynamometer drivetrain and associated transmission losses in each component.

At least one practice test cycle was then performed to allow the driver to become familiar with vehicle characteristics, and to help the instrument operator determine proper analyzer settings. Prior to taking the first data set, the vehicle transmission was set to neutral and the engine was allowed to idle for a period of 17 minutes. The vehicle was then driven though a set of practice ramps to expel constituents that may have collected in the exhaust system during idling. Twenty seconds after completion of the final practice ramp, data collection was initiated.

2.2 Emissions Measurement

During an emissions test, the driver was provided with a visual speed trace displaying both the actual and the desired vehicle speed. The driver was instructed to follow the prescribed speed trace as closely as possible. While the driver operated the vehicle through the speed cycle, continuous dilute exhaust samples from the dilution tunnel were monitored and recorded in the instrumentation trailer. At the completion of the test cycle, integrated bag samples were analyzed and recorded and particulate filters were changed. Data from each test were recorded and preparations for the next test were initiated. Particulate data were not available until the filters could be appropriately conditioned after the test. This involved placing the filters in an environmental chamber where they were left for at least 4 hours prior to weighing.

Test to test variation was monitored to assure quality of the research conclusions. Testing was considered to be complete when a minimum of 4 complete test were performed and the test to test variation showed acceptable repeatability.

3 Vehicles, Fuels and Tests Performed

3.1 Test Vehicles

Resistance to auto-ignition and high heat of vaporization make alcohol fuels difficult for compression ignition application. In addition, the low heating value of alcohol fuels demands that a greater volume of fuel must be injected into the cylinder than for diesel. Other problems that must be addressed are related to poor fuel lubricity, the changed heat release rates relative to diesel and the presence of corrosive products of combustion in the cylinder. Despite these obstacles, Detroit Diesel Corporation (DDC) has manufactured a methanol compression ignition engine based on the 6V92 diesel engine. The design uses the two stroke cycle, with exhaust valves in the head and is supercharged and turbocharged. Injection is managed electronically. After treatment catalytic converters are used to oxidize emissions.

Three Transit Motor Corp. methanol fueled transit buses (1993 T80206 model) were tested on both CGM and FGM in 1998. They were equipped with Detroit Diesel 6V92 engines. These vehicles were selected from Triboro Coach Company's in-service fleet in Brooklyn, NY. Details on the engine and vehicles are contained in Table 2.

Vehicle Number	2145	2139	2143
Model Year	1994	1993	1993
Seating Capacity	43	43	43
Frontal Area (ft^2)	80.5	80.5	80.5
Tire Diameter (in.)	41.8	41.8	41.8
GVW (lb.)	39500	39500	39500
Curb Weight (lb.)	28500	28500	28500
Test Weight (lb.)	34500	34500	34500
Odometer Reading (miles)	10000	69020	88772
Engine Type	DD6V92TA	DD6V92TA	DD6V92LH
Engine Displacement (liters)	9.0	9.0	9.0
Engine Rated Power (hp)	253	253	253

Table 2-- Data from vehicles tested in this study

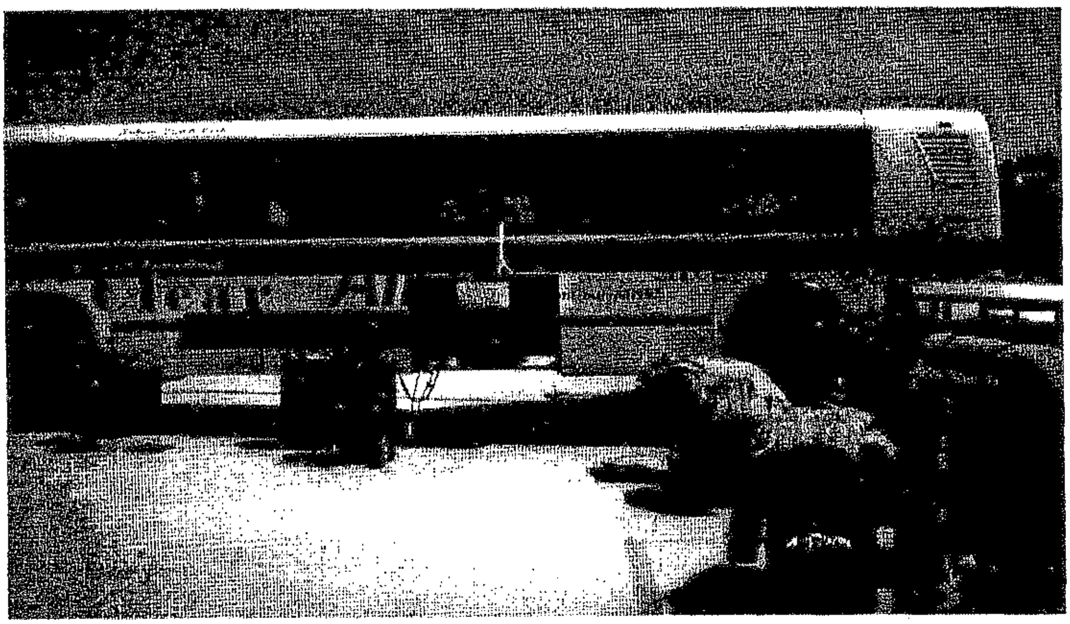

Figure 6 --Triboro Methanol bus running on Air Products methanol

3.2 Fuels

The fuels used in this research program were the fuel grade methanol (FGM) supplied by Air Products from their plant in Laporte, TX, and the chemical grade methanol (CGM) in current use by Triboro coach. The CGM, supplied by Rad Energy Corp., was essentially pure and its specifications are given in

Table 3.

Table 3—Chemical grade methanol fuel specifications

PURITY	99.85 minimum *wt%*
APPEARANCE	bright & clear, free of suspended matter
COLOR	5 maximum *Platinum cobalt scale*
SPECIFIC GRAVITY	0.7928 maximum *at 20 degrees/20 degrees C*
WATER	0.10 maximum *wt%*
ACIDITY	0.003 maximum *as acetic acid wt%*
ALKALINITY	0.003 maximum *as ammonia wt%*
PERMANGANATE TEST	60 minimum *at 15 degrees C, minutes*
ACETONE	0.003 maximum *wt%*
DISTILLATION RANGE	not more than 1 degrees including 64.6 degrees C *at 760mm Hg*
CARBONIZABLE SUBSTANCE	30 maximum *platinum cobalt scale*
WATER MISCIBILITY	No turbidity after 1 hour at 25degreesC *when 1 volume is distilled with 3 volumes of distilled water*
NON-VOLATILES	0.001 maximum *gram/100ml*

Received: July 8, 1998 (by Boyce)
From: Rad Energy Corp.
287 Bowman Ave.
Purchase, NY 10577-2540
914-701-2710

An additive, manufactured by Lubrizol, was customarily used by Triboro to treat the chemical grade fuel. The same additive was used to doctor the FGM before the comparative emissions research commenced. The additive was mixed 0.06 percent by volume.

3.3 Tests Perfomed

The vehicles were tested on fuel grade methanol (FGM) that was developed by Air Products (Figure 6). They were also tested using the regularly used fuel, which was chemical grade methanol (CGM). All three vehicles were tested using the Central Business District (CBD) cycle (Figure 7), and one vehicle was tested using both the CBD and the 5 mile route (Figure 8).

The Central Business District Cycle is a fixed speed-versus-time trace that the driver must follow. It is intended to simulate the use of a transit bus in city service and is also used to ratify the performance of new models of transit bus. Details of the CBD are given in SAE Recommended Practice J1376. The CBD is two miles long, and is customarily followed without difficulty by transit buses in current service. All cruise sections are at 20 mph.

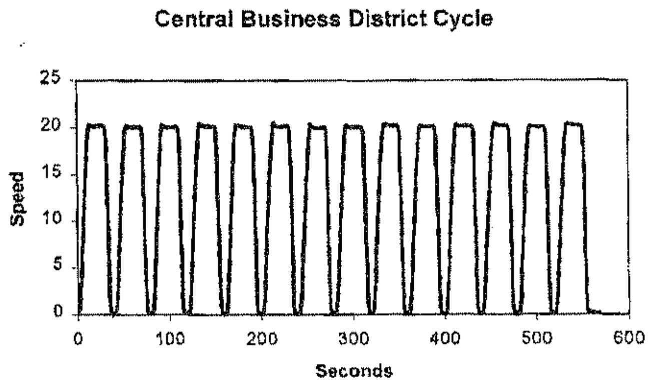

Figure 7 – Vehicle speed from a CBD cycle

The 5 mile route is less energy intensive than the CBD cycle, having longer cruise sections. It consists of five acceleration, cruise and deceleration segments, at 20, 25, 30, 35 and 40 mph. The accelerations are designed to be free accelerations at maximum axle power, so that a more powerful vehicle will complete a 5 mile route in less time. Therefore, completion time for the route may vary from vehicle to vehicle. This route was originally designed for heavy over-the-road trucks and has been discussed in more detail by Clark and Lyons (ASAE 986082).

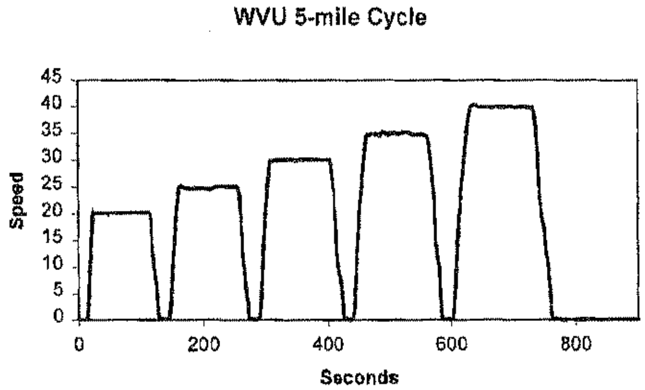

Figure 8 – Vehicle speed from a 5 mile route.

When testing on the FGM, a 55-gallon drum was used to replace the fuel tank as shown in Figure 9. Braided Stainless Teflon line was used to replace the fuel line. The line from the fuel tank was disconnected and capped, and an identical line was attached in its place, which came from the Air Products methanol drum. The return line to the fuel tank was also replaced (Figure 10).

Initial attempts to operate the engine using the fueling system described above failed. The reason for these failures was found to have been caused by low pressure in the substitute fuel return line. Without the backpressure normally created by an orifice in the origional line, the engine would not operate properly. To remedy this, a restriction to increase backpressure was created by installing a stainless steel ball valve in the return line. A mechanic from the transit agency adjusted the backpressure to the same level as when the original return line was in use.

To minimize contamination of the test fuels, the return line was directed into a waste drum and the fuel pump was operated until approximately 10 gallons had cycled through the system. The return line was then directed back into the drum of test fuel. This insured that the FGM was not contaminated with CGM during a test run.

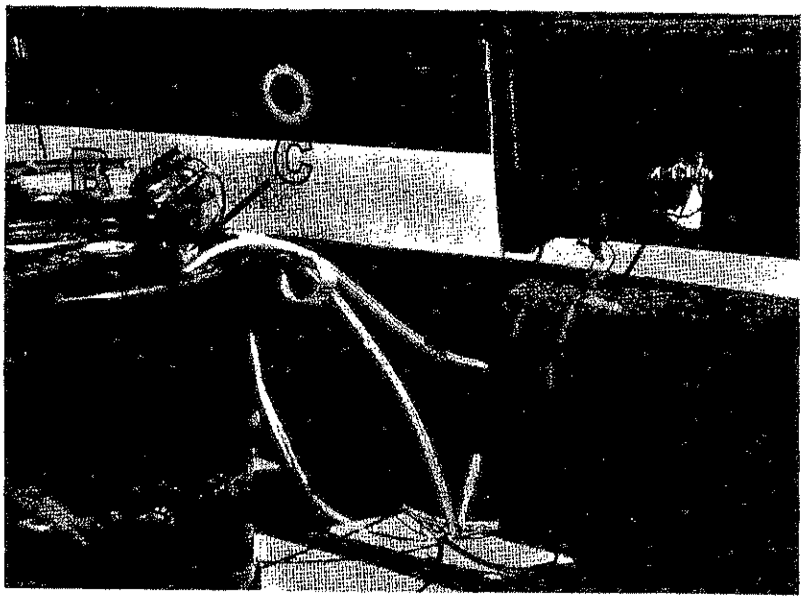

Figure 9 -- Fuel tank replacement

A. Air Products methanol 55-gal drum
B. Waste fuel 55-gal drum
C. Valve on return line used as restriction to increase fuel system pressure

Figure 10 -- Fuel line replacement

A. Intake from 55-gal drum
B. Capped line from fuel tank
C. One of two fuel filters
D. Fuel pump
E. Return line to 55-gal drum

4 Emissions Data

4.1 Fuel and Chemical Grade Methanol

This section discusses emissions measured from the methanol fueled transit buses with Detroit Diesel DD6V92 engines, and the contrast between the results obtained using Air Products FGM and the currently used CGM. Table 4 shows the emissions results, in g/mile, for all three buses operated through the CBD cycle, and one bus operated through the 5-mile test. Each entry in these tables is the average of several test runs. The data from individual runs appears in **6.1 Short Reports** on page 18 of this report. An explanation of terms can be found in Section **6, Reading the Short Report**

Table 4—Methanol Emissions Summary

Vehicle #2145 using the CBD test cycle

Seq #	Fuel	CO	NOx	FIDHC	PM	CO2	MPG	BTU/mile	CH3OH	HCHO	OMHCE
1097	CGM	5.83	4.62	2.17	0.09	2382	1.72	33131	2.66	1.35	0.79
1099	FGM	4.01	3.47	4.10	0.11	2489	1.65	34578	4.16	2.03	3.08
	% diff. *	***-31%***	***-25%***	***89%***	***24%***	***4%***	***-4%***	***4%***	***56%***	***50%***	***290%***

Vehicle #2139 using the CBD test cycle

Seq #	Fuel	CO	NOx	FIDHC	PM	CO2	MPG	BTU/mile	CH3OH	HCHO	OMHCE
1101	CGM	12.90	6.61	5.28	0.10	3013	1.36	42035	6.17	1.17	3.34
1103	FGM	11.80	6.24	5.55	0.12	2953	1.38	41171	6.05	1.41	3.59
	% diff. *	***-9%***	***-6%***	***5%***	***25%***	***-2%***	***1%***	***-2%***	***-2%***	***21%***	***7%***

Vehicle #2143 using the CBD test cycle

Seq #	Fuel	CO	NOx	FIDHC	PM	CO2	MPG	BTU/mile	CH3OH	HCHO	OMHCE
1106	CGM	12.50	5.56	8.71	0.44	2923	1.40	40778	9.84	1.35	5.16
1105	FGM	13.00	5.63	11.00	0.49	2992	1.37	41748	13.99	1.44	6.64
	% diff. *	***4%***	***1%***	***26%***	***11%***	***2%***	***-2%***	***2%***	***42%***	***7%***	***29%***

Vehicle Average using the CBD test cycle

Seq #	Fuel	CO	NOx	FIDHC	PM	CO2	MPG	BTU/mile	CH3OH	HCHO	OMHCE
Average	CGM	10.41	5.60	5.39	0.21	2772.67	1.49	38648	6.22	1.29	3.10
Average	FGM	9.60	5.11	6.88	0.24	2811.33	1.47	39166	8.07	1.63	4.44
	% diff. *	***-8%***	***-9%***	***28%***	***15%***	***1%***	***-2%***	***1%***	***30%***	***26%***	***43%***

Vehicle #2143 using the 5-mile test cycle

Seq #	Fuel	CO	NOx	FIDHC	PM	CO2	MPG	BTU/mile	CH3OH	HCHO	OMHCE
1107	CGM	11.80	3.47	51.10	0.39	1962	2.08	27447	71.19	2.54	29.53
1109	FGM	15.70	3.53	54.80	0.52	1965	2.07	27575	71.85	2.40	31.78
	% diff. *	***33%***	***2%***	***7%***	***33%***	***0%***	***0%***	***0%***	***1%***	***-6%***	***8%***

*** % diff.***--*The percent difference of FGM emissions versus CGM emissions using: %diff=(FGM-CGM)/CGM)*

Carbon Monoxide (CO): For the CBD cycle, the average level of CO for the three vehicles when tested on CGM was 10.4 g/mile. The average level for the three vehicles when tested on Air Products FGM was comparable at 9.6 g/mile. This represented an 8% decrease.

Oxides of Nitrogen (NOx): For the CBD cycle, the average level of NOx for the three vehicles when tested on CGM was 5.6 g/mile. The average level for the three vehicles when tested on Air Products FGM was comparable at 5.1 g/mile. This represented a 9% decrease.

Hydrocarbons (HC): For the CBD cycle, the average level of HC when tested on CGM was 5.4 g/mile. The average level for the three vehicles when tested on Air Products FGM was 6.9 g/mile, representing a 28% increase.

Particulate Matter (PM): For the CBD cycle, low levels of PM were experienced from both fuels. However, PM was 15% higher on average when using the FGM.

Carbon Dioxide (CO2) and Fuel Consumption: For the CBD cycle, CO2 levels were about 2800 g/mi. and energy equivalent fuel consumption was approximately 1.5 mpg and for both fuels.

Raw Methanol (CH3OH): The average level for the three vehicles when tested on CGM was 6.22 g/mile and average level for the three vehicles when tested on Air Products FGM was 8.07 g/mile. This indicates a 30% increase using FGM. This comparison assumes 100% recovery by the methanol (water impinger) sampling system.

Formaldehyde (HCHO): The average level for the three vehicles when tested on CGM was 1.29 g/mile and average level for the three vehicles when tested on Air Products FGM was 1.63 g/mile. This indicates a 26% increase using FGM. This comparison assumes 100% recovery by the aldehyde (DNPH cartridge) sampling system.

Organic Material HC Equivalent (OMHCE): OMHC is the designation used by the EPA to denote the total HC mass emitted from the engine as unburned and partially burned fuel. OMHC was calculated by adding the residual hydrocarbons (RHC) mass to the contributions of methanol (CH3OH) and formaldehyde (HCHO). The masses were each multiplied by the ratio of the molecular weight of gasoline associated with each carbon atom (13.8756) to their respective molecular weight per carbon atom.

4.2 Fuel Grade Methanol (FGM) and Diesel (D2)

Although no diesel bus emission characterization was performed in this research effort, existing data were previously acquired by West Virginia University through funding from the Department of Energy, Office of Transportation Technologies. Two sets of diesel bus data were selected for comparison with the FGM bus emission. The first set of buses, in use in Peoria, Ill., in 1996, employed Detroit Diesel 2 stroke 6V92 diesel engines (277HP DDC6V-92TA DDECII), and represent the same era of technology as the methanol buses that are the subject of the present study. The second set of buses, tested in Flint, MI, in 1997, had newer technology four stroke cycle Detroit Diesel Series 50 engines. Although these buses were not identical in weight and transmission configuration, they represented closely the same 40ft transit bus class as the methanol buses under investigation. All data discussed below were acquired using the CBD cycle.

Table 5—Triboro FGM vs. Peoria D2

	Fuel	CO	NOx	FIDHC	PM	CO2
Peoria	D2	5.3	22.9	2.8	0.9	3115
Triboro	FGM	9.6	5.1	6.9	0.24	2811

Table 5 compares the emissions from the Peoria diesel buses with the Triboro buses operated on FGM. It is evident that the methanol buses offer advantages in reducing NOx and PM, but that HC and CO emissions are higher for the methanol buses.

Table 6—Triboro FGM vs. Flint D2

	Fuel	CO	NOx	FIDHC	PM	CO2
Flint	D2	4.9	30.1	0.13	0.28	2611
Triboro	FGM	9.6	5.1	6.9	0.24	2811

Table 6 shows the comparison of the Triboro buses on FGM with the newer Flint diesel buses tested in 1997. Notice that the series 50 (275HP) buses enjoy very low hydrocarbon and PM emissions. The Methanol buses showed lower NOx emission and similar PM emission, but higher HC and CO.

5 Conclusions

Fuel grade methanol, containing small quantities of organic compounds besides the methanol, can be more economically produced than can the chemical grade methanol currently in use as a heavy-duty automotive fuel. Forty-foot transit buses, powered by Detroit Diesel 6V92 methanol fueled compression ignition engines, were subjected to emission characterization using both fuel and chemical grade methanol. Data gathered using the Central Business District test revealed that the FGM offered a slight reduction in oxides of nitrogen (NOx) produced, but an increase in hydrocarbon emissions. It is difficult to argue the cause of such changes, but the NOx emission variation might be influenced by cetane rating change and a consequent shift in the premix/diffusion burn ration. Exhaust catalyst selectivity might influence the hydrocarbon emissions. No difficulties were experienced in operating the buses on the FGM. Emission using FGM were also compared with existing data from diesel buses with Detroit Diesel 6V92 engines. The benefit of the methanol fuel in yielding particulate matter (PM) and NOx emission below those of the diesel engine was evident, but hydrocarbon emission were higher. It is concluded that the Air Products fuel grade methanol is well suited to use in alcohol fuel compression ignition engine from the standpoint of emissions benefit.

6 Reading the Short Report

The short report shows the vehicle information, vehicle engine information, emissions data in grams/mile, and fuel economy for each test run, average emissions over all test runs, and brief comments for each test in a compact format on one page. The odometer mileage reading or hub mileage reading in the short reports is rounded to the nearest 100 miles.

Symbols used in Short Report Emissions data result table:

- **a** A value was measured and identified as an apparent outlier, and therefore is not reported and not used to compute other parameters or the average values.
- **b** The residual hydrocarbon emissions (RHC) is calculated from the difference between the methanol (CH_3OH) and the FID-HC concentrations. For 100% alcohol fuels, the value of RHC is small and due to experimental variations, it may be measured as positive or negative but can best be assumed to be zero.
- **c** A value cannot be calculated because the parameters required for calculation are not available.
- **d** A value of coefficient variance (CV%) is not meaningful because the average value is too small or not available. A significant coefficient of variance may exist for PM from CNG vehicles, where the PM is at very low levels. Note that CNG PM is more than an order of magnitude less than PM usually measured from diesel vehicles. Similarly some modern diesel vehicles will yield very low hydrocarbon emissions.

Component codes used in the short report data table:

CO: Carbon monoxide in grams/mile

CO_2: Carbon dioxide in grams/mile

NO_x: Oxides of nitrogen in grams/mile

FIDHC: Total hydrocarbon measured by HFID in grams/mile. For CNG and LNG vehicle test, unburned methane is included and no HFID response factor was corrected.

PM: Particulate matter in grams/mile

CH_4: Unburned methane emissions in grams/mile

mile/gal: Calculated fuel economy in mile/gallon. For NG fueled vehicles, MPG means miles per equivalent gallon diesel. In this table, 137 cubic feet CNG at standard temperature and pressure (STP) is equivalent to 1 gallon of #1 diesel.

BTU/mile: Calculated fuel energy used by the vehicle, in BTU/mile.

Miles: Total actual driving distance for a test run

CH3OH Raw unburned methanol

HCHO Formaldehyde

OMHCE Organic Material HC Equivalent

6.1 Short Reports

Copies of the short reports from the tests conducted follow. They are organized in chronological order.

Test Sequence Number: 1097
WVU Test Reference Number: TCC-2145-M100

Fleet Owner Full Name	Triboro Coach Company
Fleet Address	85-01 24th Ave.
Fleet Address (City, State, Zip)	Jackson Heights, NY 11359
Vehicle Type	Transit Bus
Vehicle ID Number (VIN)	1TUMDTDA6PR829624
Vehicle Manufacturer	Transit Motor Corp.
Vehicle Model Year	1994
Gross Vehicle Weight (GVW) (lb.)	39500
Vehicle Total Curb Weight (lb.)	28500
Vehicle Tested Weight (lb.)	34500
Odometer Reading (mile)	10000
Transmission Type	Automatic
Transmission Configuration	3-Speed
Number of Axles	2
Engine Type	Detroit Diesel Corp. 6V-92TA
Engine ID Number	06VF204716
Engine Displacement (Liter)	9.05
Number of Cylinders	6
Engine Rated Power (hp)	253
Primary Fuel	M100
Test Cycle	CBD
Test Date	4/24/98
Engineer	J. Boyce
Driver	L. McGrath

Emissions Results (g/mile) **Fuel Economy**

Run Seq. No.	CO	NO_x	FIDHC	PM	CO_2	mile/gal	BTU/mile	Miles
1097-1	5.70	4.69	2.16	0.125	2429	1.69	33789	2.02
1097-2	5.53	4.55	2.04	0.094	2367	1.73	32916	1.99
1097-3	6.15	4.63	2.25	0.075	2381	1.72	33127	2.00
1097-4	5.93	4.59	2.22	0.063	2350	1.74	32693	1.98
1097 Average	5.83	4.62	2.17	0.089	2382	1.72	33131	2.00
Std. Dev.	0.27	0.06	0.09	0.027	34	0.02	473	0.02
CV%	4.6	1.2	4.3	30.4	1.4	1.4	1.4	0.8

Run Seq. No.	CH_3OH	HCHO	CH_3CHO	RHC	OMHCE
1097-1	2.84	1.38	0.00	b	0.43
1097-2	2.46	1.34	0.00	b	0.38
1097-3	2.68	1.36	0.00	b	0.54
1097-4	2.64	1.31	0.00	b	1.80

Test Sequence Number: 1099
WVU Test Reference Number: TCC-2145-M100-FGM

Fleet Owner Full Name	Triboro Coach Company
Fleet Address	85-01 24th Ave.
Fleet Address (City, State, Zip)	Jackson Heights, NY 11359
Vehicle Type	Transit Bus
Vehicle ID Number (VIN)	1TUMDTDA6PR829624
Vehicle Manufacturer	Transit Motor Corp.
Vehicle Model Year	1994
Gross Vehicle Weight (GVW) (lb.)	39500
Vehicle Total Curb Weight (lb.)	28500
Vehicle Tested Weight (lb.)	34500
Odometer Reading (mile)	10000
Transmission Type	Automatic
Transmission Configuration	3-Speed
Number of Axles	2
Engine Type	Detroit Diesel Corp. 6V-92TA
Engine ID Number	06VF204716
Engine Displacement (Liter)	9.05
Number of Cylinders	6
Engine Rated Power (hp)	253
Primary Fuel	M100
Test Cycle	CBD
Test Date	4/27/98
Engineer	J. Boyce
Driver	L. McGrath

Emissions Results (g/mile) **Fuel Economy**

Run Seq. No.	CO	NO_x	FIDHC	PM	CO_2	mile/gal	BTU/mile	Miles
1099-1	4.87	3.50	3.93	0.12	2510	1.63	34883	1.99
1099-2	3.77	3.46	3.96	0.11	2484	1.65	34496	2.00
1099-3	3.78	3.48	4.48	0.12	2497	1.64	34685	1.99
1099-4	3.64	3.44	4.04	0.11	2466	1.66	34248	1.99
1099 Average	4.01	3.47	4.10	0.11	2489	1.65	34578	1.99
Std. Dev.	0.57	0.03	0.25	0.01	19	0.01	271	0.00
CV%	14.3	0.7	6.2	4.9	0.8	0.8	0.8	0.2

Run Seq. No.	CH_3OH	HCHO	CH_3CHO	RHC	OMHCE
1099-1	3.86	2.00	0.01	b	2.97
1099-2	3.74	1.89	0.01	b	2.92
1099-3	4.81	2.16	0.01	b	3.36
1099-4	4.24	2.06	0.01	b	3.08
[illegible]	[illegible]	[illegible]	[illegible]		[illegible]

Test Sequence Number: 1101
WVU Test Reference Number: TCC-2139-M100

Fleet Owner Full Name	Triboro Coach Company
Fleet Address	85-01 24th Ave.
Fleet Address (City, State, Zip)	Jackson Heights, NY 11359
Vehicle Type	Transit Bus
Vehicle ID Number (VIN)	1TUMDTDA0PR629618
Vehicle Manufacturer	Transit Motor Corp.
Vehicle Model Year	1993
Gross Vehicle Weight (GVW) (lb.)	39500
Vehicle Total Curb Weight (lb.)	28500
Vehicle Tested Weight (lb.)	34500
Odometer Reading (mile)	69000
Transmission Type	Automatic
Transmission Configuration	3-Speed
Number of Axles	2
Engine Type	Detroit Diesel Corp. 6V-92TA
Engine ID Number	06VF204716
Engine Displacement (Liter)	9.05
Number of Cylinders	6
Engine Rated Power (hp)	253
Primary Fuel	M100
Test Cycle	CBD
Test Date	4/28/98
Engineer	J. Boyce
Driver	L. McGrath

Emissions Results (g/mile) **Fuel Economy**

Run Seq. No.	CO	NO_x	FIDHC	PM	CO_2	mile/gal	BTU/mile	Miles
1101-1	12.7	6.64	4.93	0.082	3056	1.34	42617	2.04
1101-2	13.0	6.56	5.48	0.088	3013	1.36	42038	2.05
1101-3	13.1	6.57	5.31	0.105	3050	1.34	42545	2.02
1101-4	12.9	6.57	5.30	0.101	2977	1.37	41532	2.04
1101-5	12.9	6.71	5.38	0.104	2971	1.38	41444	2.02
1101 Average	12.9	6.61	5.28	0.096	3013	1.36	42035	2.03
Std. Dev.	0.1	0.06	0.21	0.010	40	0.02	548	0.01
CV%	1.1	1.0	3.9	10.9	1.3	1.3	1.3	0.5

Run Seq. No.	CH_3OH	HCHO	CH_3CHO	RHC	OMHCE
1101-1	5.48	0.93	0.01	b	3.05
1101-2	6.48	a	0.01	b	C
1101-3	6.25	1.23	0.00	b	3.42
1101-4	6.30	1.23	0.01	b	3.42
1101-5	6.35	1.28	0.01	b	3.48
1101 Average	6.17	1.17	0.00	c	3.34
Std. Dev.	0.40	0.16	0.00	c	0.20
CV%	6.4	13.6	d	d	5.9

Test Purpose:
Testing vehicle on chemical grade (currently used) of methanol for comparison to fuel grade methanol.

Test Sequence Number: 1103
WVU Test Reference Number: TCC-2139-M100-FGM

Fleet Owner Full Name	Triboro Coach Company
Fleet Address	85-01 24th Ave.
Fleet Address (City, State, Zip)	Jackson Heights, NY 11359
Vehicle Type	Transit Bus
Vehicle ID Number (VIN)	1TUMDTDA0PR829618
Vehicle Manufacturer	Transit Motor Corp.
Vehicle Model Year	1993
Gross Vehicle Weight (GVW) (lb.)	39500
Vehicle Total Curb Weight (lb.)	28500
Vehicle Tested Weight (lb.)	34500
Odometer Reading (mile)	69000
Transmission Type	Automatic
Transmission Configuration	3-Speed
Number of Axles	2
Engine Type	Detroit Diesel Corp. 6V-92TA
Engine ID Number	06VF204716
Engine Displacement (Liter)	9.05
Number of Cylinders	6
Engine Rated Power (hp)	253
Primary Fuel	M100
Test Cycle	CBD
Test Date	4/29/98
Engineer	J. Boyce
Driver	L. McGrath

Emissions Results (g/mile) **Fuel Economy**

Run Seq No	CO	NO_x	FIDHC	PM	CO_2	mile/gal	BTU/mile	Miles
1103-1	11.5	6.12	5.81	0.12	3019	1.35	42080	2.02
1103-2	12.7	6.40	5.69	0.12	3014	1.36	42041	2.02
1103-3	12.4	6.24	5.53	0.12	2908	1.41	40560	2.04
1103-4	11.3	6.21	5.43	0.13	2920	1.40	40714	2.03
1103-5	11.2	6.22	5.31	0.13	2902	1.41	40461	2.03
1103 Average	11.8	6.24	5.55	0.12	2953	1.38	41171	2.03
Std. Dev.	0.7	0.10	0.20	0.01	59	0.03	817	0.01
CV%	5.6	1.6	3.6	4.5	2.0	2.0	2.0	0.5

Run Seq No	CH_3OH	HCHO	CH_3CHO	RHC	OMHCE
1103-1	6.68	1.51	0.01	b	3.80
1103-2	6.33	1.49	0.01	b	3.71
1103-3	5.37	1.48	0.01	b	3.55
1103-4	5.82	1.36	0.01	b	3.49
1103-5	6.04	1.22	0.01	b	3.40
1103 Average	6.05	1.41	0.01	c	3.59
Std. Dev.	0.50	0.12	0.00	c	0.16
CV%	8.3	8.5	d	d	4.6

Test Purpose:

testing of fuel grade methanol to compare with chemical grade methanol

Special Procedures:

Pumping fuel from 55 gal drum in place of 175 gal fuel tank. Restriction made from stainless whitey valve. Fuel pressure set at 90 psi at idle

Test Sequence Number: 1105
WVU Test Reference Number: TCC-2143-M100-FGM

Fleet Owner Full Name	Triboro Coach Company
Fleet Address	85-01 24th Ave.
Fleet Address (City, State, Zip)	Jackson Heights, NY 11359
Vehicle Type	Transit Bus
Vehicle ID Number (VIN)	1TUMDTDA2PR829622
Vehicle Manufacturer	Transit Motor Corp.
Vehicle Model Year	1993
Gross Vehicle Weight (GVW) (lb.)	39500
Vehicle Total Curb Weight (lb.)	28500
Vehicle Tested Weight (lb.)	34500
Odometer Reading (mile)	88800
Transmission Type	Automatic
Transmission Configuration	3-Speed
Number of Axles	2
Engine Type	Detroit Diesel Corp. 6V-92LH
Engine ID Number	06VF204696
Engine Displacement (Liter)	9.05
Number of Cylinders	6
Engine Rated Power (hp)	253
Primary Fuel	M100
Test Cycle	CBD
Test Date	4/29/98
Engineer	J. Boyce
Driver	L. McGrath

Emissions Results (g/mile) / **Fuel Economy**

Run Seq. No.	CO	NO_x	FIDHC	PM	CO_2	mile/gal	BTU/mile	Miles
1105-1	12.9	5.63	9.9	0.51	2997	1.36	41810	2.00
1105-2	12.9	5.71	11.6	0.47	3009	1.36	41979	1.99
1105-3	13.1	5.58	11.8	0.46	3018	1.35	42099	1.98
1105-4	12.9	5.60	11.0	0.48	2962	1.38	41322	1.98
1105-5	13.2	5.63	10.5	0.51	2976	1.37	41530	2.00
1105 Average	13.0	5.63	11.0	0.49	2992	1.37	41748	1.99
Std. Dev.	0.1	0.05	0.8	0.02	23	0.01	320	0.01
CV%	0.9	0.9	7.1	4.8	0.8	0.8	0.8	0.5

Run Seq. No.	CH_3OH	HCHO	CH_3CHO	RHC	OMHCE
1105-1	10.11	1.19	0.02	b	5.74
1105-2	13.76	1.58	0.02	b	6.96
1105-3	14.26	1.47	0.02	b	7.04
1105-4	14.52	1.50	0.02	b	6.74
1105-5	17.30	1.42	0.02	b	6.71
1105 Average	13.99	1.44	0.02	c	6.64
Std. Dev.	2.57	0.15	0.00	c	0.52
CV%	18.4	10.2	7.0	d	7.9

Test Purpose:
testing of fuel grade methanol to compare with chemical grade methanol

Special Procedures:
Pumping fuel from 55 gal drum in place of 175 gal fuel tank. Restriction made from stainless whitey valve. Fuel pressure set at 90 psi at idle

Test Sequence Number: 1106
WVU Test Reference Number: TCC-2143-M100

Fleet Owner Full Name	Triboro Coach Company
Fleet Address	85-01 24th Ave.
Fleet Address (City, State, Zip)	Jackson Heights, NY 11359
Vehicle Type	Transit Bus
Vehicle ID Number (VIN)	1TUMDTDA2PR829622
Vehicle Manufacturer	Transit Motor Corp.
Vehicle Model Year	1993
Gross Vehicle Weight (GVW) (lb.)	39500
Vehicle Total Curb Weight (lb.)	28500
Vehicle Tested Weight (lb.)	34500
Odometer Reading (mile)	88800
Transmission Type	Automatic
Transmission Configuration	3-Speed
Number of Axles	2
Engine Type	Detroit Diesel Corp. 6V-92LH
Engine ID Number	06VF204696
Engine Displacement (Liter)	9.05
Number of Cylinders	6
Engine Rated Power (hp)	253
Primary Fuel	M100
Test Cycle	CBD
Test Date	4/30/98
Engineer	J. Boyce
Driver	L. McGrath

Emissions Results (g/mile) / **Fuel Economy**

Run Seq. No	CO	NO_x	FIDHC	PM	CO_2	mile/gal	BTU/mile	Miles
1106-1	12.8	5.64	10.11	0.41	2997	1.36	41806	2.00
1106-2	12.9	5.61	9.53	0.39	2944	1.39	41080	1.99
1106-5	12.7	5.57	8.00	0.47	2904	1.41	40516	2.01
1106-6	11.9	5.41	7.95	0.47	2892	1.41	40330	2.01
1106-7	12.0	5.55	7.96	0.48	2879	1.42	40159	2.00
1106 Average	12.5	5.56	8.71	0.44	2923	1.40	40778	2.00
Std. Dev.	0.5	0.09	1.04	0.04	48	0.02	671	0.01
CV%	3.9	1.6	11.9	9.4	1.6	1.6	1.6	0.4

Run Seq. No	CH_3OH	HCHO	CH_3CHO	RHC	OMHCE
1106-1	11.98	1.53	0.01	b	6.14
1106-2	10.60	a	0.01	b	C
1106-5	9.02	1.30	0.02	b	4.86
1106-6	8.84	1.18	0.01	b	4.76
1106-7	8.76	1.38	0.01	b	4.86
1106 Average	9.84	1.35	0.01	c	5.16
Std. Dev.	1.41	0.15	0.00	c	0.66
CV%	14.4	11.0	d	d	12.8

Test Purpose:
Testing vehicle on chemical grade (currently used) of methanol for comparison to fuel grade methanol.

Test Sequence Number: 1107
WVU Test Reference Number: TCC-2143-M100-5MILES

Fleet Owner Full Name	Triboro Coach Company
Fleet Address	85-01 24th Ave.
Fleet Address (City, State, Zip)	Jackson Heights, NY 11359
Vehicle Type	Transit Bus
Vehicle ID Number (VIN)	1TUMDTDA2PR829622
Vehicle Manufacturer	Transit Motor Corp.
Vehicle Model Year	1993
Gross Vehicle Weight (GVW) (lb.)	39500
Vehicle Total Curb Weight (lb.)	28500
Vehicle Tested Weight (lb.)	34500
Odometer Reading (mile)	88800
Transmission Type	Automatic
Transmission Configuration	3-Speed
Number of Axles	2
Engine Type	Detroit Diesel Corp. 6V-92LH
Engine ID Number	06VF204696
Engine Displacement (Liter)	9.05
Number of Cylinders	6
Engine Rated Power (hp)	253
Primary Fuel	M100
Test Cycle	5 Mile Route
Test Date	4/30/98
Engineer	J. Boyce
Driver	L. McGrath

Emissions Results (g/mile) / **Fuel Economy**

Run Seq. No.	CO	NO_x	FIDHC	PM	CO_2	mile/gal	BTU/mile	Miles
1107-2	11.7	3.45	50.1	0.40	1962	2.08	27444	5.01
1107-3	11.8	3.49	50.4	0.39	1965	2.07	27492	5.01
1107-4	11.8	3.46	52.8	0.38	1959	2.08	27406	5.01
1107 Average	11.8	3.47	51.1	0.39	1962	2.08	27447	5.01
Std. Dev.	0.1	0.02	1.5	0.01	3	0.00	43	0.00
CV%	0.5	0.6	2.9	1.4	0.2	0.2	0.2	0.0

Run Seq. No.	CH_3OH	HCHO	CH_3CHO	RHC	OMHCE
1107-2	73.89	2.61	0.00	b	29.36
1107-3	65.23	2.52	0.00	b	28.70
1107-4	74.44	2.50	0.00	b	30.54
1107 Average	71.19	2.54	0.00	c	29.53
Std. Dev.	5.17	0.06	0.00	c	0.93
CV%	7.3	2.3	d	d	3.2

Test Purpose:

Testing vehicle on chemical grade (currently used) of methanol for comparison to fuel grade methanol.

Test Sequence Number: 1109
WVU Test Reference Number: TCC-2143-M100-5MILES-FGM

Fleet Owner Full Name	Triboro Coach Company
Fleet Address	85-01 24th Ave.
Fleet Address (City, State, Zip)	Jackson Heights, NY 11359
Vehicle Type	Transit Bus
Vehicle ID Number (VIN)	1TUMDTDA2PR829622
Vehicle Manufacturer	Transit Motor Corp.
Vehicle Model Year	1993
Gross Vehicle Weight (GVW) (lb.)	39500
Vehicle Total Curb Weight (lb.)	28500
Vehicle Tested Weight (lb.)	34500
Odometer Reading (mile)	88800
Transmission Type	Automatic
Transmission Configuration	3-Speed
Number of Axles	2
Engine Type	Detroit Diesel Corp. 6V-92LH
Engine ID Number	06VF204696
Engine Displacement (Liter)	9.05
Number of Cylinders	6
Engine Rated Power (hp)	253
Primary Fuel	M100
Test Cycle	5 Mile Route
Test Date	5/1/98
Engineer	J. Boyce
Driver	L. McGrath

Emissions Results (g/mile) / **Fuel Economy**

Run Seq No	CO	NO_x	FIDHC	PM	CO_2	mile/gal	BTU/mile	Miles
1109-1	15.5	3.56	55.9	0.53	1994	2.04	27964	5.01
1109-2	16.5	3.57	57.0	0.54	1978	2.05	27762	5.01
1109-3	15.2	3.45	51.5	0.51	1925	2.11	27000	5.02
1109 Average	15.7	3.53	54.8	0.52	1965	2.07	27575	5.02
Std. Dev.	0.7	0.07	2.9	0.02	36	0.04	508	0.01
CV%	4.2	1.9	5.4	3.3	1.8	1.9	1.8	0.2

Run Seq No	CH_3OH	HCHO	CH_3CHO	RHC	OMHCE
1109-1	73.74	2.36	0.01	b	31.76
1109-2	67.97	2.43	0.01	b	31.80
1109-3	73.84	a	0.00	b	C
1109 Average	71.85	2.40	0.00	c	31.78
Std. Dev.	3.36	0.05	0.00	c	0.03
CV%	4.7	2.0	d	d	0.1

Test Purpose:
testing of fuel grade methanol to compare with chemical grade methanol

Special Procedures:
Pumping fuel from 55 gal drum in place of 175 gal fuel tank. Restriction made from stainless whitey valve. Fuel pressure set at 90 psi at idle