FPC FUEL CATALYST LOADBOX TEST

BY

INDIANA HARBOR BELT RR

Report prepared
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Abstract

This report documents the effect of Fuel Performance Catalyst-2 (FPC) upon engine efficiency, and exhaust smoke during loadbox tests of three Indiana Harbor Belt (IHB) locomotive engines. The EMD engines powered a SW1500, a GP38-2, and a SD40. The test fleet was first tested under load at throttle notch positions 1, 3, and 5 using untreated (baseline) fuel. The test fleet was then treated with FPC-2, a fuel combustion catalyst, and operated as normal for approximately 600 hours. The fleet was then re-tested with FPC-2 treated fuel, while reproducing all engine and power output conditions.

The method of determining fuel consumption and emissions output is known as the carbon mass balance (CMB), and is an adaptation of the EPA standardized Federal Test Procedures, which also uses CMB for fuel consumption and engine emissions determination. The engines were loaded using a loadbox. IHB engine and electrical technicians collected engine and power data. A summary of the results are as follows:

(1) Fuel consumption was reduced 7% to 9%, depending upon throttle setting. The overall fuel consumption reduction for the test fleet was **7.7%** with FPC treatment.

(2) Exhaust smoke density was reduced 10% to 60%. Smoke density reductions averaged **21.7%** for the entire fleet at all throttle settings. Smoke density reductions were generally most profound at notch 1 averaging **30%.**

These benefits are supported by several laboratory tests, including Southwest Research Institute's (SwRI) test of a 12 cylinder, 645E3B using the Association of American Railroads Recommended Practice 503 (RP-503). Other test data reviewed in this report include findings of the Western Australia Institute of Technology (WAIT) and several power generating operations (gensets) where specific fuel consumption tests have been possible. The last studies verify FPC is most effective when used in engines operating under conditions that more closely approach the transient duty cycle of typical field operation.

The findings of the Indiana Harbor Belt test of the FPC catalyst are also supported by findings of several loadbox tests recently conducted by several other railroads.

1.0 INTRODUCTION

During the period of May 1992 to June 1992, a rigorous test of FPC was completed by Southwest Research Institute (SwRI), San Antonio, Texas. The test program determined the effect of the fuel combustion catalyst upon fuel properties, engine wear, deposit formation, and engine performance. The test procedure was the Recommended Practice 503 (RP-503), a procedure authored and recognized by the Association of American Railroads (AAR).

The final phase of the RP-503 test program was an engine performance test on a twelve cylinder, 645E3B EMD locomotive engine. The test engine was operated under steady-state conditions at maximum horsepower output per unit of fuel consumed (brake specific fuel consumption). Brake specific fuel consumption (bsfc) was improved 1.74% by FPC treatment when compared to base diesel fuel bsfc [Ref 1].

After the completion of the RP-503, combustion experts concluded that the 1.74% improvement in bsfc would translate to improvements **several times greater in engines operated in the field due to the transient nature of actual operating conditions** [Ref 6].

Other independent laboratory studies, including the Varimax engine test conducted by the Western Australia Institute of Technology (WAIT), Perth, Western Australia, by Curtin University, also in Western Australia, and by the University of Perugia, Perugia, Italy, confirm this conclusion. Tests at varying engine speeds, loads, and injection timing, which more closely approach field conditions, agree with expert opinion.

Further, test data from over a dozen specific fuel consumption (sfc) trials of diesel power generating equipment agree with the lab studies. Diesel power generators can be tested in the field at specific loads and rpm. In these applications, it is reasonable to accurately measure fuel consumption and power output in kilowatts. And, although not subjected to severe transient operation, their application yields test results that are more representative of real world conditions, than do those from the laboratory [Ref 3].

The loadbox test conducted by Indiana Harbor Belt, using three EMD powered locomotives, is yet another example of greater FPC effectiveness in engines used and tested in the "real world". Several throttle notch positions were selected for the test, and each engine fully loaded in an attempt to create conditions that more closely duplicate actual duty cycles. The results also agree with those of previous railroad loadbox tests and are supported by expert opinion.

2.0 BACKGROUND

2.1 Diesel Combustion Theory

2.1.1 The Combustion Process

The four-cycle compression-ignition engine employs the conventional four strokes per power cycle of intake, compression, power, and exhaust. The two-cycle engine shortens the number of strokes of the piston by combining the power and exhaust stroke, and the intake and compression stroke.

The air inducted on the intake is either normally aspirated or forced in by the supercharger, while the fuel is injected into the cylinder near the end of the compression stroke. In most diesel engines, the combustion chamber temperature at the end of the compression stroke is approximately 600 degrees C (Celsius). This temperature is dependent upon the compression ratio and the initial air temperature.

Near the end of the compression stroke, fuel is sprayed into the combustion chamber at pressures varying from about 1,200 psi to over 30,000 psi. The injection pressure is governed by engine speed and size, and by the type of combustion chamber and injection system used [Ref 4].

With the commencement of fuel injection, the combustion process is initiated. Each charge of injected fuel experiences several phases in the reaction as follows:

(1) An ignition delay period

(2) A period of rapid combustion

(3) A period of combustion where the remainder of the fuel charge is burned as it is injected.

(4) An after burning period in which the unburned fuel may find oxygen and burn, often times referred to as the tail of combustion.

In following the combustion process and the path of fuel particles, it should be understood that after ignition has occurred, many of these steps will be proceeding at the same time, since the mixture is homogeneous [Ref 5].

2.1.2 The Delay Period

The delay consists of a physical and a chemical delay. The physical delay is required to atomize the fuel, mix it with air, vaporize it, and produce a mixture of fuel vapor and air.

During the chemical delay, preflame oxidation reactions occur in localized regions with temperature increases of 540 to 1100 degrees C. These preflame reactions are initiated by the catalytic effect of wall surfaces, high temperatures, and miscellaneous particles that form the active chain carriers prior to rapid combustion. As the local temperature increases, the fuel vapors begin to crack at an accelerating rate and produce material with high percentages of carbon, which become heated to incandescence as local ignition is initiated.

Inflammation develops quickly either by rapid and complete oxidation of the fuel and air or the oxidation of the intermediate products of the chain reactions of the fuel [Ref 5].

2.1.3 The Period of Rapid Combustion

Combustion during the period of rapid combustion is due chiefly to the burning of fuel that has had time to vaporize and mix with air during the delay period. The rate and extent of the burning during this period are closely associated with the length of the delay period and its relation to the injection process.

The relation of the delay on both the rate and extent of pressure rise during this phase is especially strong when the delay period is shorter than the injection period [Ref 5].

2.1.4 The Third Phase of Combustion

The third phase is the period from maximum pressure to the point where combustion is measurably complete.

When the delay period is longer than the injection period, the third period of combustion will involve only the fuel that has not found the necessary oxygen during the period of rapid combustion. In this case, only the mixing process limits the combustion rate. However, even when all the fuel is injected before the end of the delay period, poor injection characteristics can extend the third period well into the power or expansion stroke, causing low output and poor efficiency.

When injection timing is such that the second phase of combustion is complete before the end of injection, some portion of the fuel is injected during the third phase, and the rate of burning will be influenced by the rate of injection, as well as by the mixing rate [Ref 4].

2.1.5 The Final Phase of Combustion

The final phase or tail of combustion continues after the third phase at a diminishing rate as any remaining fuel and oxygen are each consumed. Diffusion combustion, with production and combustion of carbon particles and a high rate of heat transfer radiation characterize this last stage and the previous one. This phase occurs well down the expansion stroke, when much of the oxygen has been consumed and combustion temperatures are lower. It is at this stage that smoke and carbon monoxide emissions are formed [Ref 4].

2.1.6 The Ideal Combustion Process

The thermal efficiency of an internal combustion engine, whether spark or compression-ignition, will increase if the combustion time is reduced. Thus, more work can be extracted from the same energy input from combustion. The rate of pressure rise during the period of rapid combustion corresponding to constant volume combustion, should be as rapid as possible without exceeding a certain value.

The fuel remaining after the period of rapid pressure rise should be burned at a rate such as to hold the cylinder pressure constant, at the maximum allowable value, until all the fuel is burned.

2.1.7 The Effects of Operating Conditions on Combustion

With respect to the diesel engine, the combustion rate as well as the rate and extent of pressure rise, depends greatly on the design of the combustion chamber and the injection system. However, injection timing, engine speed, turbulence, compression ratio, fuel-air ratio, spray characteristics, fuel cetane number, and inlet temperature and pressure all effect the combustion rate or flame speed.

A detailed discussion of the impact of these operating conditions on combustion is found in Reference 4.

2.2 Possible Mode of Action of the FPC Combustion Catalyst

2.2.1 Flame Propagation

As previously mentioned, the speed with which the combustion process takes place influences the efficiency of the heat released by the chemical reaction. With greater rates of heat release, it is often possible to transfer more of the heat into useful energy.

The combustion catalyst manufactured by FPC International is a burn rate modifier. When the combustion catalyst is introduced into a liquid hydrocarbon fuel and combustion begins, the catalyst appears to form propagating centers that initiate multiple flame fronts. These propagating centers in effect increase the thermal conductivity of the fuel-air mixture, since heat transmission through it is more rapid with their presence. The effect appears to be most profound during the mixing–controlled and final phases of combustion when flame propagation is slowed or controlled by the rate at which fuel and air can mix to combustible proportions. The combustion catalyst assists in maintaining flame speed through the third and last phases of combustion.

The completeness of combustion may also be positively affected. If combustion is more complete, more energy is liberated while the flame front traverses through the fuel-air mixture. **Controlled engine tests with FPC catalyst reveal not only increased horsepower output and reduced fuel consumption, but also typically reduced unwanted gaseous and particulate exhaust emissions.**

Further, when engine operating conditions are such that flame speed is slowed, creating greater combustion time losses, the FPC fuel catalyst will recover a greater percentage of those losses. Thus, the catalyst will have a more profound effect upon engines operating in the field, than engines operating in the laboratory.

3.0 SUPPORT DATA: LABORATORY AND STATIONARY ENGINE TESTS

3.1 The AAR RP-503

In early 1992, UHI Corporation was encouraged by several major railroads to conduct tests with FPC catalyst (FPC-1® 1/5000 ratio was used) at Southwest Research Institute (SwRI) using the Association of American Railroads (AAR), the Recommended Practice 503 (RP-503).

The RP-503 constitutes two screening tests and an engine performance trial. The screening tests include the determination of the additive effect upon fuel properties, engine deposit formation, and engine wear. The final procedure is an engine performance trial conducted in a 12 cylinder, 645E3B EMD locomotive engine.

These studies concluded that FPC catalyst had no measurable effect on the chemical properties of the fuel, nor did it detrimentally impact engine life and deposit formation. The EMD engine also showed a 1.74% improvement in bsfc at a 95% confidence level with FPC catalyst treated fuel [Ref 1].

This is a remarkable improvement given the existing efficiency of this particular engine (37.2% brake thermal efficiency and 0.354 bsfc) and the fact the test engine was run under optimum engine conditions (steady-state, notch 8, 900 rpm). Under these conditions, injection timing is the best match for maximum horsepower and lowest bsfc, and therefore, combustion time losses are minimized. Further, the engine was in like-new condition, and smoke emissions were nil.

The AAR specifies these engine test conditions since a typical locomotive engine operates 50 to 60% of the time at notch 8. However, the steady-state, maximum horsepower operating conditions tend to minimize the potential for horsepower and bsfc gains [Ref 6].

3.2 The WAIT Study

Studies by the Western Australian Institute of Technology (WAIT) have collected considerable data demonstrating the effect of the FPC catalyst on engine efficiency while operating at varying rpm, load, and injection timing. The test was designed to best illustrate the effects of the combustion catalyst. In addition, the test conditions were meant to relate the effect of the catalyst, to the most commonly altered settings and conditions encountered, during normal field operation of a heavy-duty compression-ignition engine.

The objective of the WAIT study was to analyze the effect of the combustion catalyst on engine brake power and brake specific fuel consumption. In order to considerably broaden the scope of the test program in terms of relevance to simulating true commercial and industrial operating conditions, the following parameters were introduced to be varied accordingly:

(1) Engine speed

(2) Throttle setting

(3) Fuel Injection Timing

(4) The concentration of the catalyst in the diesel fuel

The manner in which each parameter was altered is described below:

* Engine speed in all tests was varied from 1600 rpm to 2400 rpm by increments of 200 rpm.

* Throttle settings were altered alternatively from half throttle to full throttle in the majority of the tests.

* Fuel injection timing was varied from 18 degrees before top dead center (BTDC) to 42 degrees BTDC, in increments of 6 degrees, in specific tests. The standard injection timing was 30 degrees BTDC.

* The concentration of the catalyst in the diesel fuel was altered by employing three different mixing ratios.

For all tests conducted in the Varimax engine test program at WAIT, full details of which parameters were altered in each particular test are given on each page of tabulated results in APPENDIX 1.0 (The WAIT Study).

3.2.1 Conclusions from WAIT Study

The Varimax engine test program has shown quite convincingly the benefits of FPC catalyst in diesel fuel. At the highest catalyst concentration in the fuel, bsfc improvements ranged from 1.71% to 4.99%.

3.3 SPECIFIC FUEL CONSUMPTION TRIALS OF DIESEL GENERATORS

For over ten years, the FPC combustion catalyst has been subjected to field trials by dozens of professional engineers representing the interest of the company by whom they are employed. These trials have involved all types of engines under virtually every operating condition imaginable. Generally speaking, these field trials reveal FPC catalyst has greater effect upon engines in mobile equipment than stationary equipment, and high-speed engines than medium or low speed engines. These data support the laboratory data mentioned above, and the theory that the catalyst affects flame speed [Ref 3].

For the purposes of this paper, although still much like laboratory engines (operating at best power, steady-state conditions), only the details of specific fuel consumption studies in diesel generators (gensets) will be given. These tend to be the best controlled field tests available, and the only tests where the measurement of specific fuel consumption (kilowatts/liter) is practical. Further, diesel power generators are similar to diesel powered locomotives.

3.3.1 Diesel Generator Test Method

Typically, the genset is operated under steady-state conditions and fixed load on baseline fuel while the rate of fuel consumption (liters or gallons) and the power output (kilowatts) are measured. Once a reliable database has been accumulated, the fuel for the gensets is treated with FPC catalyst and the gensets operated as normal from three to five hundred hours. This is known as the preconditioning period, and is allowed due to the considerable data that indicates the catalyst first functions to remove existing engine carbon residue, therefore delaying the achievement of maximum catalyst effectiveness.

Once the engine-preconditioning period is completed, the gensets are again tested. The procedure, engine speed, and load are reproduced, with the only deviation being the baseline fuel is now treated with FPC catalyst.

All parameters affecting engine efficiency (intake air temperature, intake pressure, fuel density) are measured and corrections to power output and fuel consumption made.

Some fourteen stationary diesel gensets have been tested in this manner. Engines tested include the following makes:

(1) Blackstone EL8

(2) Caterpillar 3412

(3) Cummins VTA28G3

(4) Detroit 12V and 16V149

(5) EMD L20/645F4B

(6) Mirrlee K8 Major

(7) Ruston

(8) English Electric

3.3.2 Conclusions from Diesel Gensets, Specific Fuel Consumption Trials

Improvements in specific fuel consumption range from 3.1 to 4.8%. Greater fuel consumption reductions are observed in higher rpm gensets. Reductions in smoke density average 23% for all gensets tested [Ref 3].

4.0 THE INDIANA HARBOR BELT LOADBOX TEST

The IHB conducted studies to determine the effect of FPC-2 on fuel economy and smoke emissions in a fleet of EMD powered locomotives. A loadbox was employed to load (full load) the engines. Fuel consumption was measured using an exhaust gas analysis method also utilized by the US-EPA, known as the carbon mass balance (cmb). A Bacharach Smokespot Method was used to determine changes in exhaust smoke density.

All locomotives were tested for fuel consumption using the cmb method. Tests were run at notches 1, 3, and 5 for all three engines. All engines were run at full load at each notch setting.

The locomotives were first tested while using untreated (baseline) number 2 diesel fuel. After the baseline tests, the fuel for the test locomotives were treated with FPC-2 for approximately 600 hours. At the end of the engine-preconditioning period, the cmb tests were repeated at identical load and notch settings. Engine rpm and temperature, power output and rack length were also reproduced. Performance data were corrected for fuel density and ambient conditions (air temperature and pressure).

4.1 Test Methodology

The test methodology for determining changes in fuel consumption was the "carbon mass balance" (cmb). The cmb method measures the carbon containing products of the combustion process (CO_2, CO, HC) found in the exhaust, rather than directly measuring fuel flow into the engine. The CMB also makes possible the determination of FPC catalyst's effect upon smoke from the diesel engine.

The cmb uses state-of-the-art, non-dispersive infrared analysis (NDIR) and the measurement of carbon containing exhaust gases to determine fuel consumption indirectly. The method has been central to the EPA Federal Test Procedures (FTP) and Highway Fuel Economy Test (HFET) since 1974, and is internationally recognized. This method has proven to be at least as accurate as more conventional flowmeter or weigh scale methods [Ref 8].

The exhaust gas data collected during the baseline and treated fuel carbon balance tests are summarized on the attached computer printouts (Appendix 3). 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) or the carbon mass in the exhaust is computed. The pf is finally corrected for exhaust temperature and pressure velocity (exhaust density), intake air pressure (barometric) and fuel density, yielding an engine performance factor (PF) or carbon mass flow rate corrected for total exhaust mass flow and fuel energy content.

The PFs are shown on the bottom of the computer printouts found in Appendix 3. The PF relates to the length of time required to consume a given volume of fuel, therefore a positive change in PF equates to a reduction in fuel consumption (longer time to consume same amount of fuel at the same load). The cmb formula and legend are found on Figure 1 under Appendix 4. A sample calculation is found on Figure 2, also under Appendix 4 (CMB Formulae).

Dr. Geoffrey J. Germane, Ph.D. Mechanical Engineering, and Former Department Chair provided these formulae for UHI at Brigham Young University, as the technical approach for the cmb. Dr. Germane's resume is also included in Appendix 5 (Dr. G. J. Germane's Resume').

4.2 Correction for Fuel Density

Dr. Germane's formulae assume a fuel density of 0.82 (reference specific gravity for diesel). UHI engineers measure fuel specific gravity (density) by taking samples from the rolling tank on each locomotive. Only the treated fuel rate of fuel consumption or PF (PF2) is corrected for changes in fuel density (energy content). The baseline fuel density is used as the reference. The correction factor (if applicable) for fuel density is made to the treated fuel and shown on the treated fuel computer printouts (Appendix 3 Raw Data Computer Printouts).

4.3 Correction for Barometric Pressure.

The barometric pressure is used in the calculation of both the baseline and treated fuel PFs. These pressure readings were not available and therefore, barometric pressure was held constant in all calculations.

4.4 Discussion of Smoke Density

Smoke is a product of incomplete combustion, and as such, is a measure of engine efficiency. Smoke is simply unburned fuel droplets that are exhausted from the engine. Generally speaking, soot particles (pure carbon) are formed during the late stages of combustion when temperatures have fallen off and oxygen availability is limited. The FPC catalyst improves the oxidation of the fuel droplets, speeding flame front development and extracting more useful energy before the exhaust valve or port opens. More power is generated and combustion is more complete (smoke emissions are reduced).

Smoke measurements from the engines tested during the baseline and treated fuel tests were collected using the Bacharach Smokespot Method. The Bacharach method draws a specific volume of exhaust gas through a standard 5-micron filter medium. The particulate in the exhaust gas sample collects on the surface of the filter medium. The surface is darkened by the particulate according to the density of the particulate in the exhaust sample. The greater the particulate density, the darker the color. The Bacharach smoke scale ranges from 0 to 9, with 0 being a white, particulate free filter, and 9 being a completely black filter.

The smoke spot numbers are relative smoke density numbers for each engine tested and can be used to determine any change in smoke emissions when compared to FPC catalyst treated fuel. A comparison of the baseline and treated Smoke Numbers (shown on Table 2, Appendix 7) indicate the use of FPC catalyst created as much as a 60% reduction in smoke density. Smoke reductions tended to be greater at lower notch settings (ave. 30%).

The reduced engine smoking leads to less carbon or soot accumulation on injectors, valves and valve seats, piston crowns and rings, air boxes, intake ports, exhaust stacks, spark arresters, turbochargers, and other critical engine components. Less engine smoke also equates to fewer and smaller soot particles exhausting from the engine. The smaller particles have less mass and therefore, carry less heat, burning out before reaching combustible materials near the tracks. Engine component life and efficiency is also maintained much longer.

4.5 Discussion of Power Output

Power output to the loadbox was measured in volts and amps. The power output was duplicated from test to test and notch setting to notch setting, except for the 9212. The IHB electrician taking the power data for the 9212 did not take into account the fact that power output changes as the engine and generator get warmer. It appears the baseline data was taken while the engine was fully warmed up, but the treated data were recorded at the beginning of each test run at each notch position before all systems were stabilized. However, the engine data indicate power output should have been identical for the baseline and treated fuel tests since engine speed (rpm), rack length, governor pressure, and fluid temperatures were virtually identical from test to test. The power data are found on Tables 1-3, and 4-6, in Appendix 7.

4.6 Discussion of Anomalies

As can be expected in any laboratory or field test, there is a certain amount of data point scatter or reading error that can lead to changes that are outliers from the mean. Two of the nine test runs, Notch 1 for the GP38-2, and Notch 3 for the SW1500, produced results that appear to be anomalies. These two test runs are not included in the computation of the fleet average.

5.0 CONCLUSIONS

(1) As concluded by Southwest Research, under ideal engine conditions, (best power timing, engine speed, load, and at steady-state) the use of FPC catalyst in a locomotive and/or any other medium-speed diesel engine will generate a significant fuel economy improvement of no less than 1.74%.

(2) Tests conducted by another independent laboratory, the Western Australia Institute of Technology (WAIT), on a Varimax engine operated at varying rpm, injection timing, and load verify that 1.74% is a minimum, and that average fuel economy improvements under more transient conditions typically experienced in the field will be several times greater.

(3) The same WAIT study determined that fuel economy gain is increased with increasing catalyst concentration and with engine operation deviating from best power parameters, supporting the theory of the catalyst mode of action.

(4) Although engine operating conditions are less severe for stationary engines than for mobile equipment, specific fuel consumption tests in over a dozen stationary heavy duty diesel generator sets operating in the field confirm the WAIT findings. The addition of FPC catalyst to standard diesel fuel improved fuel economy approximately 4% in these studies.

(5) The Indiana Harbor Belt loadbox tests agree with the above conclusions. Fuel consumption was reduced 7% to 9% with FPC catalyst fuel treatment. Additional benefits include reduced engine smoking, which will lead to reduced carbon or soot buildup on critical combustion chamber, intake and exhaust components.

(6) These data agree with the conclusions rendered by Dr. Geoffrey J. Germane, Ph.D., Mechanical Engineering and Chairman of the Department of Mechanical Engineering, Brigham Young University, in a letter to Mr. Vernon Markworth, Principal Engineer, Design and Development, Department of Engine Research, Southwest Research Institute, 6 August 1992 [Ref 6].

(7) Other combustion experts, such as Dr. G. K. Sharma, Senior Research Manager, Indian Oil Corporation, with whom the writer of this paper has discussed FPC catalyst benefits, also agree [Ref 7].

6.0 RECOMMENDATIONS

Given the considerable independent laboratory and field data collected verifying the potential for fuel savings by treating diesel fuel with FPC-2, IHB can realize a significant fuel cost savings with FPC-2 fuel treatment. IHB can expect fuel savings of 7% or more with FPC-2 fuel treatment. Exact dollar savings will depend upon fuel cost and volume of fuel consumed, and the duty cycles of the fleet. FPCI recommends IHB commence fuel treatment with FPC-2 as soon as possible, and begin now to recover the losses being sustained from using untreated fuel.

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6. Letter to Mr. Vernon Markworth, Principal Engineer, Design and Development, Department of Engine Research, SwRI, from Dr. Geoffrey J. Germane, Chairman, Department Mechanical Engineering, Brigham Young University

7. Meeting with Dr. G. K. Sharma, Senior Research Manager, Indian Oil Co. and Mr. S. Craig Flinders, VP, Tech Services, UHI Corporation, 2 June 1994.

8. SAE PAPER, 75302; by Bruce Simpson, Ford Motor Company.

Company Name:	Indiana Harbor Belt	***Location***	Hammond		***Date:***	8/4/97
Test Portion:	Baseline	***Stack Dian***	10	Inches		
Engine Type:	SW1500	***Mile/Hrs***				
Equipment Type:	EMD	***ID #:***	9212		***Baro***	29.92
Fuel Sp. Gravity(S	.854	***Temp:***	72			
					Time:	16:30

RPM	Exh Temp	Pv Inch	CO	HC	CO2	O2	
1	196.2	1	0.01	2	0.88	19.9	
1	194.4	1	0.01	2	0.87	19.9	
1	195	1	0.01	4	0.89	19.9	
1	194.2	1	0.01	4	0.89	19.8	
1	195.4	1	0.01	4	0.87	19.7	
1	**195.040**	**1.000**	**.010**	**3.200**	**.880**	**19.840**	Mean
0	**.805**	**.000**	**.000**	**1.095**	**.010**	**.089**	Std Dev

VFHC	VFCO	VFCO2	VFO2	Mtw1	pf1	PF1
3.20E-06	0.0001	.009	.198	28.935	723,821	195,190

Denominator pfl		(d/2)^2*3.1 Denominator				F
0.1239058	655.04	0.5451389	0.060521495	16.523055	4.0648561	2429.0818

Company Name:	Indiana Harbor Belt	***Location:***	Hammond		***Test Date:***	9/10/97
Test Portion:	Treated	***Stack Dian***	10	Inches		
Engine Type:	SW1500	***Mile/Hrs:***				
Equipment Type	EMD	***ID #:***	9212		***Baro:***	29.92
Fuel Sp. Gravity:	.854	***Temp:***	72			
SG Corr Factor:	1.000				***Time:***	16:30

1	Exh Temp	Pv Inch	CO	HC	CO2	O2	
1	191.5	1	0.02	4	0.81	19.9	
1	190.5	1	0.02	4	0.82	19.9	
1	191.5	1	0.02	3	0.81	19.9	
1	192	1	0.02	3	0.79	19.8	
1	192	1	0.01	1	0.81	19.7	
1.000	**191.500**	**1.000**	**.018**	**3.000**	**.808**	**19.840**	Mean
0	**.612**	**.000**	**.004**	**1.225**	**.011**	**.089**	Std Dev

VFHC	VFCO	VFCO2	VFO2	Mtw2	pf2	PF2
3.00E-06	0.00018	.008	.198	28.923	779,575	209,656

0.1149984	651.50	0.5451389	0.060850345	16.43376	4.0538575	2422.5092

Performance factor adjusted for fuel density: 209,656

****% Change PF= 7.41**

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

Company Name:	Indiana Harbor Belt	*Location:*	Hammond	*Date:*	8/4/97
Test Portion:	Baseline	*Stack Dian*	10 Inches		
Engine Type:	SW1500	*Mile/Hrs*		***Ambient Temp:***	
Equipment Type:	EMD	*ID #:*	9212	*Baro*	29.92
Fuel Sp. Gravity(S	.854	***Temp:***			
				Time:	16:30

RPM	Exh Temp	Pv Inch	CO	HC	CO2	O2	
3	362.8	2.4	0.01	6	3.01	17.5	
3	371.8	2.4	0.01	6	3.01	17.5	
3	373.8	2.4	0.01	6	2.99	17.5	
3	377.2	2.4	0.01	9	2.99	17.5	
3	379.6	2.4	0.01	9	2.99	17.5	
3.000	**373.040**	**2.400**	**.010**	**7.200**	**2.998**	**17.500**	Mean
0	**6.467**	**.000**	**.000**	**1.643**	**.011**	**.000**	Std Dev

VFHC	VFCO	VFCO2	VFO2	Mtw1	pf1	PF1
7.20E-06	0.0001	.030	.175	29.180	216,146	42,429

0.418452 833.04 0.5451389 0.047589552 50.431238 7.1014955 4243.7205

Company Name:	Indiana Harbor Belt	*Location:*	Hammond	*Test Date:*	8/4/97
Test Portion:	Treated	*Stack Dian*	10 Inches	***Load/Volts DC:***	
Engine Type:	SW1500	*Mile/Hrs:*		***Ambient Temp:***	
Equipment Type	EMD	*ID #:*	9212	*Baro:*	29.92
Fuel Sp. Gravity:	.854	*Temp:*			
SG Corr Factor:	1.000			*Time:*	16:30

RPM	Exh Temp	Pv Inch	CO	HC	CO2	O2	
3	395.2	2.3	0.01	2	2.77	17.5	
3	398	2.3	0.01	2	2.76	17.5	
3	401	2.4	0.01	2	2.76	17.5	
3	402	2.4	0.01	2	2.76	17.5	
3	401.8	2.3	0.01	2	2.78	17.5	
3.000	**399.600**	**2.340**	**.010**	**2.000**	**2.766**	**17.500**	Mean
0	**2.936**	**.055**	**.000**	**.000**	**.009**	**.000**	Std Dev

VFHC	VFCO	VFCO2	VFO2	Mtw2	pf2	PF2
2.00E-06	0.0001	.028	.175	29.143	234,160	47,287

Denominator pf1 (d/2)^2*3.1 Denominator F

0.3857644 859.60 0.5451389 0.046119125 50.73817 7.1230731 4256.6149

Performance factor adjusted for fuel density: 47,287

****% Change PF= 11.45**

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

Company Name:	Indiana Harbor Belt	*Location:*	Hammond		*Date:*	8/4/97
Test Portion:	Baseline	*Stack Dian*	10	Inches		
Engine Type:	SW1500	*Mile/Hrs*			**Ambient Temp:**	
Equipment Type:	EMD	*ID #:*	9212		*Baro*	29.92
Fuel Sp. Gravity(S	.854	*Temp:*				
					Time:	16:30

RPM	Exh Temp	Pv Inch	CO	HC	CO2	O2	
5	616.4	4.5	0.04	17	5.03	14.7	
5	622.8	4.5	0.04	17	5.03	14.7	
5	627.6	4.5	0.04	17	5.04	14.7	
5	630.6	4.5	0.04	19	5.02	14.8	
5	636.8	4.5	0.04	19	5.02	14.7	
5.000	**626.840**	**4.500**	**.040**	**17.800**	**5.028**	**14.720**	Mean
0	**7.734**	**.000**	**.000**	**1.095**	**.008**	**.045**	Std Dev

VFHC	VFCO	VFCO2	VFO2	Mtw1	pf1	PF1
1.78E-05	0.0004	.050	.147	29.394	129,138	21,146

Denominator pf1		(d/2)^2*3.1 Denominator				F
0.7055294	1086.84	0.5451389	0.03647639	123.36747	11.107091	6637.3893

Company Name:	Indiana Harbor Belt	*Location:*	Hammond		*Test Date:*	9/10/97
Test Portion:	Treated	*Stack Dian*	10	Inches		
Engine Type:	SW1500	*Mile/Hrs:*			**Ambient Temp:**	
Equipment Type	EMD	*ID #:*	9212		*Baro:*	29.92
Fuel Sp. Gravity:	.854	*Temp:*				
SG Corr Factor:	1.000				*Time:*	16:30

RPM	Exh Temp	Pv Inch	CO	HC	CO2	O2	
5	655.6	4.4	0.03	5	4.79	14.7	
5	662.4	4.4	0.03	5	4.81	14.8	
5	662.3	4.5	0.03	5	4.83	14.7	
5	665.4	4.5	0.03	5	4.8	14.7	
5	665.6	4.5	0.03	5	4.82	14.7	
5	667.2	4.5	0.03	5	4.8	14.7	
5.000	**663.083**	**4.467**	**.030**	**5.000**	**4.808**	**14.717**	Mean
0	**4.141**	**.052**	**.000**	**.000**	**.015**	**.041**	Std Dev

VFHC	VFCO	VFCO2	VFO2	Mtw2	pf2	PF2
5.00E-06	0.0003	.048	.147	29.358	135,317	22,608

Denominator pf1		(d/2)^2*3.1 Denominator				F
0.6724895	1123.08	0.5451389	0.035299251	126.53715	11.248873	6722.1158

Performance factor adjusted for fuel density: 22,608

****% Change PF= 6.91**

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

Company Name:	Indiana Harbor Belt	*Location:*	Hammond	*Date:*	8/4/97
Test Portion:	Baseline	*Stack Dian*	24 Inches		
Engine Type:	SD40	*Mile/Hrs*		**Ambient Temp:**	
Equipment Type:	EMD	*ID #:*	4001	*Baro*	29.92
Fuel Sp. Gravity(S	.854	*Temp:*		*Time:*	

RPM	Exh Temp	Pv Inch	CO	HC	CO2	O2	
1	211.8	1.50	0.01	3	0.89	19.5	
1	212.8	1.50	0.01	3	0.87	19.5	
1	215	1.50	0.01	5	0.87	19.5	
1	215.6	1.50	0.01	5	0.87	19.4	
1	215.8	1.50	0.01	6	0.87	19.4	
1.000	**214.200**	**1.500**	**.010**	**4.400**	**.874**	**19.460**	Mean
0	**1.794**	**.000**	**.000**	**1.342**	**.009**	**.055**	Std Dev

VFHC	VFCO	VFCO2	VFO2	Mtw1	pf1	PF1
4.40E-06	0.0001	.009	.195	28.918	727,686	28,220

0.1231792 674.20 3.14 0.058801543 25.509535 5.0506965 17384.841

Company Name:	Indiana Harbor Belt	*Location:*	Hammond	*Test Date:*	9/10/97
Test Portion:	Treated	*Stack Dian*	24 Inches		
Engine Type:	SD40	*Mile/Hrs:*		**Ambient Temp:**	
Equipment Type	EMD	*ID #:*	4001	*Baro:*	29.91
Fuel Sp. Gravity:	.854	*Temp:*			
SG Corr Factor:	1.000			*Time:*	

RPM	Exh Temp	Pv Inch	CO	HC	CO2	O2	
1	214.8	1.5	0	5	0.81	19.5	
1	214.8	1.5	0	4	0.83	19.5	
1	214.4	1.5	0.01	4	0.83	19.5	
1	214.6	1.5	0.01	3	0.82	19.4	
1	216	1.5	0.01	3	0.81	19.4	
1.000	**214.920**	**1.500**	**.006**	**3.800**	**.820**	**19.460**	Mean
	.626	**.000**	**.005**	**.837**	**.010**	**.055**	Std Dev

VFHC	VFCO	VFCO2	VFO2	Mtw2	pf2	PF2
3.80E-06	0.00006	.008	.195	28.910	778,736	30,211

Denominator pf1 (d/2)^2*3.1 Denominator F
0.1150696 674.92 3.14 0.058719182 25.545315 5.0542374 17397.029

Performance factor adjusted for fuel density: 30,211

****% Change PF= 7.05**

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

Company Name: Indiana Harbor Belt *Location* Hammond *Date:* 9/10/97

Test Portion:	Baseline	*Stack Dian*	24	Inches			
Engine Type:	EMD	*Mile/Hrs*			***Ambient Temp:***		
Equipment Type:	SD40	*ID #:*	4001		*Baro*	29.92	
Fuel Sp. Gravity(S	.854	***Temp:***					
					Time:		

RPM	Exh Temp	Pv Inch	CO	HC	CO2	O2	
3	370.8	2.1	0.01	9	2.75	17.3	
3	367.8	2.1	0.01	9	2.75	17.4	
3	378.4	2.1	0.01	6	2.76	17.4	
3	375.6	2.1	0.01	6	2.76	17.4	
3	382.2	2.1	0.01	6	2.75	17.4	
3.000	**374.960**	**2.100**	**.010**	**7.200**	**2.754**	**17.380**	Mean
0	**5.771**	**.000**	**.000**	**1.643**	**.005**	**.045**	Std Dev

VFHC	VFCO	VFCO2	VFO2	Mtw1	pf1	PF1
7.20E-06	0.0001	.028	.174	29.136	234,842	8,566
0.3845604	834.96	3.14	0.047480119	44.229038	6.6504916	22891.444

Company Name:	Indiana Harbor Belt	*Location:*	Hammond		*Test Date:*	9/10/97	
Test Portion:	Treated	*Stack Dian*	24	Inches			
Engine Type:	EMD	*Mile/Hrs:*			***Ambient Temp:***		
Equipment Type	SD40	*ID #:*	4001		*Baro:*	29.91	
Fuel Sp. Gravity:	.854	***Temp:***					
SG Corr Factor:	1.000				*Time:*		

RPM	Exh Temp	Pv Inch	CO	HC	CO2	O2	
3	377.6	2.1	0	0	2.58	17.3	
3	377.4	2.1	0	0	2.57	17.4	
3	378.2	2.1	0	0	2.58	17.4	
3	381.4	2.1	0	0	2.58	17.4	
3	384.4	2.1	0	0	2.58	17.4	
3.000	**379.800**	**2.100**	**.000**	**.000**	**2.578**	**17.380**	Mean
0	**3.036**	**.000**	**.000**	**.000**	**.004**	**.045**	Std Dev

VFHC	VFCO	VFCO2	VFO2	Mtw2	pf2	PF2
0.00E+00	0	.026	.174	29.108	251,958	9,215
0.3580842	839.80	3.14	0.0471907	44.500293	6.670854	22961.533

Performance factor adjusted for fuel density: 9,215

****% Change PF= 7.58**

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

Company Name:	Indiana Harbor Belt	*Location*	Hammond		*Date:*	8/4/97
Test Portion:	Baseline	*Stack Dian*	24	Inches		

Engine Type:	EMD	*Mile/Hrs*		***Ambient Temp:***	
Equipment Type:	SD40	*ID #:*	4001	*Baro*	29.92
Fuel Sp. Gravity(S	.854	***Temp:***			
				Time:	

RPM	Exh Temp	Pv Inch	CO	HC	CO2	O2	
5	539.6	4.2	0.02	4	4.39	15.6	
5	539.4	4.2	0.02	4	4.39	15.6	
5	535.4	4.2	0.01	4	4.29	15.6	
5	534.2	4.2	0.01	6	4.30	15.5	
5	536.8	4.2	0.02	6	4.40	15.4	
5.000	**537.080**	**4.200**	**.016**	**4.800**	**4.354**	**15.540**	Mean
0	**2.394**	**.000**	**.005**	**1.095**	**.054**	**.089**	Std Dev

VFHC	VFCO	VFCO2	VFO2	Mtw1	pf1	PF1
4.80E-06	0.00016	.044	.155	29.319	149,609	4,217

Denominator pfl		(d/2)^2*3.1 Denominator				F
0.6074202	997.08	3.14	0.039760099	105.63354	10.277818	35376.948

Company Name:	Indiana Harbor Belt	*Location:*	Hammond	*Test Date:*	9/10/97
Test Portion:	Treated	*Stack Dian*	24	Inches	
Engine Type:	EMD	*Mile/Hrs:*		***Ambient Temp:***	
Equipment Type	SD40	*ID #:*	4001	*Baro:*	29.92
Fuel Sp. Gravity:	.854	***Temp:***			
SG Corr Factor:	1.000			*Time:*	

RPM	Exh Temp	Pv Inch	CO	HC	CO2	O2	
5	541.0	4.2	0.01	2	4.07	15.6	
5	544.0	4.2	0.01	2	4.07	15.6	
5	539.4	4.2	0.01	3	4.08	15.6	
5	540.6	4.2	0.01	3	4.07	15.5	
5	542.7	4.2	0.01	3	4.09	15.4	
5.000	**541.540**	**4.200**	**.010**	**2.600**	**4.076**	**15.540**	Mean
0	**1.813**	**.000**	**.000**	**.548**	**.009**	**.089**	Std Dev

VFHC	VFCO	VFCO2	VFO2	Mtw2	pf2	PF2
2.60E-06	0.0001	.041	.155	29.274	159,812	4,514

Denominator pfl		(d/2)^2*3.1 Denominator				F
0.5677768	1001.54	3.14	0.039583042	106.10604	10.300779	35455.981

Performance factor adjusted for fuel density: 4,514

****% Change PF= 7.06**

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

Company Name:	Indiana Harbor Belt	*Location*	Hammond	*Date:*	8/4/97
Test Portion:	Baseline	*Stack Dian*	24	Inches	

Engine Type:	EMD	*Mile/Hrs*		**Ambient Temp:**	
Equipment Type:	GP38-2	*ID #:*	3801	*Baro*	29.92
Fuel Sp. Gravity(S	.854	*Temp:*			
				Time:	

RPM	Exh Temp	Pv Inch	CO	HC	CO2	O2	
1	206.4	1.00	0.01	4	1.10	19.2	
1	209.8	1.00	0.01	4	1.10	19.2	
1	208.6	1.00	0.01	4	1.10	19.2	
1	211.6	1.00	0.01	5	1.12	19.2	
1	212.8	1.00	0.01	5	1.13	19.3	
1.000	**209.840**	**1.000**	**.010**	**4.400**	**1.110**	**19.220**	Mean
0	**2.512**	**.000**	**.000**	**.548**	**.014**	**.045**	Std Dev

VFHC	VFCO	VFCO2	VFO2	Mtw1	pf1	PF1
4.40E-06	0.0001	.011	.192	28.947	575,297	27,236

0.1559596 669.84 3.14 0.059184283 16.896378 4.1105204 14148.691

Company Name:	Indiana Harbor Belt	*Location:*	Hammond	*Test Date:*	9/10/97
Test Portion:	Treated	*Stack Dian*	24 Inches		
Engine Type:	EMD	*Mile/Hrs:*		**Ambient Temp:**	
Equipment Type	GP38-2	*ID #:*	3801	*Baro:*	29.92
Fuel Sp. Gravity:	.854	*Temp:*			
SG Corr Factor:	1.000			*Time:*	

RPM	Exh Temp	Pv Inch	CO	HC	CO2	O2	
1	207.4	1	0.01	5	0.99	19.2	
1	207.6	1	0.01	5	0.99	19.2	
1	207.4	1	0.01	3	1	19.2	
1	207.8	1	0.01	3	1	19.2	
1	207.4	1	0.01	3	0.99	19.3	
1.000	**207.520**	**1.000**	**.010**	**3.800**	**.994**	**19.220**	Mean
0	**.179**	**.000**	**.000**	**1.095**	**.005**	**.045**	Std Dev

VFHC	VFCO	VFCO2	VFO2	Mtw2	pf2	PF2
3.80E-06	0.0001	.010	.192	28.928	641,412	30,314

Denominator pf1 (d/2)^2*3.1 Denominator F

0.1397938 667.52 3.14 0.059389981 16.837857 4.1033958 14124.167

Performance factor adjusted for fuel density: 30,314

****% Change PF= 11.30**

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

Company Name:	Indiana Harbor Belt	*Location*	Hammond	*Date:*	8/4/97
Test Portion:	Baseline	*Stack Dian*	24 Inches		
Engine Type:	EMD	*Mile/Hrs*		**Ambient Temp:**	

Equipment Type:	GP38-2	***ID #:***	3801	***Baro***	29.92
Fuel Sp. Gravity(S	.854	***Temp:***			
				Time:	

RPM	Exh Temp	Pv Inch	CO	HC	CO2	O2	
3	396.4	3.40	0.01	8	3.11	17.1	
3	408.8	3.40	0.01	8	3.12	17.1	
3	415.6	3.40	0.01	8	3.09	17.1	
3	419.2	3.40	0.01	4	3.09	17.1	
3	422.4	3.40	0.01	4	3.11	17.1	
3.000	**412.480**	**3.400**	**.010**	**6.400**	**3.104**	**17.100**	Mean
0	**10.313**	**.000**	**.000**	**2.191**	**.014**	**.000**	Std Dev

VFHC	VFCO	VFCO2	VFO2	Mtw1	pf1	PF1
6.40E-06	0.0001	.031	.171	29.181	208,814	6,119

Denominator pf1		(d/2)^2*3.1 Denominator				F
0.43315976	872.48	3.14	0.045438291	74.826758	8.6502461	29774.735

Company Name:	Indiana Harbor Belt	***Location:***	Hammond	***Test Date:***	9/10/97
Test Portion:	Treated	***Stack Dian***	24 Inches		
Engine Type:	EMD	***Mile/Hrs:***		***Ambient Temp:***	
Equipment Type	GP38-2	***ID #:***	3801	***Baro:***	29.92
Fuel Sp. Gravity:	.854	***Temp:***			
SG Corr Factor:	1.000			***Time:***	

RPM	Exh Temp	Pv Inch	CO	HC	CO2	O2	
3	407.0	3.40	0.01	5	2.85	17.1	
3	409.9	3.40	0.01	5	2.86	17.1	
3	410.0	3.40	0.01	3	2.85	17.1	
3	412.0	3.40	0.01	3	2.86	17.1	
3	413..8	3.40	0.01	3	2.86	17.1	
3.000	**409.725**	**3.400**	**.010**	**3.800**	**2.856**	**17.100**	Mean
0	**2.058**	**.000**	**.000**	**1.095**	**.005**	**.000**	Std Dev

VFHC	VFCO	VFCO2	VFO2	Mtw2	pf2	PF2
3.80E-06	0.0001	.029	.171	29.141	226,707	6,633

0.3984256	869.73	3.14	0.045582224	74.59048	8.636578	29727.689

Performance factor adjusted for fuel density: 6,633

% Change PF= 8.40

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

Company Name:	Indiana Harbor Belt	***Location***	Hammond	***Date:***	8/4/97
Test Portion:	Baseline	***Stack Dian***	24 Inches		
Engine Type:	EMD	***Mile/Hrs***		***Ambient Temp:***	

Equipment Type:	GP38-2	*ID #:*	3801	*Baro*	29.92
Fuel Sp. Gravity(S	.854	***Temp:***		*Time:*	

RPM	Exh Temp	Pv Inch	CO	HC	CO2	O2	
5	624.2	7.8	0.02	6		16	
5	625.2	7.8	0.02	6		16	
5	633.4	8.0	0.02	9	4.59	16	
5	633.6	8.0	0.02	9	4.56	16	
5	633.2	8.0	0.02	9	4.55	16	
5.000	**629.920**	**7.920**	**.020**	**7.800**	**4.567**	**16.000**	Mean
0	**4.780**	**.110**	**.000**	**1.643**	**.021**	**.000**	Std Dev

VFHC	VFCO	VFCO2	VFO2	Mtw1	pf1	PF1
7.80E-06	0.0002	.046	.160	29.371	142,743	3,063

0.6377822 1089.92 3.14 0.036373312 217.74206 14.756086 50791.45

Company Name:	Indiana Harbor Belt	*Location:*	Hammond		*Test Date:*	9/10/97
Test Portion:	Treated	*Stack Dian*	24	Inches		
Engine Type:	EMD	*Mile/Hrs:*			***Ambient Temp:***	
Equipment Type	GP38-2	*ID #:*	3801		*Baro:*	29.92
Fuel Sp. Gravity:	.854	*Temp:*				
SG Corr Factor:	1.000				*Time:*	

RPM	Exh Temp	Pv Inch	CO	HC	CO2	O2	
5	608	8	0.02	4	4.10	16	
5	609.2	8	0.02	4	4.12	16	
5	610	8	0.02	4	4.12	16	
5	610.2	8	0.02	4	4.11	16	
5	611.2	8	0.02	4	4.11	16	
5.000	**609.720**	**8.000**	**.020**	**4.000**	**4.112**	**16.000**	Mean
0	**1.197**	**.000**	**.000**	**.000**	**.008**	**.000**	Std Dev

VFHC	VFCO	VFCO2	VFO2	Mtw2	pf2	PF2
4.00E-06	0.0002	.041	.160	29.298	158,130	3,345

Denominator pf1		(d/2)^2*3.1 Denominator				F
0.5742908	1069.72	3.14	0.037060165	215.8652	14.692352	50572.074

Performance factor adjusted for fuel density: 3,345

****% Change PF= 9.20**

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