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EVALUATION OF FPC-1® FUEL PERFORMANCE CATALYST

AT

Boise Urban Stages

REPORT PREPARED BY
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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 9%.

This report summarizes the results of controlled back-to-back field tests conducted by BOISE URBAN STAGES, Boise, Idaho, with and without FPC-1® added to the fuel. The test procedure applied was the Carbon Balance Exhaust Emission Tests at a given engine load and speed.

EQUIPMENT TESTED

The following bus engines were tested:

4 x 6V92 Detroits
1 x 6V71 Detroit

TEST EQUIPMENT:

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.

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 hydrometer for fuel specific gravity (density) measurement.

A Bacharach True-Spot Smoke meter for determining exhaust smoke density.

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 (O2), 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 Appendix 1.

Fuel 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. A significant change in fuel density (measured as its specific gravity) can lead to inaccuracies in the test results, unless corrected for.

Five buses were tested for both baseline and treated fuel segments. Table 1 below summarizes the percent change in fuel consumption documented with the carbon balance on an individual unit basis.

Table 1:
Summary of Carbon Balance Fuel Consumption Changes

Unit	Engine	RPM	% Change Fuel Consumed
403	6V92 Detroit	1580	- 1.53
408	6V92 Detroit	1550	- 9.00
410	6V92 Detroit	1580	- 7.50
402	6V92 Detroit	1430	- 9.55
303	6V71 Detroit	1511	- 6.34

DISCUSSION

1) Changes in CO and HC

Baseline emissions of carbon monoxide (CO) and unburned hydrocarbons (HC) were extremely low. CO ranged from 0.010 to 0.014%; HC ranged from 4.8 to 7.8 parts per million (ppm). Previous laboratory and field tests document FPC-1® has little effect upon CO and HC where these are already near zero. The Boise Urban Stages fleet was no exception.

FPC-1® fuel treatment produced a 14% reduction in HC (hexane gas). CO emissions were also reduced slightly (5.5%), but not significantly.

2) Exhaust Odor and Smoke

Exhaust odor (due to unburned fuel) was significantly reduced with FPC-1® treatment. Engine smoke was also visibly reduced. The smoke density test verified all of the buses in the fleet were smoking less on FPC-1® treated fuel. Bacharach smoke density data indicate an 18.2% reduction in particulate density in the exhaust stream.

CONCLUSIONS

1) The fuel consumption change determined by the carbon balance method for the fleet, ranges from - 1.53% to - 9.55%. The fleet average reduction in fuel consumed is approximately 6.78%

2) Unburned hydrocarbons decreased 14%, while carbon monoxide was directionally improved (5.5%).

3) Diesel odor and visible smoke were reduced after FPC-1® treatment. The smoke density test confirmed an 18.2% reduction in smoke particulate in the exhaust.

APPENDICES

CARBON BALANCE METHOD TECHNICAL APPROACH:

A fleet of diesel buses owned and operated by BOISE URBAN STAGES was selected for the FPC-1® field test. The fleet was made up of buses powered by 6V92 and 6V71 Detroit bus engines.

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.

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. # 2 Diesel fuel was exclusively used for the diesel fleet throughout the evaluation. Fuel specific gravity 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 and intake air temperature were also recorded at approximately 90 second intervals.

Smoke density readings were also recorded under the same steady-state engine conditions noted above.

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). Additional fuel supplied to BOISE URBAN STAGES after the baseline was also treated.

Throughout the baseline and treated test measurement process, 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.
Summary of Emissions Data

	Base Fuel				FPC-1® Fuel			
Unit #	**CO%**	**HC**	**CO2%**	**RPM**	**CO%**	**HC**	**CO2%**	**RPM**
403	.010	5.3	1.89	1580	.010	5.2	2.067	1582
408	.010	4.8	1.68	1550	.010	5.4	1.656	1551
410	.010	6.3	1.64	1580	.010	5.3	1.700	1581
402	.014	7.6	1.51	1430	.011	7.8	1.506	1430
303	.010	7.8	1.54	1511	.010	3.7	1.527	1510

Table 3.
Bacharach Smoke Number (Density) Comparison

Unit #	Base Fuel Ave.	FPC-1® Fuel Ave.	% Change
403	3.75	*3.00	- 20
408	4.50	4.00	- 11
410	3.75	3.00	- 20
402	3.75	3.50	- 7
303	6.00	4.00	- 33

* A smaller smoke number indicates less smoke particulate in the exhaust.

Table 4
Summary of Ambient Conditions

	Ave. Air Temperature	Barometric Pressure (uncorrected)
Baseline	61-69 deg F	27.120
Treated	79-88 deg F	27.000-27.023

Table 5
Fuel Density (specific gravity) Comparison

	Base Fuel SG	Treated Fuel SG	Correction Factor
Diesel	.833	*.832	1.0012

* A lower specific gravity indicates a less dense fuel.

Calculation of Fuel Consumption Changes

Table 6
403/1580 RPM

Mwt1	29.0129	Mwt2	29.0266
pf1	324,174	pf2	296,583
PF1	265,893	PF2	269,644

269,644 (1.0012) = 269,968

% Change PF = [(269,968 - 265,893)/265,893](100)

***% Change PF = + 1.53%**

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

Table 7
408/1550 RPM

Mwt1	28.9923	Mwt2	28.9905
pf1	363,981	pf2	367,120
PF1	294,070	PF2	320,251

320,251 (1.0012) = 320,635

% Change PF = [(320,635 - 294,070)/294,070](100)

***% Change PF = + 9.00%**

Table 8
410/1580 RPM

Mwt1	28.9928	Mwt2	28.9923
pf1	371,469	pf2	359,677
PF1	314,266	PF2	337,431

337,431 (1.0012) = 337,835

% Change PF = [(337,835 - 314,266)/314,266](100)
***% Change PF = + 7.50%**

Table 9

402/1430 RPM

Mwt1	28.9724	Mwt2	28.9694
pf1	404,155	pf2	404,606
PF1	344,590	PF2	373,749

373,749 (1.0012) = 374,197

% Change PF = [(374,197 - 344,590)/344,590](100)

***% Change PF = + 9.55%**

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

Table 10

303/1511 RPM

Mwt1	28.9797	Mwt2	28.9769
pf1	394,884	pf2	400,120
PF1	286,244	PF2	304,040

304,040 (1.0012) = 304,405

% Change PF = [(304,405 - 286,244)/286,244](100)

***% Change PF = + 6.54%**

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

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
Pb	=	Barometric pressure in inches of mercury
Te	=	Exhaust temperature ^{O}F

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

EQUATIONS:

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

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

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

PF1 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)

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

$$pf1 = 329{,}809$$

Equation 4 (CFM Calculations)

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

d =Exhaust stack diameter in inches
Pv =Velocity pressure in inches of H_20
Pb =Barometric pressure in inches of mercury
Te =Exhaust temperature ^0F

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

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)

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

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

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

$$CFM = 2320.51$$

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.