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EVALUATION OF FPC-1® FUEL PERFORMANCE CATALYST

by

BROWARD COUNTY SCHOOL SYSTEM

Report Prepared by

UHI CORPORATION
PROVO, UTAH,
and
INTERNAL COMBUSTION ENHANCEMENT, INC
Tampa, Florida

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INTRODUCTION

FPC-1® is a combustion catalyst which, when added to liquid hydrocarbon fuels at a ratio of 1:5000, improves the combustion reaction resulting in increased engine efficiency and reduced fuel consumption. The products of incomplete combustion are also positively affected.

Field and laboratory tests alike indicate a potential to reduce fuel consumption in diesel fleets in the range of 5% to 10%. Smoke and carbon monoxide emissions are typically reduced 15 to 30%. This report summarizes the results of controlled back-to-back field tests conducted by the Broward County School System , UHI Corporation, and ICE, Inc., engineers, with and without FPC-1® added to the diesel fuel for a fleet of school buses. The fuel consumption determination procedure applied was the Carbon Balance Exhaust Emission Test at a given engine load and speed.

This same method also measures the exhaust concentrations of carbon monoxide and unburned hydrocarbons. Smoke testing was also conducted using the Bacharach Smokemeter method.

TEST INSTRUMENTS:

The equipment and instruments involved in the carbon balance test program were:

Sun Electric SGA-9000 non-dispersive, infrared analyzer (NDIR) for measuring the exhaust gas constituents, HC (unburned hydrocarbons as hexane gas), CO, CO_2, and O_2.

Scott Specialty BAR 90 calibration gases for SGA-9000 internal calibration of the SGA-9000.

A Fluke Model 51 type "k" thermometer and wet/dry probe for measuring exhaust, fuel, and ambient temperature.

A Dwyer magnehelic and pitot tube for exhaust pressure differential measurement and exhaust air flow determination (CFM).

A Monarch phototachometer to determine and control engine speed (rpm).

A Bacharach True-Spot smokespot meter to determine the density of exhaust smoke from diesel engines.

A hydrometer for fuel specific gravity (density) measurement.

A Snap On throttle control for setting and holding engine speed at a fixed rpm.

TEST PROCEDURE

Carbon Balance

The carbon balance technique for determining changes in fuel consumption has been recognized by the US Environment Protection Agency (EPA) since 1973 and is central to the EPA-Federal Test Procedures (FTP) and Highway Fuel Economy Test (HFET). The method relies upon the measurement of vehicle exhaust emissions to determine fuel consumption rather than direct measurement (volumetric or gravimetric) of fuel consumption.

The application of the carbon balance test method utilized in this study involves the measurement of exhaust gases of a stationary vehicle under steady-state engine conditions. The method produces a value of engine fuel consumption with FPC-1® relative to a baseline value established with the same vehicle.

Engine speed and load are duplicated from test to test, and measurements of carbon containing exhaust gases (CO_2, CO, HC), oxygen (O_2), exhaust and ambient temperature, and exhaust and ambient pressure are made. A minimum of five readings are taken for each of the above parameters after engine stabilization has taken place (rpm, and exhaust, oil, and water temperature have stabilized). The technical approach to the carbon balance method is detailed in the Appendices.

Fuel specific gravity or density is measured enabling corrections to be made to the final engine performance factors based upon the energy content of the fuel reaching the injectors.

Smoke density was determined by drawing a fixed quantity of exhaust gases through a filter medium. The particulate's were collected onto the filter surface and the density determined by comparing the discoloration of the filter paper to a color calibrated scale.

Ten buses made up the final test fleet. Table 1 in the Appendices summarizes the percent change in fuel consumption based upon the change in carbon flow rate in the exhaust.

DISCUSSION

1. Fuel Density

Fuel specific gravity (density) was lower during the treated fuel carbon balance test than the baseline fuel test, therefore, the fuel had a lower energy content during the treated test. The correction factor shown on the computer printouts in the Appendices adjusts the treated fuel density to that of the baseline.

2. The Effect of FPC-1 upon Smoke Density

Smoke density was determined using the Bacharach smoke spot method. The Bacharach True-Spot Smokemeter measures smoke density by drawing a specific volume of exhaust gas through a fine paper filter medium (5 micron) while the engine is operating at a fixed rpm and under steady-state engine conditions. The smoke particles are trapped on the surface of the filter paper as the exhaust gases are drawn through it forming a darkened area called a "smoke spot". The filter paper is then removed from the smoke tester and the smoke spot visually compared to a precoded smoke scale. A smoke number is then assigned to the smoke spot according to the darkness of the spot. The smoke number scale ranges from 0 to 9. Higher smoke numbers correspond to darker smoke spots, which correspond to a greater smoke density in the exhaust. The baseline and treated fuel smoke spot numbers are found on Table 2 in the Appendices.

A reduction in smoke is prime evidence of improved combustion (Germane, SAE Technical Paper # 831204). Further, reduced exhaust smoking has been shown to be one of first evidences that engine carbon residue and soot blowby into the motor oil are also being reduced (ibid). The reductions in exhaust smoke are logical extensions of improved combustion created by FPC-1.

CONCLUSIONS

1) The fuel consumption change determined by the carbon balance method ranged from a decrease of 3.70% to a decrease of 11.26%. The fleet averaged a 7.68% reduction in fuel consumed after FPC-1 fuel treatment and engine preconditioning.

2) Smoke density was reduced 18% after FPC-1 treated fuel.

APPENDICES

CARBON BALANCE METHOD TECHNICAL APPROACH:

All test instruments were calibrated and zeroed prior to both baseline and treated fuel data collection. The SGA-9000 NDIR exhaust gas analyzer was internally calibrated using Scott Calibration Gases (BAR 90 Gases), and a leak test on the sampling hose and connections was performed. The same procedure was repeated after each test segment to determine any instrument drift.

Each vehicle's engine was brought up to operating temperature at a set rpm and allowed to stabilize as indicated by the engine water and exhaust temperature, and exhaust pressure. No exhaust gas measurements were made until each engine had stabilized at the rpm selected for the test. Engine rpm was set using the dash mounted tachometer and checked peridocally to prevent any change in engine speed during the data collection period. #2 diesel was used exclusively throughout the evaluation. Fuel specific gravity (density) and temperature were also taken.

The baseline fuel consumption test consisted of a minimum of five sets of measurements of CO_2, CO, HC, O_2, and exhaust temperature and pressure made at 90 second intervals. Each engine was tested in the same manner. Engine rpm were also recorded at approximately 90 second intervals.

After the baseline test the fuel storage tanks were treated with FPC-1® at the recommended level of 1 oz. of catalyst to 40 gallons of fuel (1:5000 volume ratio). Each succeeding fuel shipment was also treated with FPC-1®. The equipment was operated on treated fuel until the final test was run.

During the two test segments, an internal self-calibration of the exhaust analyzer was performed after every two sets of measurements to correct instrument drift, if any.

From the exhaust gas concentrations of $C0_2$, CO, HC, and O_2 measured during the test, the average molecular weight of these gases, and the temperature and volumetric flow rate of the exhaust stream, the mass flow rate of the fuel to the engine (rate of fuel consumption) may be expressed as a engine "performance factor" which relates the fuel consumption of the treated fuel to the baseline. The calculations are based on the assumption that engine operating conditions are essentially the same throughout the test. Engines with known mechanical problems or having undergone repairs affecting fuel consumption are removed from the sample.

The carbon mass balance formulae are found on Figure 1 in the Appendices. For illustation purposes, a sample calculation is also included (Figure 2).

COMPUTER PRINTOUTS

Company Name:	Broward County Schools	*Location*	Twin Lakes, FL	*Date:*	10/28/94
Test Portion:	Baseline	*Stack Diam.*	4 Inches		
Engine Type:	Navistar 444	*Mile/Hrs*	4533		
Equipment Type:	School Bus	*ID #:*	94130	*Baro*	29.95
Fuel Sp. Gravity(SG	.843	*Temp:*			
				Time:	

RPM	Exh Temp	Pv Inch	CO	HC	CO2	O2	
1800	194	0.6	0.04	12	1.49	18.1	
1800	206	0.6	0.05	12	1.48	18.2	
1800	217.8	0.6	0.05	13	1.51	18.2	
1800	218	0.6	0.05	14	1.6	18	
1800	220.6	0.7	0.04	15	1.61	18.1	
1800	222.8	0.7	0.04	15	1.6	18	
1800	223.8	0.7	0.05	15	1.6	18.1	
1800	224	0.7	0.04	14	1.53	18.2	
1800	224.4	0.7	0.04	14	1.53	18.2	
1800	223.6	0.7	0.04	14	1.6	18.2	
1800	**217.500**	**.660**	**.044**	**13.800**	**1.555**	**18.130**	Mean
0	**9.940**	**.052**	**.005**	**1.135**	**.052**	**.082**	Std Dev

VFHC	VFCO	VFCO2	VFO2	Mtw1	pf1	PF1
1.38E-05	0.00044	.016	.181	28.975	402,143	848,892

Company Name:	Broward County Schools	*Location:*	Twin Lakes, FL	*Test Date:*	3/31/95
Test Portion:	Treated	*Stack Diam:*	4 Inches		
Engine Type:	Navistar 444	*Mile/Hrs:*	12463		
Equipment Type	School Bus	*ID #:*	94130	*Baro:*	29.93
Fuel Sp. Gravity:	.832	*Temp:*			
SG Corr Factor:	1.013			*Time:*	908

RPM	Exh Temp	Pv Inch	CO	HC	CO2	O2	
1800	227.8	0.6	0.04	12	1.61	17.8	
1850	230.2	0.6	0.04	12	1.62	17.8	
1800	232.8	0.55	0.03	12	1.61	17.9	
1800	233.4	0.55	0.03	12	1.62	18	
1800	235	0.55	0.03	12	1.61	17.8	
1800	235	0.55	0.03	13	1.63	17.2	
1800	235.2	0.55	0.04	13	1.56	18.4	
1800	235	0.6	0.03	12	1.55	18.3	
1800	234.6	0.55	0.03	13	1.55	18.2	
1800	234.6	0.6	0.03	13	1.56	18.1	
1805.000	**233.360**	**.570**	**.033**	**12.400**	**1.592**	**17.950**	Mean
15.8113883	**2.489**	**.026**	**.005**	**.516**	**.033**	**.341**	Std Dev

VFHC	VFCO	VFCO2	VFO2	Mtw2	pf2	PF2
1.24E-05	0.00033	.016	.180	28.973	395,942	909,532

Performance factor adjusted for fuel density: 921,400

****% Change PF= 8.54 %**

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

Company Name:	Broward County Schools	*Location:*	Twin Lakes, FL	*Date:*	10/28/94
Test Portion:	Baseline	*Stack Diam.*	4 Inches		
Engine Type:	Navistar 444	*Mile/Hrs*	5752		
Equipment Type:	School Bus	*ID #:*	94129	*Baro*	29.95
Fuel Sp. Gravity(SG	.842	*Temp:*			
				Time:	

RPM	Exh Temp	Pv Inch	CO	HC	CO2	O2	
1800	195.5	0.8	0.03	10	1.71	18	
1800	201.4	0.8	0.03	10	1.69	18.1	
1800	214.4	0.8	0.04	10	1.79	17.7	
1800	217.8	0.8	0.04	13	1.72	17.7	
1800	224.4	0.8	0.04	13	1.67	17.9	
1800	228.2	0.8	0.04	13	1.68	17.9	
1800	230	0.8	0.05	13	1.7	18	
1800	232.4	0.8	0.04	13	1.7	17.9	
1800	233	0.8	0.04	14	1.68	17.8	
1800.000	**219.678**	**.800**	**.039**	**12.111**	**1.704**	**17.889**	Mean
0	**13.651**	**.000**	**.006**	**1.616**	**.036**	**.136**	Std Dev

VFHC	VFCO	VFCO2	VFO2	Mtw1	pf1	PF1
1.21E-05	0.000388889	.017	.179	28.989	369,425	709,452

Company Name:	Broward County Schools	*Location:*	Twin Lakes, FL	*Test Date:*	3/31/95
Test Portion:	Treated	*Stack Diam:*	4 Inches		
Engine Type:	Navistar 444	*Mile/Hrs:*	16332		
Equipment Type	School Bus	*ID #:*	94129	*Baro:*	29.93
Fuel Sp. Gravity:	.832	*Temp:*			
SG Corr Factor:	1.012			*Time:*	830

RPM	Exh Temp	Pv Inch	CO	HC	CO2	O2	
1800	214.4	0.7	0.03	10	1.66	17.6	
1750	217.6	0.7	0.03	10	1.63	17.3	
1800	237.4	0.7	0.04	14	1.76	18.2	
1800	238.4	0.7	0.04	13	1.76	18.4	
1800	241.4	0.7	0.04	10	1.75	18.3	
1800	241.8	0.7	0.03	10	1.75	18.3	
1800	241.4	0.7	0.03	10	1.74	17.6	
1800	241.4	0.7	0.03	13	1.72	17.8	
1800	244.2	0.7	0.03	12	1.69	18.1	
1800	244.6	0.75	0.03	12	1.69	18.2	
1795.000	**236.260**	**.705**	**.033**	**11.400**	**1.715**	**17.980**	Mean
15.8113883	**10.926**	**.016**	**.005**	**1.578**	**.046**	**.377**	Std Dev

VFHC	VFCO	VFCO2	VFO2	Mtw2	pf2	PF2
1.14E-05	0.00033	.017	.180	28.994	368,606	762,954

Performance factor adjusted for fuel density: 772,015

****% Change PF = 8.82 %**

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

Company Name:	Broward County Schools	*Location:*	Twin Lakes, FL	*Date:*	10/28/94
Test Portion:	Baseline	*Stack Diam.*	4 Inches		
Engine Type:	Cummins B	*Mile/Hrs*	39855		
Equipment Type:	School Bus	*ID #:*	334	*Baro*	29.95
Fuel Sp. Gravity(SG	.840	*Temp:*			
				Time:	

RPM	Exh Temp	Pv Inch	CO	HC	CO2	O2	
1800	229.6	0.5	0.04	9	1.77	17.7	
1800	233.2	0.5	0.04	10	1.77	17.7	
1800	235	0.5	0.04	10	1.77	17.7	
1800	236.8	0.5	0.04	10	1.76	17.8	
1800	238.4	0.5	0.04	10	1.75	17.7	
1800	238.8	0.5	0.04	10	1.74	17.8	
1800	239.8	0.5	0.04	10	1.74	17.8	
1800.000	**235.943**	**.500**	**.040**	**9.857**	**1.757**	**17.743**	Mean
0	**3.616**	**.000**	**.000**	**.378**	**.014**	**.053**	Std Dev

VFHC	VFCO	VFCO2	VFO2	Mtw1	pf1	PF1
9.86E-06	0.0004	.018	.177	28.991	358,729	881,775

Company Name:	Broward County Schools	*Location:*	Twin Lakes, FL	*Test Date:*	3/31/95
Test Portion:	Treated	*Stack Diam:*	4 Inches		
Engine Type:	Cummins B	*Mile/Hrs:*	47396		
Equipment Type	School Bus	*ID #:*	334	*Baro:*	29.90
Fuel Sp. Gravity:	.825	*Temp:*			
SG Corr Factor:	1.018			*Time:*	1355

RPM	Exh Temp	Pv Inch	CO	HC	CO2	O2	
1800	244.2	0.45	0.04	10	1.82	17.5	
1800	248.2	0.45	0.04	10	1.82	17.5	
1800	250	0.45	0.04	10	1.82	17.5	
1800	254.2	0.4	0.04	10	1.81	17.6	
1800	255	0.4	0.04	10	1.79	17.6	
1800	254.8	0.4	0.04	10	1.79	17.5	
1800	256.8	0.4	0.04	11	1.81	17.6	
1800	256.6	0.4	0.04	10	1.81	17.6	
1800.000	**252.475**	**.419**	**.040**	**10.125**	**1.809**	**17.550**	Mean
0	**4.525**	**.026**	**.000**	**.354**	**.012**	**.053**	Std Dev

VFHC	VFCO	VFCO2	VFO2	Mtw2	pf2	PF2
1.01E-05	0.0004	.018	.176	28.992	348,724	946,926

Performance factor adjusted for fuel density: 963,835

****% Change PF= 9.31 %**

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

Company Name:	Broward County Schools	*Location:*	Twin Lakes, FL	*Date:*	10/28/94
Test Portion:	Baseline	*Stack Diam.*	4 Inches		
Engine Type:	Navistar 7.3	*Mile/Hrs*	162729		
Equipment Type:	School Bus	*ID #:*	645	*Baro*	29.95
Fuel Sp. Gravity(SG	.844	*Temp:*			
				Time:	

RPM	Exh Temp	Pv Inch	CO	HC	CO2	O2	
1750	198.2	0.8	0.02	2	1.94	17.8	
1750	190.8	0.8	0.02	3	1.97	17.9	
1770	191.6	0.8	0.03	5	2.04	17.4	
1770	192.2	0.8	0.03	5	2.05	17.4	
1770	192.4	0.8	0.03	5	2.04	17.4	
1770	192.8	0.8	0.03	4	2.04	17.6	
1770	193.6	0.8	0.03	4	2.04	17.6	
1770	193.2	0.8	0.02	5	2.03	17.4	
1770	191.8	0.8	0.02	5	2.04	17.4	
1770	192	0.8	0.03	5	2.03	17.5	
1766.000	**192.860**	**.800**	**.026**	**4.300**	**2.022**	**17.540**	Mean
8.432740427	**2.042**	**.000**	**.005**	**1.059**	**.036**	**.184**	Std Dev

VFHC	VFCO	VFCO2	VFO2	Mtw1	pf1	PF1
4.30E-06	0.00026	.020	.175	29.025	315,840	594,459

Company Name:	Broward County Schools	*Location:*	Twin Lakes, FL	*Test Date:*	3/31/95
Test Portion:	Treated	*Stack Diam:*	4 Inches		
Engine Type:	Navistar 7.3	*Mile/Hrs:*	169715		
Equipment Type	School Bus	*ID #:*	645	*Baro:*	29.93
Fuel Sp. Gravity:	.830	*Temp:*			
SG Corr Factor:	1.017			*Time:*	945

RPM	Exh Temp	Pv Inch	CO	HC	CO2	O2	
1735	199.8	0.75	0.02	4	1.95	17.8	
1735	199.8	0.75	0.02	4	1.95	17.8	
1755	203.4	0.7	0.02	2	2.09	17.3	
1755	203.4	0.7	0.02	4	2.09	17.4	
1785	204.4	0.7	0.02	4	2.11	17.2	
1797	206.6	0.7	0.02	3	2.1	17.2	
1797	206.8	0.7	0.02	3	2.1	17.3	
1797	206.8	0.7	0.02	5	2.09	17.4	
1797	206.4	0.7	0.02	5	2.07	17.4	
1772.556	**204.156**	**.711**	**.020**	**3.778**	**2.061**	**17.422**	Mean
27.34552574	**2.832**	**.022**	**.000**	**.972**	**.064**	**.228**	Std Dev

VFHC	VFCO	VFCO2	VFO2	Mtw2	pf2	PF2
3.78E-06	0.0002	.021	.174	29.027	310,888	625,769

Performance factor adjusted for fuel density: 636,149

****% Change PF= 7.01 %**

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

Company Name:	Broward County Schools	*Location*	Twin Lakes, FL	*Date:*	10/28/94
Test Portion:	Baseline	*Stack Diam.*	4 Inches		
Engine Type:	Navistar DT 360	*Mile/Hrs*	66468		
Equipment Type:	School Bus	*ID #:*	302	*Baro*	29.95
Fuel Sp. Gravity(SG	.840	*Temp:*			
				Time:	

RPM	Exh Temp	Pv Inch	CO	HC	CO2	O2	
1800	232	0.4	0.02	12	1.91	17.6	
1800	240.6	0.4	0.02	13	1.9	17.7	
1800	243.6	0.4	0.02	13	1.9	17.7	
1800	248	0.4	0.02	10	1.93	17.7	
1800	251.8	0.4	0.03	12	1.92	17.7	
1800	258.2	0.4	0.03	14	1.93	17.5	
1800	260	0.4	0.03	14	1.93	17.5	
1800	260.2	0.4	0.03	14	1.94	17.7	
1800	259.2	0.4	0.03	14	1.94	17.6	
1800	258.4	0.4	0.03	14	1.95	17.7	
1800.000	**251.200**	**.400**	**.026**	**13.000**	**1.925**	**17.640**	Mean
0	**9.847**	**.000**	**.005**	**1.333**	**.017**	**.084**	Std Dev

VFHC	VFCO	VFCO2	VFO2	Mtw1	pf1	PF1
1.30E-05	0.00026	.019	.176	29.014	330,452	918,045

Company Name:	Broward County Schools	*Location:*	Twin Lakes, FL	*Test Date:*	3/31/95
Test Portion:	Treated	*Stack Diam:*	4 Inches		
Engine Type:	Navistar DT 360	*Mile/Hrs:*	74801		
Equipment Type	School Bus	*ID #:*	302	*Baro:*	29.90
Fuel Sp. Gravity:	.826	*Temp:*			
SG Corr Factor:	1.017			*Time:*	1250

RPM	Exh Temp	Pv Inch	CO	HC	CO2	O2	
1800	266.6	0.35	0.04	22	1.83	17.3	
1800	267.6	0.4	0.03	22	1.82	17.4	
1800	267.4	0.4	0.03	18	1.82	17.7	
1800	265.6	0.4	0.03	18	1.82	17.7	
1800	265.8	0.45	0.03	21	1.82	17.7	
1800	266.4	0.4	0.03	21	1.84	17.5	
1800	267.4	0.4	0.04	21	1.85	17.5	
1800	269	0.4	0.03	22	1.84	17.4	
1800.000	**266.975**	**.400**	**.033**	**20.625**	**1.830**	**17.525**	Mean
0	**1.108**	**.027**	**.005**	**1.685**	**.012**	**.158**	Std Dev

VFHC	VFCO	VFCO2	VFO2	Mtw2	pf2	PF2
2.06E-05	0.000325	.018	.175	28.995	344,953	968,090

Performance factor adjusted for fuel density: 984,225

****% Change PF= 7.21 %**

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

Company Name:	Broward County Schools	*Location*	Twin Lakes, FL	*Date:*	10/28/94
Test Portion:	Baseline	*Stack Diam.*	4 Inches		
Engine Type:	Cummins B Series	*Mile/Hrs*	46357		
Equipment Type:	School Bus	*ID #:*	310	*Baro*	29.95
Fuel Sp. Gravity(SG	.844	*Temp:*			
				Time:	

RPM	Exh Temp	Pv Inch	CO	HC	CO2	O2	
2700	259.8	0.8	0.04	10	1.9	17.7	
2700	266.8	0.8	0.04	10	1.91	17.6	
2700	274	0.9	0.04	10	1.83	17.9	
2700	271.4	0.9	0.04	10	1.83	17.9	
2700	270	0.8	0.04	10	1.89	17.8	
2700	278.4	0.8	0.04	10	1.92	17.8	
2700	275	0.8	0.04	10	1.91	17.8	
2700.000	**270.771**	**.829**	**.040**	**10.000**	**1.884**	**17.786**	Mean
0	**6.105**	**.049**	**.000**	**.000**	**.038**	**.107**	Std Dev

VFHC	VFCO	VFCO2	VFO2	Mtw1	pf1	PF1
1.00E-05	0.0004	.019	.178	29.013	335,344	656,153

Company Name:	Broward County Schools	*Location:*	Twin Lakes, FL	*Test Date:*	3/31/95
Test Portion:	Treated	*Stack Diam:*	4 Inches		
Engine Type:	Cummins B Series	*Mile/Hrs:*	57823		
Equipment Type	School Bus	*ID #:*	310	*Baro:*	29.90
Fuel Sp. Gravity:	.824	*Temp:*			
SG Corr Factor:	1.024			*Time:*	1318

RPM	Exh Temp	Pv Inch	CO	HC	CO2	O2	
2700	271.6	0.9	0.04	12	1.96	17.2	
2700	273.4	0.75	0.04	13	1.96	17.2	
2700	274	0.75	0.04	12	1.96	17.2	
2700	274.8	0.75	0.04	10	1.97	17.3	
2700	274.8	0.7	0.04	10	1.97	17.2	
2700	275.6	0.7	0.04	13	1.97	17.3	
2700	272.8	0.7	0.04	13	1.97	17.4	
2700	273.4	0.7	0.04	10	1.97	17.4	
2700.000	**273.800**	**.744**	**.040**	**11.625**	**1.966**	**17.275**	Mean
0	**1.278**	**.068**	**.000**	**1.408**	**.005**	**.089**	Std Dev

VFHC	VFCO	VFCO2	VFO2	Mtw2	pf2	PF2
1.16E-05	0.0004	.020	.173	29.006	321,441	664,665

Performance factor adjusted for fuel density: 680,415

****% Change PF= 3.70 %**

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

Company Name:	Broward County Schools	*Location*	Twin Lakes, FL	*Date:*	10/28/94
Test Portion:	Baseline	*Stack Diam.*	4 Inches		
Engine Type:	Navistar DT 360	*Mile/Hrs*			
Equipment Type:	School Bus	*ID #:*	471	*Baro*	29.95
Fuel Sp. Gravity(SG	.830	*Temp:*			
				Time:	

RPM	Exh Temp	Pv Inch	CO	HC	CO2	O2	
1800	217.8	0.5	0.02	12	1.77	17.9	
1800	252.6	0.5	0.02	14	1.79	17.9	
1800	255.8	0.5	0.02	15	1.79	17.8	
1800	255	0.5	0.02	13	1.78	17.9	
1800	254.8	0.5	0.02	13	1.77	17.9	
1800	255.4	0.5	0.02	12	1.79	18	
1800	254.6	0.5	0.02	13	1.78	17.8	
1800	254.8	0.5	0.02	14	1.78	17.7	
1800	254.6	0.5	0.02	12	1.79	17.9	
1800.000	**250.600**	**.500**	**.020**	**13.111**	**1.782**	**17.867**	Mean
0	**12.332**	**.000**	**.000**	**1.054**	**.008**	**.087**	Std Dev

VFHC	VFCO	VFCO2	VFO2	Mtw1	pf1	PF1
1.31E-05	0.0002	.018	.179	29.001	357,423	887,767

Company Name:	Broward County Schools	*Location:*	Twin Lakes, FL	*Test Date:*	3/31/95
Test Portion:	Treated	*Stack Diam:*	4 Inches		
Engine Type:	Navistar DT 360	*Mile/Hrs:*	22969		
Equipment Type	School Bus	*ID #:*	471	*Baro:*	29.93
Fuel Sp. Gravity:	.826	*Temp:*			
SG Corr Factor:	1.005			*Time:*	1215

RPM	Exh Temp	Pv Inch	CO	HC	CO2	O2	
1800	264.2	0.45	0.02	17	1.72	17.7	
1800	264.2	0.45	0.02	17	1.72	17.7	
1800	261	0.45	0.02	17	1.71	17.7	
1800	259.2	0.45	0.02	17	1.71	17.8	
1800	260.9	0.4	0.02	17	1.71	17.6	
1800	260.2	0.45	0.02	17	1.72	17.8	
1800	260.4	0.45	0.02	17	1.72	17.7	
1800	259.6	0.45	0.02	17	1.72	17.8	
1800.000	**261.213**	**.444**	**.020**	**17.000**	**1.716**	**17.725**	Mean
0	**1.939**	**.018**	**.000**	**.000**	**.005**	**.071**	Std Dev

VFHC	VFCO	VFCO2	VFO2	Mtw2	pf2	PF2
1.70E-05	0.0002	.017	.177	28.985	370,205	982,990

Performance factor adjusted for fuel density: 987,727

****% Change PF= 11.26 %**

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

Company Name:	Broward County Schools	*Location*	Twin Lakes, FL	*Date:*	10/28/94
Test Portion:	Baseline	*Stack Diam.*	4 Inches		
Engine Type:	Navistar DT 360	*Mile/Hrs*	11039		
Equipment Type:	School Bus	*ID #:*	488	*Baro*	29.95
Fuel Sp. Gravity(SG	.845	*Temp:*			
				Time:	

RPM	Exh Temp	Pv Inch	CO	HC	CO2	O2	
1800	229.6	0.4	0.02	10	1.74	17.8	
1800	235.4	0.4	0.02	12	1.73	17.8	
1800	240.2	0.4	0.02	13	1.74	17.9	
1800	242.8	0.4	0.02	12	1.85	17.7	
1800	244.2	0.4	0.02	13	1.85	17.7	
1800	245.6	0.4	0.02	12	1.87	17.6	
1800	247.2	0.4	0.02	13	1.8	17.8	
1800	248.4	0.4	0.02	13	1.82	17.8	
1800	248.4	0.4	0.02	12	1.89	17.8	
1800	249.4	0.4	0.02	12	1.88	17.8	
1800.000	**243.120**	**.400**	**.020**	**12.200**	**1.817**	**17.770**	Mean
0	**6.413**	**.000**	**.000**	**.919**	**.061**	**.082**	Std Dev

VFHC	VFCO	VFCO2	VFO2	Mtw1	pf1	PF1
1.22E-05	0.0002	.018	.178	29.002	350,818	969,071

Company Name:	Broward County Schools	*Location:*	Twin Lakes, FL	*Test Date:*	3/31/95
Test Portion:	Treated	*Stack Diam:*	4 Inches		
Engine Type:	Navistar DT 360	*Mile/Hrs:*	21464		
Equipment Type	School Bus	*ID #:*	488	*Baro:*	29.93
Fuel Sp. Gravity:	.828	*Temp:*			
SG Corr Factor:	1.020			*Time:*	

RPM	Exh Temp	Pv Inch	CO	HC	CO2	O2	
1800	251.8	0.35	0.02	19	1.74	17.9	
1800	252.4	0.35	0.02	19	1.73	17.9	
1800	252.4	0.4	0.02	21	1.74	17.9	
1800	253	0.4	0.02	21	1.76	17.8	
1800	254.6	0.4	0.02	18	1.79	17.8	
1800	255.4	0.4	0.02	18	1.79	17.8	
1800	255.4	0.4	0.02	18	1.79	17.8	
1800.000	**253.571**	**.386**	**.020**	**19.143**	**1.763**	**17.843**	Mean
0	**1.525**	**.024**	**.000**	**1.345**	**.027**	**.053**	Std Dev

VFHC	VFCO	VFCO2	VFO2	Mtw2	pf2	PF2
1.91E-05	0.0002	.018	.178	28.997	360,463	1,021,153

Performance factor adjusted for fuel density: 1,041,697

****% Change PF= 7.49 %**

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

Company Name:	Broward County Schools	*Location*	Twin Lakes, FL	*Date:*	10/28/94
Test Portion:	Baseline	*Stack Diam.*	4 Inches		
Engine Type:	Cummins B	*Mile/Hrs*	30375		
Equipment Type:	School Bus	*ID #:*	350	*Baro*	29.95
Fuel Sp. Gravity(SG	.843	*Temp:*			
				Time:	

RPM	Exh Temp	Pv Inch	CO	HC	CO2	O2	
1800	241.2	0.5	0.04	12	1.6	17.9	
1800	244	0.5	0.04	13	1.59	17.9	
1800	244.8	0.5	0.04	12	1.52	18.1	
1800	250.8	0.5	0.04	12	1.5	18.1	
1800	250.4	0.5	0.04	10	1.79	17.9	
1800	250.4	0.5	0.04	12	1.66	18.1	
1800	251.2	0.5	0.04	14	1.65	18	
1800	250.8	0.5	0.04	14	1.64	17.9	
1800	250.2	0.5	0.04	10	1.63	17.9	
1800	250	0.5	0.04	10	1.76	17.7	
1800.000	**248.380**	**.500**	**.040**	**11.900**	**1.634**	**17.950**	Mean
0	**3.610**	**.000**	**.000**	**1.524**	**.091**	**.127**	Std Dev

VFHC	VFCO	VFCO2	VFO2	Mtw1	pf1	PF1
1.19E-05	0.0004	.016	.180	28.980	384,569	953,701

Company Name:	Broward County Schools	*Location:*	Twin Lakes, FL	*Test Date:*	3/31/95
Test Portion:	Treated	*Stack Diam:*	4 Inches		
Engine Type:	Cummins B	*Mile/Hrs:*	38248		
Equipment Type	School Bus	*ID #:*	350	*Baro:*	29.93
Fuel Sp. Gravity:	.824	*Temp:*			
SG Corr Factor:	1.023			*Time:*	

RPM	Exh Temp	Pv Inch	CO	HC	CO2	O2	
1815	252.4	0.4	0.04	17	1.69	17.5	
1810	253.2	0.4	0.04	17	1.69	17.5	
1810	254.4	0.45	0.04	14	1.69	17.8	
1800	254	0.45	0.04	14	1.69	17.9	
1800	256	0.45	0.04	12	1.72	17.7	
1800	254.6	0.45	0.04	12	1.72	17.7	
1800	255.4	0.4	0.04	15	1.69	17.6	
	255.4	0.4	0.04	15	1.69	17.5	
1805.000	**254.425**	**.425**	**.040**	**14.500**	**1.698**	**17.650**	Mean
6.454972244	**1.207**	**.027**	**.000**	**1.927**	**.014**	**.151**	Std Dev

VFHC	VFCO	VFCO2	VFO2	Mtw2	pf2	PF2
1.45E-05	0.0004	.017	.177	28.978	370,201	999,691

Performance factor adjusted for fuel density: 1,022,222

****% Change PF= 7.18**

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

Company Name:	Broward County Schools	*Location*	Twin Lakes, FL	*Date:*	10/28/94

Test Portion:	Baseline	*Stack Diam.*	4	Inches		
Engine Type:	Navistar DT 360	*Mile/Hrs*	11772			
Equipment Type:	School Bus	*ID #:*	486		*Baro*	29.95
Fuel Sp. Gravity(SG	.840	*Temp:*				
					Time:	

RPM	Exh Temp	Pv Inch	CO	HC	CO2	O2	
1800	242.6	0.5	0.02	10	1.84	17.6	
1800	254.2	0.5	0.02	10	1.82	17.5	
1800	257	0.5	0.02	10	1.74	18	
1800	262.6	0.5	0.02	12	1.72	17.9	
1800	263.4	0.5	0.02	12	1.81	17.9	
1800	264	0.5	0.02	12	1.81	17.8	
1800	264.6	0.5	0.02	10	1.81	17.9	
1800	265.6	0.5	0.02	10	1.86	17.8	
1800	267	0.5	0.02	10	1.86	17.8	
1800	267	0.5	0.02	10	1.78	17.9	
1800.000	**260.800**	**.500**	**.020**	**10.600**	**1.805**	**17.810**	Mean
0	**7.629**	**.000**	**.000**	**.966**	**.047**	**.152**	Std Dev

VFHC	VFCO	VFCO2	VFO2	Mtw1	pf1	PF1
1.06E-05	0.0002	.018	.178	29.002	353,307	883,821

Company Name:	Broward County Schools	*Location:*	Twin Lakes, FL		*Test Date:*	3/31/95
Test Portion:	Treated	*Stack Diam:*	4	Inches		
Engine Type:	Navistar DT 360	*Mile/Hrs:*	22253			
Equipment Type	School Bus	*ID #:*	486		*Baro:*	29.93
Fuel Sp. Gravity:	.828	*Temp:*				
SG Corr Factor:	1.014				*Time:*	1047

RPM	Exh Temp	Pv Inch	CO	HC	CO2	O2	
1800	266	0.4	0.02	18	1.91	17.6	
1800	266	0.4	0.02	18	1.91	17.6	
1800	265.4	0.4	0.02	17	1.91	17.7	
1800	267.2	0.4	0.02	18	1.91	17.7	
1800	267.6	0.4	0.02	17	1.93	17.6	
1800	264.8	0.4	0.02	18	1.91	17.6	
1800	263.2	0.4	0.02	18	1.91	17.7	
1800	264.8	0.45	0.02	21	1.92	17.7	
1800.000	**265.625**	**.406**	**.020**	**18.125**	**1.914**	**17.650**	Mean
0	**1.412**	**.018**	**.000**	**1.246**	**.007**	**.053**	Std Dev

VFHC	VFCO	VFCO2	VFO2	Mtw2	pf2	PF2
1.81E-05	0.0002	.019	.177	29.013	332,812	926,409

Performance factor adjusted for fuel density: 939,644

****% Change PF= 6.32**

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

Table 1:
Summary of Carbon Balance Fuel Consumption Changes

Unit	Engine	RPM	% Change Fuel Consumption
302	Navistar DT 360	1800	- 7.21
310	Cummins B Series	2700	- 3.70
334	Cummins B Series	1800	- 9.31
350	Cummins B Series	1800	- 7.18
471	Navistar DT 360	1800	- 11.26
486	Navistar DT 360	1800	- 6.32
488	Navistar DT 360	1800	- 7.49
645	Navistar 7.3	1750	- 7.01
94129	Navistar 444	1800	- 8.82
94130	Navistar 444	1800	- 8.54
Average:			**- 7.68**

Table 2:
Comparison of Smoke Spot Numbers

Unit No.	Base SS#	Treated SS#	% Change
302	3	2.5	- 17%
310	3.5	2	- 43%
334	3.5	3	- 14%
350	3	3.5	17%
471	4	4	
486	5	3.5	- 30%
488	3.5	3	- 14%
645	8	6	- 25%
94129	2.5	2	- 20%
94130	2.5	2	- 20%
Average:			- 18%

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 ^oF

VFHC	= "reading" ÷ 1,000,000
VFCO	= "reading" ÷ 100
$VFCO_2$	= "reading" ÷ 100
VFO_2	= "reading" ÷ 100

EQUATIONS:

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

$$pf1 \text{ or } pf2 = \frac{3099.6 \times Mwt}{86(VFHC)+13.89(VFCO)+13.89(VFCO_2)}$$

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

$$PF1 \text{ or } PF2 = \frac{pf \times (Te+460)}{CFM}$$

FUEL ECONOMY:
PERCENT INCREASE (OR DECREASE) $\frac{PF2 - PF1}{PF1} \times 100$

Figure 2.

SAMPLE CALCULATION FOR THE CARBON MASS BALANCE

BASELINE:

Equation 1 (Volume Fractions)

VFHC = 13.20/1,000,000
= 0.0000132

VFCO = 0.017/100
= 0.00017

$VFCO_2$ = 1.937/100
= 0.01937

VFO_2 = 17.10/100
= 0.171

Equation 2 (Molecular Weight)

$$Mwt1 = (0.0000132)(86)+(0.00017)(28)+(0.01937)(44)+(0.171)(32) + [(1-0.0000132-0.00017-0.01937-0.171)(28)]$$

$$Mwt1 = 28.995$$

Equation 3 (Calculated Performance Factor)

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

$$pf1 = 329{,}809$$

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

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

CFM =2358.37

Equation 5 (Corrected Performance Factor)

$$PF1 = \frac{329.809(313.1 \text{ deg F} + 460)}{2358.37 \text{ CFM}}$$

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:)

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

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

= +7.65

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

RAW DATA WORK SHEETS