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EVALUATION OF FPC-1® FUEL PERFORMANCE CATALYST

BY

CITY OF SOUTHAVEN, MS

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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.

Field and laboratory tests alike indicate a potential to reduce fuel consumption in diesel fleets in the range of 5% to 10%. This report summarizes the results of controlled back-to-back field tests conducted at the City of Southaven, MS, with and without FPC-1® added to the gasoline and diesel fuel. The procedure applied was the Carbon Balance Exhaust Emission Tests at a given engine load and speed.

EQUIPMENT TESTED

The following vehicles were tested:

- 3 x Crown Victoria Patrol Cars
- 1 x Isuzu Pickup
- 1 x Ford Econoline Ambulance (diesel)
- 2 x Kodiak Rear Dumps (Cat 3208)
- 1 x Garbage Truck (3208)

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, CO2, and O2.

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 hand held photo tachometer for engine speed (rpm) determination where dash mounted tachometers are not available.

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

A hydrometer for fuel specific gravity (density) measurement.

A Hewlett Packard Model 42S programmable calculator for the calculation of the engine performance factors.

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 (CO2, CO, HC), oxygen (02), 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 particulates were collected onto the filter surface and the density determined by comparing the discoloration of the filter paper to a color calibrated scale.

Eight pieces of equipment were tested for both baseline and treated fuel segments. Table 1 below summarizes the percent change in fuel consumption.

Table 1: Fuel Consumption Changes

Unit	Engine	RPM	% Change Fuel Consumption
2	Ford	1900	- 7.87
509	CAT	2000	- 5.55
444	CAT	2000	- 1.48
443	CAT	2000	- 7.64
11	Ford	2350	-12.36
801	Isuzu	2800	-12.67
262	Ford	2550	-21.05
283	Ford	2550	- 8.30

DISCUSSION

1. Fuel Density

Fuel specific gravity (density) for the baseline and treated tests are found on Table 2, along with the correction factors applied to the final engine performance factors (PF). Fuel samples could not be removed from the rolling tanks on the gasoline power vehicles, nor on the ambulance, therefore, fuel density corrections were made to the heavy duty diesel equipment only. However, the change in fuel density affected the rate of fuel consumption by less than 1%, and therefore, would not be expected to have a significant impact on the outcome of the test.

Fuel being consumed by the heavy duty diesels during the FPC-1® treated test was slightly more dense and, therefore, contained more energy. The correction factor corrects fuel consumption to that of the baseline fuel on a fuel density basis only, after the effect of FPC-1 is taken into consideration in the calculation.

2. Emissions Changes, Gasoline vs Diesel Engines

Emissions of carbon monoxide (CO) and unburned hydrocarbons (HC) were reduced in all gasoline power engines after FPC-1 fuel treatment. The reverse was true for the diesel engines, with the only exception being the Ford Econoline Ambulance. This is likely the result of two known facts about FPC-1 and engine performance.

Engine Pre-Conditioning

First, laboratory studies have documented a distinct engine pre-conditioning period before maximum fuel savings can be realized (Southwest Research Institute {SwRI} and Systems Control Engineering {SCI} studies). In connection with this engine conditioning time lag requirement, there is a similar lag before the products of incomplete combustion (CO, HC, and smoke) will be positively affected. These same studies indicate the engine pre-conditioning period is much shorter for gasoline power engines (approx. 60 to 100 hours) than diesel power vehicles (150 to 500 hours), perhaps due to the inherently cleaner combustion surfaces in the gasoline power engine. It is because of the engine pre-conditioning period that UHI recommends a minimum 300 hours of actual engine operation with FPC-1 treated fuel before the treated fuel test is run.

The gasoline power portion of the Southaven test fleet accumulated more test miles than the diesel power portion. The treated fuel mileage for the gasoline fleet also exceeds that of the vehicles tested in the various lab tests conducted with the FPC-1 catalyst (SCI, ATL, BYU). Therefore, these engines would be expected to experience greater improvements in both emissions reductions and fuel savings than the diesel power fleet in a shorter period of time. This was the case with the Southaven test fleet.

Engine studies with diesels reveal a minimum 160 (SwRI) and up to 500 (Ore-Ida Foods) engine hour pre-conditioning period before maximum benefit from FPC-1 use is realized. This time lag appears to be extended if the diesel engines are subject to adverse operating conditions, such as high idle time, heavy stop and go driving, or extremely cold climate. For example, over-the-road truck fleets respond to FPC-1 fuel treatment much faster than construction and mining fleets.

In the case of the Southaven test, the two dump trucks, and the garbage truck had accumulated approximately 2,000 miles or less with FPC-1 treated fuel. Assuming an average of 30 miles per hour, the heavy duty diesel fleet accumulated the equivalent of 66 hours of engine operation (approx. 1/3rd to 1/8th of the time needed) in terms of actual miles driven. The remainder of the time these trucks operated must have been either idling or moving garbage, etc. This kind of work load would tend to extend the pre-conditioning period as engine temperatures, fuel/air ratios, etc., would be less than optimum much of the time the engines were operating. This portion of the test fleet will likely require an additional 5,000 to 10,000 miles before engine stabilization takes place and maximum benefit is realized.

Conversely, the ambulance operated almost 4,000 miles on treated fuel. Emissions from the ambulance engine were slightly improved. Apparently, the ambulance operated more of the time at temperatures that are closer to optimum for the diesel engine.

Second, ambient air (and therefore, intake air) was much colder (42 to 43 degrees F), and more humid (93%) during the treated test. Baseline air temperatures were in the upper 60s; Humidity was also lower (it was a clear day with no rainfall). Colder intake air temperatures are known to reduce the rate of pressure rise inside the combustion chamber. Increased humidity also decreases the oxygen per unit volume of fresh air ingested by the engine, having the effect of enriching the fuel/air ratio. Both lower air temperature and higher humidity combine to reduce flame propagation, increasing the formation of the products of incomplete combustion. The effect would be more profound in diesel engines due to the diffusion type flame (fuel injected). The pre-mix flame in a gasoline engine would tend to minimize the negative effect of colder intake temperatures and higher humidity.

3. The Effect of Air Temperature and Barometric Pressure on Fuel Consumption

Average air temperature was in the high 60s for the baseline test and in the low 40s for the treated fuel tests. Barometric pressure for the base fuel test averaged 29.75 inches of mercury ("Hg). Barometric pressure averaged 29.68 "Hg for the treated fuel test. The skies were clear during the baseline; Skies were overcast and there was rainfall during the treated fuel test.

These data were used to correct engine parameters to standard conditions. Therefore, ambient conditions were corrected for and had little impact upon the fuel consumption changes, although emissions could be negatively effected by the colder, more humid ambient conditions.

The equations for the carbon balance, including the corrections for ambient conditions are found on Figure 1 in the Appendices. A sample calculation is also found in the Appendices on Figure 2.

4. Units 1262 and 444

The data from Unit 1262 indicates a 21% reduction in fuel consumption. The data from Unit 444 indicates a 1.48% reduction in fuel consumption. Both results fall outside of the range of normal distribution for the test fleet and are, therefore, considered anomalies. These are not included in the body of data used to compute the average reduction in fuel consumption with FPC-1 treated fuel.

CONCLUSIONS

1) The fuel consumption change determined by the carbon balance method ranged from a 5.55% to -12.67%. The fleet averaged a 9.06% reduction in fuel consumed.

2) The average reduction in fuel consumption for the gasoline power fleet is 11.11%.

3) The average reduction for the diesel power fleet is 7.02%.

4) Unburned hydrocarbons (HC) and carbon monoxide (CO) emissions were reduced 40% and 79.5%, respectively, in the gasoline power engines, a result of the improved combustion created by the addition of FPC-1 and sufficient time to reach full engine pre-conditioning after catalyst treatment.

5) Emissions of HC and CO increased 26.5% and 42%, respectively, after FPC-1® treatment. As discussed above, this is a result of insufficient engine pre-conditioning. The colder intake air temperature and increased relative humidity, which would have a more profound impact upon diesel engine combustion, may have contributed to the increase in emissions.

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, oil, and exhaust temperature, and exhaust pressure. No exhaust gas measurements were made until each engine had stabilized at the rpm selected for the test. Premium unleaded gasoline and #2 diesel were used exclusively throughout the evaluation. Fuel specific gravity (density) and temperature were taken before testing.

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. Rpm, exhaust temperature, exhaust pressure, and intake air temperature 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 measured during the test, the molecular weight of each constituent, and the temperature and density of the exhaust stream , the fuel consumption may be expressed as a "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.

A sample calculation is found in Figure 2. All performance factors are rounded off to the nearest meaningful place in the sample.

Table 2: Fuel Density (specific gravity) Comparison

Unit #	Base Fuel SG	Treated Fuel SG	*PF Correction Factor
443	.853	.855	0.9977
444	.846	.860	0.9835
509	.850	.860	0.9882

Table 3: Summary of Emissions Data
Gasoline Engines

	Base Fuel				FPC-1® Fuel			
Unit #	CO%	HC	CO2%	RPM	CO%	HC	CO2%	RPM
1283	.010	4.50	14.14	2481	.010	3.33	13.13	2540
1262	.010	5.33	8.99	2555	.000	6.00	7.09	2533
801	.048	3.33	14.03	2796	.007	1.33	14.19	2779
11	.010	15.0	9.55	2337	.000	6.17	7.55	2345
FLEET AVE.	**.0195**	**7.04**	**11.68**	**2542**	**.004**	**4.21**	**10.49**	**2549**
% Change from Base Fuel:					**-79.5**	**-40.2**	**-10.18**	**+0.27**

Diesel Engines

	Base Fuel				FPC-1® Fuel			
Unit #	CO%	HC	CO2%	RPM	CO%	HC	CO2%	RPM
2	.030	4.92	2.23	1924	.030	4.00	2.00	1911
509	.030	10.40	1.73	2000	.047	12.00	1.56	2000
444	.040	13.43	1.60	2000	.070	20.33	1.48	2000
443	.052	13.67	1.61	2000	.070	17.33	1.49	2000
FLEET AVE.	**.038**	**10.60**	**1.75**	**1981**	**.054**	**13.41**	**1.63**	**1978**
% Change from Base Fuel:					**+42.0**	**+26.5**	**-6.85**	**-0.20**

Table 4: Summary of Barometric Pressure Readings

Base Ave.	29.70 "Hg
Treated Ave.	29.68 "Hg

Tables 5-12: Carbon Balance Calculation of Fuel Consumption Changes

Table 5: Unit 2

Mwt1	29.0531	Mwt2	29.0222
pf1	272,870	pf2	303,503
PF1	538,753	PF2	581,147

% Change PF = 538,753-581,147= 42,394/538,753=.0787

***% Change PF = + 7.87%**

Table 6: Unit 11

Mwt1	29.8249	Mwt2	29.5364
pf1	66,245	pf2	83,109
PF1	3,000,605	PF2	3,371,488

% Change PF = 3,371,488-3,000,605 = 370,883/3,000,605 = .1236

***% Change PF = + 12.36%**

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

Table 7: Unit 443

Mwt1	28.9926	Mwt2	28.9827
pf1	368,963	pf2	390,202
PF1	428,457	PF2	462,266

462,266(.9977)= 461202

% Change PF = [(461202-428,457)/428457](100)

***% Change PF = + 7.64%**

Table 8: Unit 444

Mwt1	28.9817	Mwt2	23.9789
pf1	374,170	pf2	354,686
PF1	493,201	PF2	508,912

508,912(.9835)= 500,515

% Change PF = [(500,515-493,201)/493,201](100)

***% Change PF = + 1.48%**

Table 9: Unit 509

Mwt1	28.9965	Mwt2	28.9862
pf1	343,509	pf2	379,972
PF1	374,656	PF2	400,186

400,186(0.9882)= 395,464

% Change PF = [(395,464-374,656)/374,656](100)

***% Change PF = +5.55%**

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

Table 10: Unit 801

Mwt1	30.3110	Mwt2	30.2773
pf1	45,757	pf2	45,327
PF1	1,451,567	PF2	1,635,517

% Change PF = 1,635,517-1,451,567 = 183,950/1,451,567 = .1267

***% Change PF = +12.67%**

Table 11: Unit 1262

Mwt1	29.7695	Mwt2	29.4967
pf1	70,279	pf2	88,381
PF1	2,125,947	PF2	2,573,485

% Change PF = 2,573,485-2,125,947 = 447,538/2,125,947 = .2105

***% Change PF = +21.05%**

Table 12: Unit 1283

Mwt1	30.3007	Mwt2	30.1010
pf1	45,505	pf2	48,683
PF1	1,705,180	PF2	1,847,038

% Change PF = 1,847,030-1,705,180 = 141,850/1,705,180 = .0830

***% Change PF= 8.30%**

Figure 1
CARBON MASS BALANCE FORMULA

ASSUMPTIONS: C_8H_{15} and SG = 0.78
Time is constant
Load is constant

DATA:

Mwt = Molecular Weight
pf_1 = Calculated Performance Factor (Baseline)
pf_2 = Calculated Performance Factor (Treated)
PF_1 = Performance Factor (adjusted for Baseline exhaust mass)
PF_2 = Performance Factor (adjusted for Treated exhaust mass)
T = Temperature (^oF)
F = Flow (exhaust CFM)
SG = Specific Gravity
VF = Volume Fraction
- $VFCO_2$ = "reading" ÷ 100
- VFO_2 = "reading" ÷ 100
- VFHC = "reading" ÷ 1,000,000
- VFCO = "reading" ÷ 100

EQUATIONS:

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

$$pf_1 \text{ or } pf_2 = \frac{2952.3 \times Mwt}{89(VFHC)+13.89(VFCO)+13.89(VFCO_2)}$$

$$PF_1 \text{ or } PF_2 = \frac{pf \times (T+460)}{F}$$

FUEL ECONOMY:
PERCENT INCREASE (OR DECREASE)

$$\frac{PF_2 - PF_1}{PF_1} \times 100$$

Figure 2.

SAMPLE CALCULATION FOR THE CARBON MASS BALANCE

Baseline:

Equation 1 Volume Fractions

$$VFCO2 = 1.932/100 = 0.01932$$

$$VFO2 = 18.95/100 = 0.1895$$

$$VFHC = 9.75/1{,}000{,}000 = 0.00000975$$

$$VFCO = 0.02/100 = 0.0002$$

Equation 2 Molecular Weight

$$Mwt1 = (0.00000975)(86)+(0.0002)(28)+(0.01932)(44)+(0.1895)(32) + [(1-0.00000975-0.0002-0.1895-0.01932)(28)]$$

$$Mwt1 = 29.0677$$

Equation 3 Calculated Performance Factor

$$pf1 = \frac{2952.3 \times 29.0677}{86(0.00000975)+13.89(0.0002)+13.89(0.01932)}$$

pf1 = 316,000 (rounded to nearest meaningful place)

Equation 4 Corrected Performance Factor

$$PF1 = \frac{316{,}000\ (357\ \text{deg F} + 460)}{850\ \text{cfm}}$$

PF1 = 304,000 (rounded)

Treated:

Equation 1 Volume Fractions

VFCO2 = 1.832/100
= 0.01832

VFO2 = 18.16/100
= 0.1816

VFHC = 10.2/1,000,000
= 0.0000102

VFCO = .02/100
= 0.0002

Equation 2 Molecular Weight

$$Mwt2 = (0.0000102)(86)+(0.0002)(28)+(0.01832)(44)+(0.1816)(32) + [(1-0.0000102-0.0002-0.1816-0.01832)(28)]$$

Mwt2 = 29.0201

Equation 3 Calculated Performance Factor

$$pf2 = \frac{2952.3 \times 29.0201}{86(0.0000102)+13.89(0.0002)+13.89(0.01832)}$$

pf2 = 332,000 (rounded)

Equation 4 Corrected Performance Factor

$$PF2 = \frac{332{,}000\ (357\ \text{deg F} + 460)}{850\ \text{cfm}}$$

PF2 = 319,000 (rounded)

Equation 5 Percent Change in Engine Performance Factor:

% Change PF = [(319,000 - 304,000)/304,000](100)

= *+ 4.9%

* Equates to a 4.9% reduction in fuel consumption.