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Laidlaw Bus Field Trial of
of FPC-1 Fuel Performance Catalyst

Test conducted for Laidlaw Bus
by
UHI Corporation
Provo, Utah
and
FPC Great Lakes
Valders, Wisconsin

May 23, 1996

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Abstract

This paper discusses the results of a field test conducted by Laidlaw Bus, Green Bay, Wisconsin, under the direction of Mr. David Van Pay, Fleet Manager, to determine the economic and environmental benefits from fuel treatment with a unique combustion catalyst called FPC-1. The study conducted on a fleet of DT 466, 7.3 International, 6.2 GM, DTA 360 International, and 8.2 Detroit diesel powered buses documented the following:

(1) All test buses realized reductions in fuel consumption after FPC-1 fuel treatment. With anomalies removed, the fleet averaged a 10.89% reduction in fuel consumption.

(2) FPC-1 treated fuel combusted more completely than the standard diesel. Carbon monoxide emissions were reduced 27.10% on a fleet average basis.

(3) Smoke density was reduced 45.10% after FPC-1 fuel treatment.

These results verify substantial fuel cost savings and environmental benefit can be derived from FPC-1 use throughout the entire Laidlaw Bus fleet operation. **The value of the improved emissions quality of the exhaust gases cannot be overstated for a transit bus operation.** Remarkable, but typical reductions in carbon monoxide and smoke emissions, seen in this study, are basically provided by FPC-1 fuel treatment with no sacrifice in operation cost.

The paper also discusses a unique, recognized test method for determining the benefits of FPC-1 in the field. The method is known as the carbon mass balance, which is central to the EPA standardized Federal Test Procedures and Highway Fuel Economy Test. The method uses exhaust gas analysis under steady-state engine operation to determine both fuel consumption and exhaust emissions.

I. Introduction

FPC-1 Fuel Performance Catalyst is a burn rate modifier or catalyst, proven to reduce fuel consumption and increase engine horsepower in several recognized, independent laboratory tests, and dozens of independent field trials. The catalyst also has a remarkable impact upon the products of incomplete combustion that are regulated by emissions reduction legislation (smoke and carbon monoxide).

The intent of the trial by Laidlaw Bus was to determine the degree of fuel consumption, and emissions reduction resulting from the addition of the FPC-1 catalyst to the blended diesel fueling a select fleet of compression-ignition engine powered buses. The test methodology for determining fuel consumption is the carbon mass balance (cmb). The cmb method measures the carbon containing products of the combustion process (CO2, CO, HC) found in the exhaust, rather than directly measuring fuel flow into the engine. Also, while conducting the cmb procedure, a Bacharach Smoke Spot method is used to determine smoke density in the exhaust of the diesel powered equipment.

This report summarizes the results of baseline and FPC-1 treated fuel consumption and emissions data, and computes and compares the mass flow rates (engine performance factors or PFs) for the same.

II. Discussion of Carbon Mass Balance Method

The carbon mass balance eliminates virtually all of the variables associated with field testing for fuel consumption changes. The method requires no modifications to fuel lines or engines, and can be conducted in a short period of time at minimal expense.

Instead of measuring fuel flow into the engine (ie., the weight or volume of the fuel), measurements are made of the exhaust gases leaving the engine. More precisely, the carbon containing gases in the exhaust are measured. The method is based upon the Law of Conservation of Matter, which states that atoms can neither be created nor destroyed. Since the engines only source of carbon is the fuel it consumes, the carbon measured in the exhaust must come from the fuel. By measuring the carbon going out of the engine in the form of products of combustion, the amount of carbon entering the engine can be determined.

Carbon Balance Calculation

The carbon leaving the engine is mainly as carbon dioxide (CO2), carbon monoxide (CO), unburned hydrocarbons (HC), and particulate (smoke). By collecting this data while the engine is operating at a given load and speed, the fuel flow rate into the engine can be accurately determined. When engine load and speed, along with other factors influencing fuel consumption are reproduced and/or monitored to make appropriate corrections, the carbon balance can be used to confidently determine changes in fuel consumption that might result from the use of a fuel catalyst, such as FPC-1.

With the carbon balance, engine efficiency is expressed in terms of engine performance factors. To calculate any change in engine performance, separate measurements are made with the engine running on base fuel (untreated) and FPC-1 treated fuel. Any changes are stated as percentage changes from the baseline.

A copy of the carbon balance equations is found on Figure 1 (Appendix 5). A sample calculation for illustration purposes is also attached (see Figure 2, Appendix 5). Additionally, the carbon balance can be used to determine the effect of FPC-1 upon harmful emissions, such as carbon monoxide and smoke.

III. Instrumentation

Precision, state-of-the-art instrumentation is used to measure the concentrations of carbon containing gases in the exhaust stream and other factors related to fuel consumption and engine performance. The instruments and their purposes are listed below:

1) A Sun Electric SGA-9000 non-dispersive infrared (NDIR) four gas analyzer - measures the volume percent of CO2, CO, and oxygen (O2) in the exhaust, and the parts per million (ppm) of HC.

2) EPA I/M Calibration Gases - known gases used internally to calibrate the NDIR analyzer.

3) A twenty (20) foot sampling train and stainless steel exhaust gas probe - inserted into the engine exhaust pipe draws a sample of exhaust gases to the analyzer.

4) A Fluke Model 52 hand held digital thermometer and wet/dry thermocouple probe - measures exhaust, ambient, and fuel temperature.

5) A Dwyer Magnehelic 2000 Series Pressure Gauge and pitot tube - measures exhaust air velocity and/or pressure.

6) A Monarch Contact/Noncontact digital tachometer and magnetic tape - measures engine rpm when dash mounted tachometers are unavailable.

7) A hydrometer and flask - determines fuel specific gravity (density).

8) Barometric pressure is acquired from local airport or weather station.

9) A Bacharach Truespot Smokemeter - for smoke density determination.

Except for engine speed, fuel density, and ambient readings, all data are collected by simply inserting probes into the exhaust stream while the engine is running at a fixed rpm and load, and the vehicle is stationary. No modifications or device installations are made to the fuel system, nor are normal equipment work cycles disrupted.

IV. Technical Approach

The following technical approach was observed during both test segments:

1) All instruments are calibrated according to accepted protocol.

2) A sample of fuel is drawn from the fuel tank on each piece of equipment. Using a hydrometer and wet/dry temperature probe, fuel specific gravity and temperature are recorded.

3) Each piece of equipment to be tested is parked, brakes locked, and run out-of-gear at a specific engine speed (RPM) until engine water, oil, and exhaust temperature, and exhaust pressure have stabilized. Engine speed is controlled using either a hand held phototach, or the tachometer in the cab, and either a Snap-On throttle lock, a high idle switch, or the programmable computer onboard the truck or bus.

4) Engine hours (or mileage) are taken from hour meters or odometers installed on the equipment.

5) After engine stabilization, the exhaust gas sampling probe is inserted into the exhaust stream. The Autocal button is depressed and after the LED readouts clear, test personnel take multiple readings of carbon dioxide, carbon monoxide, unburned hydrocarbons, and oxygen, along with engine speed, exhaust temperature and pressure. Smoke readings are taken on the diesel engines after exhaust gas testing.

6) Periodically, ambient air temperature, atmospheric pressure, and relative humidity are recorded. Temperature readings are taken at the test site. Other ambient readings are acquired from local weather information services.

7) All data are recorded until technicians are confident the information is consistent and reproducible.

8) After completing the baseline, the test fleet fuel was treated with FPC-1. All equipment operated as normal for approximately 400 to 500 hours, at which time the above procedure was reproduced without alteration, except FPC-1 fuel treatment in the test fleet.

V. Discussion

The data collected during the tests are summarized on the attached computer printouts (Appendix 1). From these data the volume fraction (VF) of each gas is determined and the average molecular weight (Mwt) of the exhaust gases computed. Next, the engine performance factor (pf) based upon the carbon mass in the exhaust is computed. The pf is finally corrected for intake air temperature and pressure (barometric), and total exhaust mass yielding a corrected engine performance factor (PF). The PFs for the diesel engines are tabulated on Table 1 of Appendix 3. The carbon monoxide percentages on tabulated on Table 2 of Appendix 3. The smoke spot (smoke density) numbers for the diesel engines are found on Table 3 of Appendix 3.

Anomalies and Fleet Exclusions

All buses tested saw significant reductions in fuel consumption, and harmful emissions. Unit Number 584 experienced an abnormally large change in fuel consumption. This change is beyond the influence of the FPC-1 fuel catalyst alone, and therefore, other factors had to have contributed to the overall change. Without knowing the exact cause of the large improvement, it is impossible to make a correction, therefore, UHI feels the unit must be removed from consideration and not included in the conclusions for this study.

With this anomaly removed, the diesel fleet averaged a 10.89% reduction in fuel consumption after FPC-1 fuel treatment. Carbon monoxide and smoke, both regulated emissions, were reduced 27.1% and 45.1%, respectively, after removal of the anomaly. The results for each unit tested are tabled on Tables 1, 2, and 3 in Appendix 3.

The Effect of Environmental Conditions

Environmental conditions can have an impact upon engine performance and therefore, emissions reductions. For this reason, UHI technicians monitored ambient pressure and temperature, so correction factors can be applied to the calculation of exhaust gas flow rates.

VI. Conclusions

(1) The addition of FPC-1 to the diesel fleet created a 10.89% reduction in fuel consumption.

(2) Carbon monoxide emissions were reduced 27.1% on a fleet average basis.

(3) Smoke density was reduced 45.1% after FPC-1 fuel treatment.

APPENDIX 1

Company Name:	Laidlaw	*Location*	Green Bay, WI		*Date:*	3/27/96
Test Portion:	Baseline	*Stack Diam.*	2	Inches		
Engine Type:	6.2 GM	*Mile/Hrs*	46412			
Equipment Type:	School Bus	*ID #:*	1249		*Baro*	30.54
Fuel Sp. Gravity(SG	.865	*Temp:*				
					Time:	1:10PM

RPM	Exh Temp	Pv Inch	CO	HC	CO2	O2	
1620	206.8	2.7	0.07	22	2.02	18.4	
1620	208.8	2.7	0.07	22	2.01	18.4	
1620	210.4	2.7	0.07	22	2.01	18.4	
1620	211.4	2.7	0.07	22	2.01	18.4	
1620	211.8	2.7	0.07	22	2.01	18.4	
1620	212.6	2.7	0.07	22	2.01	18.4	
1620	213.4	2.7	0.07	22	2.01	18.4	
1620.000	**210.743**	**2.700**	**.070**	**22.000**	**2.011**	**18.400**	Mean
0	**2.291**	**.000**	**.000**	**.000**	**.004**	**.000**	Std Dev

VFHC	**VFCO**	**VFCO2**	**VFO2**	**Mtw1**	**pf1**	**PF1**
2.20E-05	0.0007	.020	.184	29.059	309,452	1,297,999

Company Name:	Laidlaw	*Location:*	Green Bay, WI		*Test Date:*	5/23/96
Test Portion:	Treated	*Stack Diam:*	2	Inches		
Engine Type:	6.2 GM	*Mile/Hrs:*	48993			
Equipment Type	School Bus	*ID #:*	1249		*Baro:*	29.94
Fuel Sp. Gravity:	.865	*Temp:*	55			
SG Corr Factor:	1.000				*Time:*	11:25

RPM	Exh Temp	Pv Inch	CO	HC	CO2	O2	
1620	208.2	2.7	0.04	16	1.9	18.5	
1620	207.4	2.7	0.04	15	1.9	18.4	
1620	207	2.7	0.04	15	1.9	18.4	
1620	206.8	2.7	0.04	15	1.89	18.4	
1620	206.4	2.7	0.04	15	1.89	18.4	
1620	206.4	2.7	0.04	15	1.89	18.4	
1620.000	**207.033**	**2.700**	**.040**	**15.167**	**1.895**	**18.417**	Mean
0	**.686**	**.000**	**.000**	**.408**	**.005**	**.041**	Std Dev

VFHC	**VFCO**	**VFCO2**	**VFO2**	**Mtw2**	**pf2**	**PF2**
1.52E-05	0.0004	.019	.184	29.041	333,238	1,380,141

Performance factor adjusted for fuel density: 1,380,141

****% Change PF= 6.33** %

*** A positive change in PF equates to a reduction in fuel consumption.*

Company Name:	Laidlaw	*Location:*	Green Bay, WI		*Date:*	3/27/96
Test Portion:	Baseline	*Stack Diam.*	4	Inches		
Engine Type:	7.3 Intern'l	*Mile/Hrs*	73361			
Equipment Type:	School Bus	*ID #:*	586		*Baro*	30.52
Fuel Sp. Gravity(SG	.865	*Temp:*				
					Time:	11:50

RPM	Exh Temp	Pv Inch	CO	HC	CO2	O2	
1800	154.6	0.54	0.03	15	1.6	18.8	
1800	153.4	0.54	0.03	15	1.59	18.8	
1800	154.8	0.54	0.03	15	1.58	18.9	
1800	155.4	0.54	0.03	15	1.59	18.9	
1800	155.8	0.54	0.03	15	1.59	18.9	
1800.000	**154.800**	**.540**	**.030**	**15.000**	**1.590**	**18.860**	Mean
0	**.917**	**.000**	**.000**	**.000**	**.007**	**.055**	Std Dev

VFHC	VFCO	VFCO2	VFO2	Mtw1	pf1	PF1
1.50E-05	0.0003	.016	.189	29.010	397,248	891,488

Company Name:	Laidlaw	*Location:*	Green Bay, WI		*Test Date:*	
Test Portion:	Treated	*Stack Diam:*	4	Inches		
Engine Type:	7.3 Intern'l	*Mile/Hrs:*	75067			
Equipment Type	School Bus	*ID #:*	586		*Baro:*	29.93
Fuel Sp. Gravity:	.865	*Temp:*	53			
SG Corr Factor:	1.000				*Time:*	10:20

RPM	Exh Temp	Pv Inch	CO	HC	CO2	O2	
1800	164.4	0.54	0.03	13	1.44	19	
1800	165.2	0.54	0.03	13	1.44	19	
1800	167.2	0.54	0.03	15	1.48	19	
1800	168.4	0.54	0.03	15	1.48	19	
1800	170.2	0.54	0.03	15	1.46	19	
1800.000	**167.080**	**.540**	**.030**	**14.200**	**1.460**	**19.000**	Mean
0	**2.356**	**.000**	**.000**	**1.095**	**.020**	**.000**	Std Dev

VFHC	VFCO	VFCO2	VFO2	Mtw2	pf2	PF2
1.42E-05	0.0003	.015	.190	28.994	431,606	968,716

Performance factor adjusted for fuel density: 968,716

****% Change PF= 8.66 %**

***** A positive change in PF equates to a reduction in fuel consumption.***

Company Name:	Laidlaw	*Location:*	Green Bay, WI		*Date:*	3/27/96
Test Portion:	Baseline	*Stack Diam.*	4	Inches		
Engine Type:	7.3 Intn'l	*Mile/Hrs*	68040			
Equipment Type:	School Bus	*ID #:*	43		*Baro*	30.52
Fuel Sp. Gravity(SG	.865	*Temp:*				
					Time:	12:10pm

RPM	Exh Temp	Pv Inch	CO	HC	CO2	O2	
1500	156.4	0.8	0.05	15	1.91	18.5	
1500	157	0.8	0.05	13	1.91	18.4	
1500	158.2	0.8	0.05	15	1.9	18.4	
1500	159	0.8	0.05	15	1.9	18.4	
1500	160.6	0.8	0.05	15	1.9	18.4	
1500	160.4	0.8	0.05	15	1.9	18.4	
1500.000	**158.600**	**.800**	**.050**	**14.667**	**1.903**	**18.417**	Mean
0	**1.730**	**.000**	**.000**	**.816**	**.005**	**.041**	Std Dev

VFHC	**VFCO**	**VFCO2**	**VFO2**	**Mtw1**	**pf1**	**PF1**
1.47E-05	0.0005	.019	.184	29.042	330,195	610,679

Company Name:	Laidlaw	*Location:*	Green Bay, WI		*Test Date:*	
Test Portion:	Treated	*Stack Diam:*	4	Inches		
Engine Type:	7.3 Intn'l	*Mile/Hrs:*	70777			
Equipment Type	School Bus	*ID #:*	43		*Baro:*	29.93
Fuel Sp. Gravity:	.860	*Temp:*	54			
SG Corr Factor:	1.006				*Time:*	10:30

RPM	Exh Temp	Pv Inch	CO	HC	CO2	O2	
1500	166.4	0.8	0.04	15	1.72	18.7	
1500	166.2	0.8	0.04	15	1.71	18.7	
1500	166.2	0.8	0.04	15	1.72	18.7	
1500	166	0.8	0.04	15	1.72	18.7	
1500.000	**166.200**	**.800**	**.040**	**15.000**	**1.718**	**18.700**	Mean
0	**.163**	**.000**	**.000**	**.000**	**.005**	**.000**	Std Dev

VFHC	**VFCO**	**VFCO2**	**VFO2**	**Mtw2**	**pf2**	**PF2**
1.50E-05	0.0004	.017	.187	29.024	366,515	675,379

Performance factor adjusted for fuel density: 679,283

****% Change PF= 11.23 %**

***** A positive change in PF equates to a reduction in fuel consumption.***

Company Name:	Laidlaw	*Location*	Green Bay, WI		*Date:*	3/27/96
Test Portion:	Baseline	*Stack Diam.*	4	Inches		
Engine Type:	DT 466	*Mile/Hrs*	1815			
Equipment Type:	School Bus	*ID #:*	1299		*Baro*	30.52
Fuel Sp. Gravity(SG	.865	*Temp:*				
					Time:	11:27am

RPM	Exh Temp	Pv Inch	CO	HC	CO2	O2	
1800	198.6	0.8	0.06	17	1.74	18.7	
1800	199.9	0.8	0.06	17	1.72	18.7	
1800	208.4	0.8	0.06	16	1.71	18.7	
1800	208.8	0.8	0.06	17	1.73	18.7	
1800.000	**203.925**	**.800**	**.060**	**16.750**	**1.725**	**18.700**	Mean
0	**5.427**	**.000**	**.000**	**.500**	**.013**	**.000**	Std Dev

VFHC	VFCO	VFCO2	VFO2	Mtw1	pf1	PF1
1.68E-05	0.0006	.017	.187	29.025	360,690	691,085

Company Name:	Laidlaw	*Location:*	Green Bay, WI		*Test Date:*	
Test Portion:	Treated	*Stack Diam:*	4	Inches		
Engine Type:	DT 466	*Mile/Hrs:*	39725			
Equipment Type	School Bus	*ID #:*	1299		*Baro:*	29.93
Fuel Sp. Gravity:	.865	*Temp:*	53			
SG Corr Factor:	1.000				*Time:*	10:30

RPM	Exh Temp	Pv Inch	CO	HC	CO2	O2	
1800	227	0.8	0.06	15	1.52	18.9	
1800	227.2	0.8	0.05	15	1.53	18.9	
1800	227.2	0.8	0.05	15	1.54	18.9	
1800	227.6	0.8	0.05	15	1.53	18.9	
1800	228	0.8	0.06	15	1.51	19	
1800.000	**227.400**	**.800**	**.054**	**15.000**	**1.526**	**18.920**	Mean
0	**.400**	**.000**	**.005**	**.000**	**.011**	**.045**	Std Dev

VFHC	VFCO	VFCO2	VFO2	Mtw2	pf2	PF2
1.50E-05	0.00054	.015	.189	29.002	407,134	786,035

Performance factor adjusted for fuel density: 786,035

****% Change PF= 13.74 %**

*** A positive change in PF equates to a reduction in fuel consumption.*

Company Name:	Laidlaw	***Location***	Green Bay, WI		***Date:***	3/27/96
Test Portion:	Baseline	***Stack Diam.***	4	Inches		
Engine Type:	DT 466	***Mile/Hrs***	21683			
Equipment Type:	School Bus	***ID #:***	1358		***Baro***	30.52
Fuel Sp. Gravity(SG	.865	***Temp:***				
					Time:	11:40am

RPM	Exh Temp	Pv Inch	CO	HC	CO2	O2	
1700	206	0.7	0.09	17	1.64	18.7	
1700	208.4	0.7	0.09	15	1.62	18.7	
1700	211.4	0.7	0.08	17	1.6	18.6	
1700	211	0.7	0.08	15	1.53	18.9	
1700	211	0.7	0.08	17	1.53	18.9	
1700	211.8	0.7	0.07	17	1.52	18.9	
1700	211.8	0.7	0.07	17	1.52	19	
1700.000	**210.200**	**.700**	**.080**	**16.429**	**1.566**	**18.814**	Mean
0	**2.188**	**.000**	**.008**	**.976**	**.052**	**.146**	Std Dev

VFHC	**VFCO**	**VFCO2**	**VFO2**	**Mtw1**	**pf1**	**PF1**
1.64E-05	0.0008	.016	.188	29.004	390,785	804,220

Company Name:	Laidlaw	***Location:***	Green Bay, WI		***Test Date:***	5/23/96
Test Portion:	Treated	***Stack Diam:***	4	Inches		
Engine Type:	DT 466	***Mile/Hrs:***	24944			
Equipment Type	School Bus	***ID #:***	1358		***Baro:***	29.93
Fuel Sp. Gravity:	.865	***Temp:***	53			
SG Corr Factor:	1.000				***Time:***	10:10

RPM	Exh Temp	Pv Inch	CO	HC	CO2	O2	
1700	225.2	0.7	0.06	15	1.41	19	
1700	226.8	0.7	0.06	15	1.41	19	
1700	228.4	0.7	0.06	15	1.4	19	
1700	229.4	0.7	0.06	15	1.4	19	
1700.000	**227.450**	**.700**	**.060**	**15.000**	**1.405**	**19.000**	Mean
0	**1.843**	**.000**	**.000**	**.000**	**.006**	**.000**	Std Dev

VFHC	**VFCO**	**VFCO2**	**VFO2**	**Mtw2**	**pf2**	**PF2**
1.50E-05	0.0006	.014	.190	28.986	438,641	905,368

Performance factor adjusted for fuel density: 905,368

****% Change PF= 12.58** %

***** A positive change in PF equates to a reduction in fuel consumption.***

Company Name:	Laidlaw	*Location:*	Green Bay, WI		*Date:*	3/27/96
Test Portion:	Baseline	*Stack Diam.*	4	Inches		
Engine Type:	DTA 360 Intn'l	*Mile/Hrs*	36450			
Equipment Type:	School Bus	*ID #:*	1935		*Baro*	30.54
Fuel Sp. Gravity(SG	.865	*Temp:*				
					Time:	1:20pm

RPM	Exh Temp	Pv Inch	CO	HC	CO2	O2	
1800	210.4	0.52	0.04	19	1.65	18.7	
1800	211.6	0.52	0.04	19	1.65	18.6	
1800	212.8	0.52	0.04	19	1.65	18.4	
1800	213	0.52	0.04	19	1.66	18.6	
1800	213.2	0.52	0.04	19	1.66	18.6	
1800.000	**212.200**	**.520**	**.040**	**19.000**	**1.654**	**18.580**	Mean
0	**1.183**	**.000**	**.000**	**.000**	**.005**	**.110**	Std Dev

VFHC	VFCO	VFCO2	VFO2	Mtw1	pf1	PF1
1.90E-05	0.0004	.017	.186	29.009	379,413	907,580

Company Name:	Laidlaw	*Location:*	Green Bay, WI		*Test Date:*	5/23/96
Test Portion:	Treated	*Stack Diam:*	4	Inches		
Engine Type:	DTA 360 Intn'l	*Mile/Hrs:*	38924			
Equipment Type	School Bus	*ID #:*	1935		*Baro:*	29.93
Fuel Sp. Gravity:	.860	*Temp:*	53			
SG Corr Factor:	1.006				*Time:*	10:00am

RPM	Exh Temp	Pv Inch	CO	HC	CO2	O2	
1800	233.6	0.52	0.03	15	1.51	18.9	
1800	234.4	0.52	0.03	15	1.51	18.9	
1800	235.2	0.52	0.03	15	1.51	18.9	
1800	236.2	0.52	0.03	15	1.51	18.9	
1800.000	**234.850**	**.520**	**.030**	**15.000**	**1.510**	**18.900**	Mean
0	**1.112**	**.000**	**.000**	**.000**	**.000**	**.000**	Std Dev

VFHC	VFCO	VFCO2	VFO2	Mtw2	pf2	PF2
1.50E-05	0.0003	.015	.189	28.998	417,595	1,005,412

Performance factor adjusted for fuel density: 1,011,223

****% Change PF= 11.42** %

***** A positive change in PF equates to a reduction in fuel consumption.***

Company Name:	Laidlaw	*Location*	Green Bay, WI		*Date:*	3/27/96
Test Portion:	Baseline	*Stack Diam.*	4	Inches		
Engine Type:	8.2 Detroit	*Mile/Hrs*	4541			
Equipment Type:	School Bus	*ID #:*	3782		*Baro*	30.52
Fuel Sp. Gravity(SG	.865	*Temp:*				
					Time:	11:18

RPM	Exh Temp	Pv Inch	CO	HC	CO2	O2	
1800	179.2	1	0.08	22	1.23	19.2	
1800	180.4	1	0.08	20	1.24	19.3	
1800	180	1	0.08	24	1.22	19.3	
1800.000	**179.867**	**1.000**	**.080**	**22.000**	**1.230**	**19.267**	Mean
0	**.611**	**.000**	**.000**	**2.000**	**.010**	**.058**	Std Dev

VFHC	VFCO	VFCO2	VFO2	Mtw1	pf1	PF1
2.20E-05	0.0008	.012	.193	28.969	488,218	821,375

Company Name:	Laidlaw	*Location:*	Green Bay, WI		*Test Date:*	5/23/96
Test Portion:	Treated	*Stack Diam:*	4	Inches		
Engine Type:	8.2 Detroit	*Mile/Hrs:*	106619			
Equipment Type	School Bus	*ID #:*	3782		*Baro:*	29.93
Fuel Sp. Gravity:	.865	*Temp:*	53			
SG Corr Factor:	1.000				*Time:*	9:20

RPM	Exh Temp	Pv Inch	CO	HC	CO2	O2	
1800	199.6	1	0.05	22	1.12	19.5	
1800	203.4	1	0.05	21	1.12	19.5	
1800	205.2	1	0.05	22	1.14	19.5	
1800	206.6	1	0.05	22	1.12	19.6	
1800.000	**203.700**	**1.000**	**.050**	**21.750**	**1.125**	**19.525**	Mean
0	**3.031**	**.000**	**.000**	**.500**	**.010**	**.050**	Std Dev

VFHC	VFCO	VFCO2	VFO2	Mtw2	pf2	PF2
2.18E-05	0.0005	.011	.195	28.962	543,597	922,375

Performance factor adjusted for fuel density: 922,375

****% Change PF= 12.30 %**

***** A positive change in PF equates to a reduction in fuel consumption.***

Company Name:	Laidlaw	*Location*	Green Bay, WI		*Date:*	3/27/96
Test Portion:	Baseline	*Stack Diam.*	4	Inches		
Engine Type:	7.3 Intern'l	*Mile/Hrs*	54154			
Equipment Type:	School Bus	*ID #:*	584		*Baro*	30.52
Fuel Sp. Gravity(SG	.865	*Temp:*				
					Time:	10:37am

RPM	Exh Temp	Pv Inch	CO	HC	CO2	O2	
1800	172.4	0.7	0.04	15	2.04	18.4	
1800	172.4	0.7	0.05	15	2.03	18.4	
1800	172.2	0.7	0.04	15	2.02	18.4	
1800	171.6	0.7	0.04	15	2.03	18.3	
1800	171.6	0.7	0.04	15	2.03	18.3	
1800.000	**172.040**	**.700**	**.042**	**15.000**	**2.030**	**18.360**	Mean
0	**.410**	**.000**	**.004**	**.000**	**.007**	**.055**	Std Dev

VFHC	**VFCO**	**VFCO2**	**VFO2**	**Mtw1**	**pf1**	**PF1**
1.50E-05	0.00042	.020	.184	29.060	311,530	622,597

Company Name:	Laidlaw	*Location:*	Green Bay, WI		*Test Date:*	5/23/96
Test Portion:	Treated	*Stack Diam:*	4	Inches		
Engine Type:	7.3 Intern'l	*Mile/Hrs:*	57127			
Equipment Type	School Bus	*ID #:*	584		*Baro:*	29.93
Fuel Sp. Gravity:	.865	*Temp:*	53			
SG Corr Factor:	1.000				*Time:*	9:30

RPM	Exh Temp	Pv Inch	CO	HC	CO2	O2	
1800	195.6	0.7	0.04	15	1.72	18.9	
1800	196.6	0.7	0.04	15	1.73	18.9	
1800	198.4	0.7	0.04	17	1.71	18.9	
1800	199.2	0.7	0.04	17	1.73	18.9	
1800.000	**197.450**	**.700**	**.040**	**16.000**	**1.723**	**18.900**	Mean
0	**1.644**	**.000**	**.000**	**1.155**	**.010**	**.000**	Std Dev

VFHC	**VFCO**	**VFCO2**	**VFO2**	**Mtw2**	**pf2**	**PF2**
1.60E-05	0.0004	.017	.189	29.033	365,460	737,678

Performance factor adjusted for fuel density: 737,678

****% Change PF= 18.48 %**

*** A positive change in PF equates to a reduction in fuel consumption.*

APPENDIX 2

Table 1. Comparison of Fuel Consumption Mass Flow Rate (PFs)

Bus No.	Baseline PF	Treated PF	% Diff
1299	691,085	786,035	+13.74
1358	804,220	905,368	+12.58
1249	1,297,999	1,380,141	+ 6.33
586	891,488	968,716	+ 8.66
43	610,679	679,283	+11.23
1935	907,580	1,005,412	+11.42
3782	821,375	922,375	+12.30
Fleet Averages:			+10.89

Note: An increase in PF equals a reduction in fuel consumption since the PF is a measure of the length of time required to consumed the same amount of fuel. The more efficient the engine, the longer it takes to consume the same amount of fuel, so the PF is higher.

Table 2. Comparison of Carbon Monoxide Emissions

Bus No.	Baseline CO	Treated CO	% Diff
1299	0.060	0.054	-10.00
1358	0.080	0.060	-25.00
3782	0.080	0.050	-38.00
1935	0.040	0.030	-25.00
43	0.050	0.040	-20.00
586	0.030	0.030	0.00
1249	0.070	0.040	-43.00
Fleet Averages:	0.059	0.043	-27.10

Table 3. Comparison of Smoke Emissions

Bus No.	Baseline Smoke #	Treated Smoke #	% Diff
1935	5.5	3.0	-45.00
43	5.0	3.0	-40.00
586	5.0	3.0	-40.00
1299	4.0	2.0	-50.00
1358	3.0	1.5	-50.00
3782	7.0	4.0	-43.00
1249	6.0	3.0	-50.00
Fleet Averages:	5.10	2.80	-45.10

APPENDIX 3

Figure 1
CARBON MASS BALANCE FORMULAE

ASSUMPTIONS: $C_{12}H_{26}$ and SG = 0.82
Time is constant
Load is constant

DATA:

Mwt = Molecular Weight
pf1 = Calculated Performance Factor (Baseline)
pf2 = Calculated Performance Factor (Treated)
PF1 = Performance Factor (adjusted for Baseline exhaust mass)
PF2 = Performance Factor (adjusted for Treated exhaust mass)
CFM = Volumetric Flow Rate of the Exhaust
SG = Specific Gravity of the Fuel
VF = Volume Fraction
d = Exhaust stack diameter in inches
Pv = Velocity pressure in inches of H_20
P_B = Barometric pressure in inches of mercury
Te = Exhaust temperature ^{O}F
VFHC = "reading" ÷ 1,000,000
VFCO = "reading" ÷ 100
$VFCO_2$ = "reading" ÷ 100
VFO_2 = "reading" ÷ 100

EQUATIONS:

Mwt =

$$(VFHC)(86)+(VFCO)(28)+(VFCO_2)(44)+(VFO_2)(32)+[(1-VFHC-VFCO-VFCO_2-VFO_2)(28)]$$

pf1 or pf2 =

$$\frac{3099.6 \text{ x } Mwt}{86(VFHC)+13.89(VFCO)+13.89(VFCO_2)}$$

CFM =

$$\frac{(d/2)^2\pi}{144}\left(1096.2\sqrt{\frac{Pv}{1.325(PB/ET+460)}}\right)$$

PF1 or PF2 =

$$\frac{pf \text{ x } (Te+460)}{CFM}$$

FUEL ECONOMY:
PERCENT INCREASE (OR DECREASE)

$$\frac{PF2 - PF1}{PF1} \text{ x } 100$$

Figure 2.

SAMPLE CALCULATION FOR THE CARBON MASS BALANCE

BASELINE:

Equation 1 (Volume Fractions)

$$\begin{aligned} \mathrm{VFHC} &= 13.20/1{,}000{,}000 \\ &= 0.0000132 \end{aligned}$$

$$\begin{aligned} \mathrm{VFCO} &= 0.017/100 \\ &= 0.00017 \end{aligned}$$

$$\begin{aligned} \mathrm{VFCO_2} &= 1.937/100 \\ &= 0.01937 \end{aligned}$$

$$\begin{aligned} \mathrm{VFO_2} &= 17.10/100 \\ &= 0.171 \end{aligned}$$

Equation 2 (Molecular Weight)

$$\begin{aligned} \mathrm{Mwt1} &= (0.0000132)(86)+(0.00017)(28)+(0.01937)(44)+(0.171)(32) \\ &\quad +[(1-0.0000132-0.00017-0.01937-0.171)(28)] \end{aligned}$$

$$\mathrm{Mwt1} = 28.995$$

Equation 3 (Calculated Performance Factor)

$$\mathrm{pf1} = \frac{3099.6 \times 28.995}{86(0.0000132)+13.89(0.00017)+13.89(0.01937)}$$

$$\mathrm{pf1} = 329{,}809$$

Equation 4 (CFM Calculations)

$$\text{CFM} = \frac{(d/2)^2\pi}{144}\left(1096.2\sqrt{\frac{Pv}{1.325(PB/ET+460)}}\right)$$

d =Exhaust stack diameter in inches
Pv =Velocity pressure in inches of H_20
P_B =Barometric pressure in inches of mercury
Te =Exhaust temperature ^{O}F

$$\text{CFM} = \frac{(10/2)^2\pi}{144}\left(1096.2\sqrt{\frac{.80}{1.325(30.00/313.100+460)}}\right)$$

CFM =2358.37

Equation 5 (Corrected Performance Factor)

$$\text{PF1} = \frac{329{,}809(313.1 \text{ deg F} + 460)}{2358.37 \text{ CFM}}$$

PF1 = 108,115

TREATED:

Equation 1 (Volume Fractions)

VFHC = 14.6/1,000,000
= 0.0000146

VFCO = .013/100
= 0.00013

$VFCO_2$ = 1.826/100
= 0.01826

VFO_2 = 17.17/100
= 0.1717

Equation 2 (Molecular Weight)

$$Mwt2 = (0.0000146)(86)+(0.00013)(28)+(0.01826)(44)+(0.1717)(32) + [(1-0.0000146-0.00013-0.01826-0.1717)(28)]$$

$$Mwt2 = 28.980$$

Equation 3 (Calculated Performance Factor)

$$pf2 = \frac{3099.6 \times 28.980}{86(0.0000146)+13.89(0.00013)+13.89(0.01826)}$$

$$pf2 = 349{,}927$$

Equation 4 (CFM Calculations)

$$CFM = \frac{(d/2)^2\pi}{144}\left(1096.2\sqrt{\frac{Pv}{1.325(PB/ET+460)}}\right)$$

d =Exhaust stack diameter in inches

Pv =Velocity pressure in inches of H_20

P_B =Barometric pressure in inches of mercury

Te =Exhaust temperature ^OF

$$CFM = \frac{(10/2)^2\pi}{144}\left(1096.2\sqrt{\frac{.775}{1.325(29.86/309.02+460)}}\right)$$

$$CFM = 2320.51$$

Equation 5 (Corrected Performance Factor)

$$PF2 = \frac{349{,}927(309.02 \text{ deg F} + 460)}{2320.51 \text{ CFM}}$$

$$= 115{,}966$$

Fuel Specific Gravity Correction Factor

Baseline Fuel Specific Gravity - Treated Fuel Specific Gravity/Baseline Fuel Specific Gravity +1

.840-.837/.840+1=1.0036

PF2 = 115,966 x Specific Gravity Correction

PF2 = 115,966 x 1.0036

PF2 = 116,384

Equation 6 (Percent Change in Engine Performance Factor:)

$$\% \text{ Change PF} = \frac{\text{PF2} - \text{PF1}}{\text{PF1}} \times 100$$

% Change PF = [(116,384 - 108,115)/108,115](100)

= +7.65

Note: A positive change in PF equates to a reduction in fuel consumption.