# EVALUATION OF FPC-1® FUEL PERFORMANCE CATALYST

## BY

## EG&G Idaho, Inc.

## AT

## Idaho National Engineering Laboratory

REPORT PREPARED BY
FPC Technology, Inc.
Boise, Idaho

and

UHI Corporation
Provo, Utah

September 12, 1993

Report No. B 102R

<u>**CONTENTS**</u>

# 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 Idaho National Engineering Laboratory (INEL) by EG&G Idaho, Inc., 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:

8 x Detroit 6V92 TA engines

## 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.

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 smoke spot meter to determine the density of exhaust smoke.

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 (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 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.

Exhaust smoke density was also measured to determine the effect of FPC-1® on this product of incomplete combustion. The change in smoke density is not used in the carbon balance calculation.

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

**Table 1:**

Summary of Carbon Balance Fuel Consumption Changes

| Unit | Engine | RPM | % Change Fuel Consumption |
|---|---|---|---|
| 327 | DT 6V92 TA | 1000 | - 9.97 |
| 322 | DT 6V92 TA | 950 | -11.81 |
| 421 | DT 6V92 TA | 748 | -11.46 |
| 401 | DT 6V92 TA | 1000 | - 9.57 |
| 365 | DT 6V92 TA | 900 | - 4.58 |
| 348 | DT 6V92 TA | 1000 | -11.02 |
| 371 | DT 6V92 TA | 1000 | - 6.32 |
| 389 | DT 6V92 TA | 900 | -12.50 |

# DISCUSSION

### 1. Change in Exhaust Smoke Density

Smoke was reduced in all buses tested. Smoke density on a fleet average was reduced 45% with FPC-1® treated fuel, inspite of a switch from a winter blend fuel to a summer blend fuel (fuel density increased from a baseline specific gravity of .821 to a treated fuel specific gravity of .833).

These data agree with the observations of the testing technicians and several drivers who have commented on the less dense, lighter colored smoke.fuel test. Table 2 in the Appendices summarizes the changes in smoke density.

Table 2 also presents a correlation between the smoke spot numbers and the smoke opacity readings taken after FPC-1® had been used by the bus fleet some three months. No base fuel opacity readings are available. The correlation between the two methods is fairly good, however, it must be noted the procedures are quite different.

The smoke spot test was conducted at high idle and under steady-state engine conditions. The opacity test is an accelerator pedal "snap" test, with the meter recording peak smoke density or opacity when smoke concentrations are greatest.

### 2. Fuel Density

Fuel specific gravity (density) for the baseline and treated tests are found on Table 3, along with the correction factors applied to the final engine performance factors (PF). Fuel being consumed by the EG&G during the FPC-1® treated test was more dense and, therefore, contained more energy. This is consistent with the reported change from a winter blend fuel to a summer blend, which would logically be somewhat heavier.

### 3. Emissions Changes

Baseline CO and HC emissions were low, averaging .0125% and 12.9 part per million (ppm), respectively. However, although produced in lower concentrations than seen in other bus fleets tested in the past, FPC-1® still had a significant impact upon CO producing a 16.8% reduction. However, the catalyst had no effect, negative or positive, upon HC. Table 4 summarizes the emissions data.

Also, exhaust odor created by unburned fuel in the exhaust was much less noticeable with FPC-1® treatment. This, too, is consistent with the CO and smoke reductions.

### 4. Effect of Ambient Conditions

Average air temperature was in the high 60s to low 70s for the base fuel test. Barometric pressure for the base fuel test averaged 29.80 inches of mercury ("Hg). Average air temperature for the treated test was in the upper 70s to low 80s. Barometric pressure was 30.15 "Hg. 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. The mathematics 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.

## CONCLUSIONS

1) The fuel consumption change determined by the carbon balance method ranged from a - 4.58% to -12.50%. The fleet averaged a 9.4% reduction in fuel consumed.

2) Smoke density using the Bacharach smoke spot method at a high idle was reduced 45%. The opacity meter test with FPC-1® treated fuel shows a good correlation between the smoke spot meter readings at high idle and peak smoke density at full throttle (snap test).
This is consistent with driver reports of less smoke from buses they are following.

3) Unburned hydrocarbons and carbon monoxide emissions were extremely low during base fuel testing. HC emissions remained unchanged FPC-1® treatment. However, CO was reduced 16.8% after FPC-1® treatment.

4) Exhaust odor was reduced. This is consistent with the reductions in CO and smoke.

# APPENDICES

## CARBON BALANCE METHOD TECHNICAL APPROACH:

A fleet of 6V92 TA powered buses operated by EG&G Idaho, Inc. for INEL was selected for the FPC-1® field test.

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 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, 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 diesel 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:**
Smoke Density Comparison

| Unit | Base Smoke # | FPC-1® Treated Smoke # | % Change | *%Opacity |
|---|---|---|---|---|
| 327 | 3.50 | 3.00 | -14.29 | 76.00 |
| 322 | 8.00 | 4.50 | -43.75 | 26.90 |
| 421 | 4.50 | 2.50 | -44.44 | 23.10 |
| 348 | 7.25 | 4.50 | -37.93 | 51.75 |
| 401 | 8.25 | 3.50 | -57.58 | 23.00 |
| 365 | 6.50 | 3.00 | -53.85 | 4.70 |
| 371 | 7.75 | 4.50 | -41.94 | 27.60 |
| 389 | 8.00 | 4.00 | -50.00 | 27.20 |
| **Fleet Average:** | **6.72** | **3.69** | **-45.09** | **32.53** |

* Opacity readings were taken with a Bosch Smoke meter after FPC-1® fuel treatment.

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**Table 3:**
Fuel Density (specific gravity) Comparison

| Base Fuel SG | Treated Fuel SG | PF Correction Factor |
|---|---|---|
| .821 | .833 | *0.9854 |

* The correction factor for fuel density is used to correct the final engine performance factor (PF).

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**Table 4:**
Summary of Emissions Data

| | Base Fuel | | | | FPC-1® Fuel | | | |
|---|---|---|---|---|---|---|---|---|
| Unit # | CO% | HC | CO2% | RPM | CO% | HC | CO2% | RPM |
| 327 | .010 | 12.3 | 1.283 | 950 | .010 | 11.7 | 1.083 | 950 |
| 322 | .012 | 15.4 | 1.292 | 1000 | .010 | 12.3 | 1.052 | 1000 |
| 421 | .013 | 10.0 | 1.392 | 749 | .013 | 11.8 | 1.234 | 748 |
| 348 | .020 | 13.8 | 1.464 | 1000 | .010 | 13.8 | 1.177 | 1000 |
| 401 | .010 | 13.6 | 1.526 | 1000 | .010 | 15.4 | 1.332 | 1000 |
| 365 | .010 | 13.0 | 1.256 | 900 | .010 | 11.6 | 1.052 | 900 |
| 371 | .015 | 14.5 | 1.425 | 1000 | .010 | 14.2 | 1.232 | 1000 |
| 389 | .010 | 10.5 | 1.470 | 900 | .010 | 12.6 | 1.186 | 900 |
| FLEET AVE. | **.0125** | **12.9** | **1.388** | **937** | **.0104** | **12.9** | **1.168** | **937** |
| **% Change from Base Fuel:** | | | | | **-16.8** | **NC** | **-15.85** | **NC** |

**Table 5:**
Summary of Ambient Conditions

| | Ave. Air Temperature | Barometric Pressure |
|---|---|---|
| Base | 69.50 deg F | 29.80 "Hg |
| Treated | 80.00 deg F | 30.15 "Hg |

Carbon Balance Calculation of Fuel Consumption Changes

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# Calculation of Fuel Comparision Changes

**Table 6**
327/1000 RPM

| | | | |
|---|---|---|---|
| Mwt1 | 228.9540 | Mwt2 | 28.9070 |
| pf1 | 473,171 | pf2 | 574,416 |
| PF1 | 499,305 | PF2 | 557,207 |

557,207(.9854) = 549,072

**% Change PF = [(549,072 - 499,305)/499,305](100)**

***% Change PF = + 9.97%**

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**Table 7**
322/950 RPM

| | | | |
|---|---|---|---|
| Mwt1 | 28.9588 | Mwt2 | 28.9100 |
| pf1 | 468,595 | pf2 | 558,492 |
| PF1 | 516,272 | PF2 | 585,785 |

585,785(.9854) = 577,232

**% Change PF = [(577,232 - 516,272)/516,272](100)**

***% Change PF = + 11.81%**

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

## Table 8

421/750 RPM

| | | | |
|---|---|---|---|
| Mwt1 | 28.9733 | Mwt2 | 28.9189 |
| pf1 | 436,385 | pf2 | 490,046 |
| PF1 | 519,806 | PF2 | 587,979 |

587,979(.9854) = 579,395

**% Change PF = [(579,395 - 519,806)/519,806](100)**

***% Change PF = + 11.46%**

## Table 9

348/1000 RPM

| | | | |
|---|---|---|---|
| Mwt1 | 28.9682 | Mwt2 | 28.9151 |
| pf1 | 412,499 | pf2 | 514,059 |
| PF1 | 589,718 | PF2 | 664,423 |

664,423(.9854) = 654,723

**% Change PF = [(654,723 - 589,718)/589,718](100)**

***% Change PF = + 11.02%**

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## Table 10

401/1000 RPM

| | | | |
|---|---|---|---|
| Mwt1 | 28.9785 | Mwt2 | 28.9303 |
| pf1 | 398,813 | pf2 | 454,293 |
| PF1 | 438,372 | PF2 | 478,563 |

478,563(.9854) = 471,576

**% Change PF = [(471,576 - 438,372)/438,372](100)**

***% Change PF = + 7.57%**

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

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## Table 11

365/900 RPM

| | | | |
|---|---|---|---|
| Mwt1 | 28.9521 | Mwt2 | 28.9090 |
| pf1 | 483,006 | pf2 | 574,698 |
| PF1 | 526,611 | PF2 | 558,893 |

558,893(.9854) = 550,734

**% Change PF = [(550,734 - 526,611)/526,611](100)**

***% Change PF = + 4.58%**

**Table 12**
371/1000 RPM

| | | | |
|---|---|---|---|
| Mwt1 | 28.9455 | Mwt2 | 28.9211 |
| pf1 | 424,647 | pf2 | 471,461 |
| PF1 | 619,545 | PF2 | 668,432 |

668,432(.9854) = 658,673

**% Change PF = [(658,673 - 619,545)/619,545](100)**

***% Change PF = + 6.32%**

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**Table 13**
389/900 RPM

| | | | |
|---|---|---|---|
| Mwt1 | 28.9656 | Mwt2 | 28.9185 |
| pf1 | 414,170 | pf2 | 510,598 |
| PF1 | 502,920 | PF2 | 574,149 |

574,149(.9854) = 565,767

**% Change PF = [(565,767 - 502,920)/502,920](100)**

***% Change PF = + 12.50%**

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

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

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

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

Figure 2.

## SAMPLE CALCULATION FOR THE CARBON MASS BALANCE

### BASELINE:

**Equation 1 (Volume Fractions)**

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)**

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

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

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

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)**

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

$$\text{Mwt2} = 28.980$$

**Equation 3 (Calculated Performance Factor)**

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

$$\text{pf2} = 349{,}927$$

**Equation 4 (CFM Calculations)**

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

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

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

$$\text{CFM} = 2320.51$$

**Equation 5 (Corrected Performance Factor)**

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

$$= 115{,}966$$

**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:)**

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

$$\% \text{ Change PF} = [(116{,}384 - 108{,}115)/108{,}115](100)$$

$$= +7.65$$

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