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EVALUATION OF FPC-1® FUEL PERFORMANCE CATALYST

AT

DISTRIBUTION TRUCKING COMPANY

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. The products of incomplete combustion are also positively affected.

Field and laboratory tests alike indicate a potential to reduce fuel consumption in diesel fleets in the range of 5% to 10%. Smoke and carbon monoxide emissions are reduced 15 to 30%. This report summarizes the results of controlled back-to-back field tests conducted by Distribution Trucking Company, Portland, OR, with and without FPC-1® added to the diesel fuel. The fuel consumption determination procedure applied was the Carbon Balance Exhaust Emission Tests at a given engine load and speed. This same method also measures the exhaust concentrations of carbon monoxide and unburned hydrocarbons. Smoke testing was conducted using the Bacharach Smokemeter method.

EQUIPMENT TESTED

The following engines were tested:

- 4 x Series 60 Detroit Diesels
- 2 x 3406B Cats
- 1 x NT-14 Cummins
- 1 x NTC-400 Cummins

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 (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.

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 over-the-road trucks 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
199	Cummins NT400	2000	- 7.66
210	CAT 3406B	1600	- 7.58
240	CAT 3406B	1700	- 12.12
273	S-60 Detroit	1900	- 5.16
274	S-60 Detroit	1900	- 5.52
294	S-60 Detroit	1800	- 3.12
311	S-60 Detroit	1600	- 6.48
313	Cummins NT14	1570	- 11.52

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). The correction factor adjusts the energy content of the treated fuel to that of the baseline fuel.

2. Emissions Changes

Emissions of carbon monoxide (CO) and unburned hydrocarbons (HC) were directional improved after FPC-1 fuel treatment. The small reduction in these gases is likely the result of the extremely low concentrations being produced by the engines even on base fuel. This is supported by the fact that the greatest reductions occurred in engines with high base fuel CO and HC output.

Previous laboratory and field test data are consistent with the results of the DTC test. Almost universally, when the gaseous products of incomplete combustion are low with base fuel, FPC-1 effects little change. However, when these same gases are produced at higher base concentrations, FPC-1 is effective in lowering the emissions.

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

Average air temperature was in the low to mid 50s for the baseline test and in the low to mid 70s for the treated fuel tests. Barometric pressure for the base test ranged from 30.27 to 30.47 inches of mercury (" Hg). For the treated fuel test, barometric pressure ranged from 29.85 to 30.05 " Hg. These data were used to correct engine parameters to standard conditions. The corrections to ambient conditions and fuel energy content mentioned in section 1 effectively eliminate any impact upon fuel consumption created by factors not related to the action of the FPC-1 catalyst.

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. The Effect of FPC-1 upon Smoke Density

The DTC test provided the opportunity to conduct smoke density testing in an A-B-A or a base fuel-treated fuel-return to base fuel format. The fleet was first tested using base fuel under steady-state engine conditions. The base fuel was then treated with FPC-1 and put back into normal operation for several hundred hours in order to condition the engines. After conditioning, the steady-state test procedure was repeated with treated fuel. After this test, the use of FPC-1 treated fuel was discontinued for another several hundred hours in an attempt to return to base fuel engine performance. Finally, the test procedure was repeated once again with no FPC-1 fuel treatment.

The results are summarized on Table 4 of the Appendices.

Smoke density was determined using the Bacharach smoke spot method. The Bacharach True-Spot smokemeter measures smoke density by drawing a specific volume of exhaust gas through a fine paper filter medium (20 micron) while the engine is operating at a fixed rpm and under steady-state engine conditions. The smoke particles are trapped on the surface of the filter paper as the exhaust gases are drawn through it forming a darken area called a "smoke spot". The filter paper is then removed from the smoke testor and the smoke spot visually compared to a precoded smoke scale. A smoke number is then assigned to the smoke spot according to the darkness of the spot.

The smoke number scale ranges from 0 to 9. Higher smoke numbers correspond to darker smoke spots, which correspond to a greater smoke density in the exhaust.

It was obvious to testing technicians that the DTC test fleet smoked less with FPC-1 treated fuel. Each truck was brought to the test site, parked and the accelerator locked at a fixed engine rpm while exhaust gas readings were taken. During base fuel testing, the exhaust was darker and had a strong diesel odor, both of which are produced by incomplete combustion. After FPC-1 treatment and engine conditioning, the exhaust gases were visibly cleaner and the diesel odor was noticeably reduced. The Bacharach smoke test confirmed the visual reduction in exhaust smoke.

Reductions in smoke emissions and unburned hydrocarbons (precursors to aldehydes and acrolein) are prime evidences of improved combustion (Germane, SAE Technical Paper # 831204). Further, reduced exhaust smoking has been shown as the one of first evidences that engine carbon residue and soot blowby into the motor oil are also being reduced (ibid). The reductions in exhaust smoke and odor are logical extensions of improved combustion created by FPC-1.

CONCLUSIONS

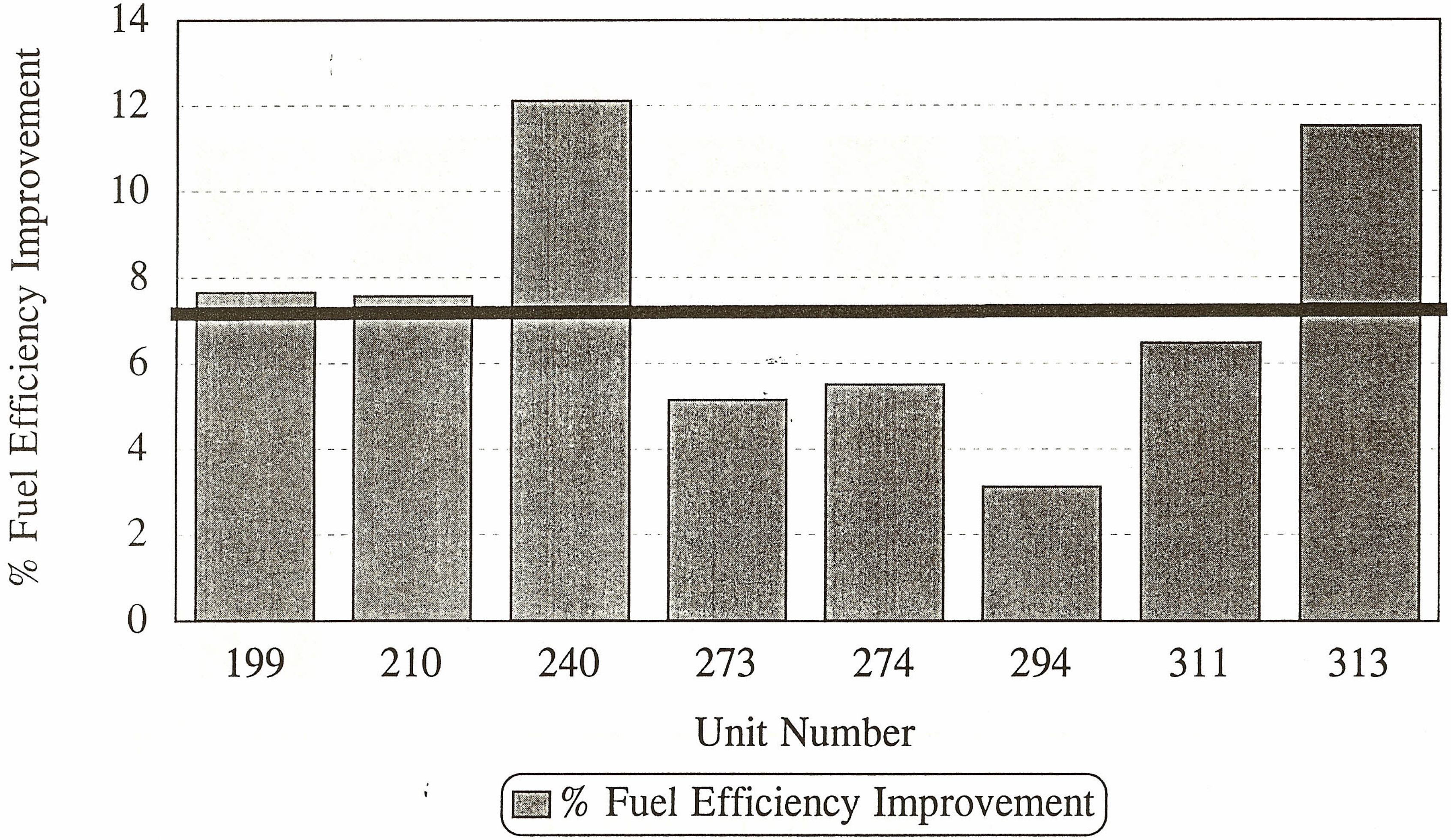
1) The fuel consumption change determined by the carbon balance method ranged from a - 3.12% to - 12.12%. The fleet averaged a 7.40% reduction in fuel consumed.

2) Smoke density was reduced approximately 17%.

3) Carbon monoxide (CO) and unburned hydrocarbon (hexane gas) emissions were directional improved after FPC-1 fuel treatment. Both gases were very low when running on base fuel, and therefore, the potential for improvement was diminished.

Distribution Trucking Co.

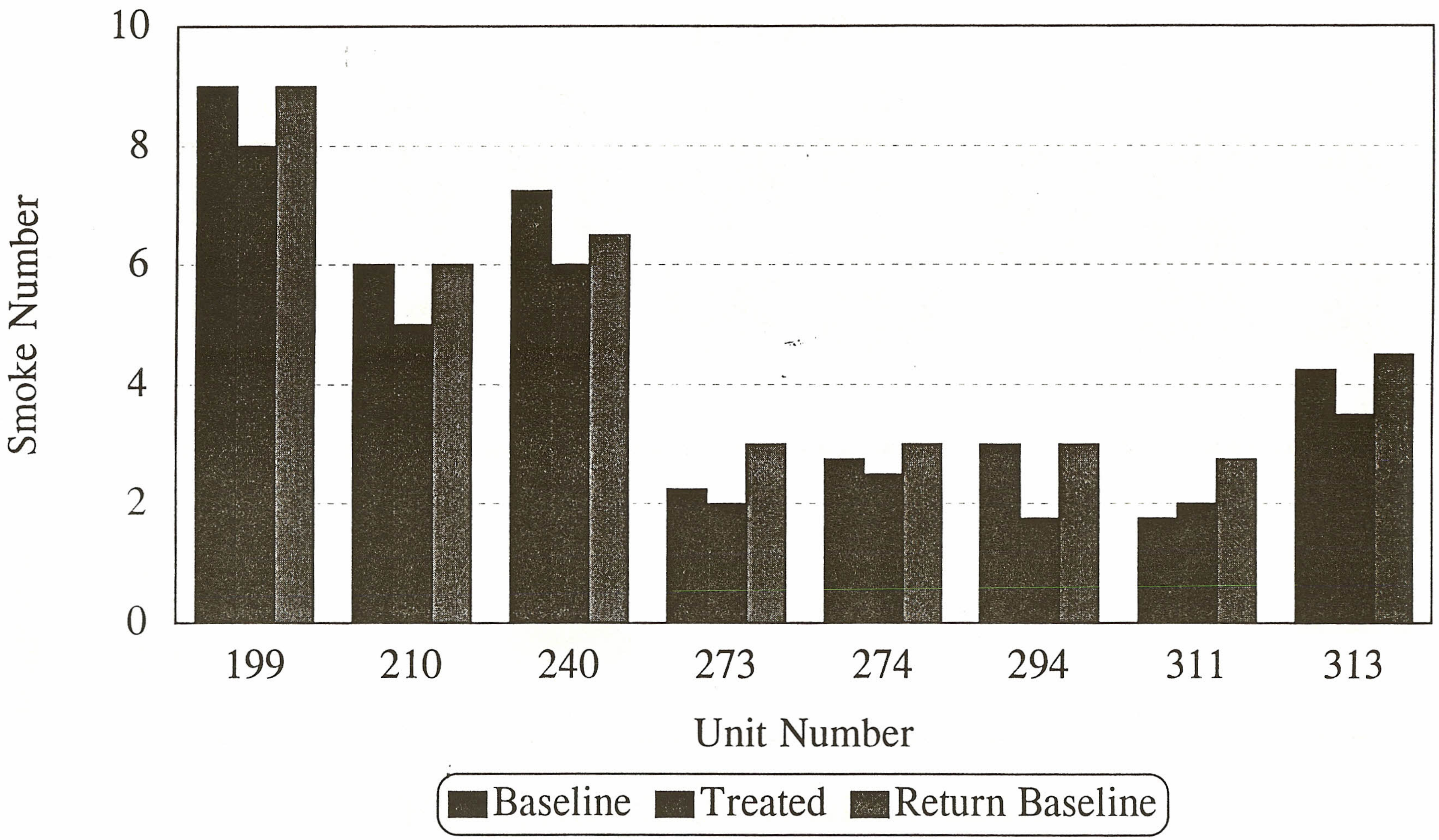
Fuel Efficiency Improvement



September 8, 1993

Distribution Trucking Co.

Smoke Spot Test



September 8, 1993

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. # 2 diesel was 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 of C02, CO, HC, and O2 measured during the test, the average molecular weight of these gases, and the temperature and density of the exhaust stream, the mass flow rate of the fuel to the engine (rate of fuel consumption) may be expressed as a engine "performance factor" which relates the fuel consumption of the treated fuel to the baseline. The calculations are based on the assumption that engine operating conditions are essentially the same throughout the test. Engines with known mechanical problems or having undergone repairs affecting fuel consumption are removed from the sample.

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
199	.852	.850	1.0023
210	.850	.852	0.9976
240	na	na	na
294	.845	.849	0.9960
273	.839	.850	0.9890
274	.845	.859	0.9834
311	.849	.852	0.9965
312	.852	.850	1.0023

* The treated fuel specific gravity for Unit 240 was mistakenly omitted.

Table 3: Summary of Emissions Data

	Base Fuel				FPC-1® Fuel			
Unit #	CO%	HCppm	CO2%	RPM	CO%	HC	CO2%	RPM
199	.050	9.2	1.928	2000	.043	7.5	1.738	2000
210	.040	8.0	1.445	1800	.030	6.2	1.342	1800
240	.030	6.0	1.400	1700	.030	5.7	1.232	1700
273	.030	7.2	1.693	1900	.033	8.0	1.575	1900
274	.030	8.5	1.668	1900	.040	6.0	1.513	1900
294	.013	4.7	1.633	1800	.010	4.2	1.593	1800
311	.020	4.8	1.400	1600	.020	4.7	1.247	1600
313	.020	5.8	1.553	1570	.017	6.3	1.432	1570

Table 4: Smoke Spot Number Comparison

Unit #	Base Fuel SS #	Treated Fuel SS#	Return to Base Fuel SS #
199	9.0+	8.0	9.0
210	6.0	5.0	6.0
240	7.25	6.0	6.5
273	2.25	2.0	3.0
274	2.75	2.5	3.0
311	1.75	2.0	2.75
313	4.25	3.5	4.5
294	3.0	1.75	3.0
Fleet Average:	4.53	3.84	4.72
% Change from Base:		15.23	
% Change from Return to Base:		18.64	

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

Table 5: Unit 199

Mwt1	29.0178	Mwt2	29.0017
pf1	310,919	pf2	345,213
PF1	359,710	PF2	386,370

386,370(1.0023)= 387,259

% Change PF = [(387,259-359,710)/359,710](100)

***% Change PF = + 7.66%**

Table 6: Unit 210

Mwt1	28.9749	Mwt2	28.9571
pf1	413,340	pf2	447,348
PF1	472,420	PF2	509,452

509,452(0.9976)= 508,229

% Change PF = [(508,229-472,420)/472,420](100)

***% Change PF = + 7.58%**

Table 7: Unit 240

Mwt1	28,9657	Mwt2	28.9415
pf1	429,409	pf2	486,078
PF1	491,716	PF2	551,321

% Change PF = [(551,321-491,716)/491,716](100)

***% Change PF = + 12.12%**

Table 8: Unit 294

Mwt1	28.9908	Mwt2	28.9923
pf1	373,698	pf2	383,799
PF1	471,400	PF2	488,056

488,056(0.9960) = 486,104

% Change PF = [(486,104-471,400)/471,400](100)

***% Change PF = + 3.12%**

Table 9: Unit 273

Mwt1	29.0053	Mwt2	28.9865
pf1	356,885	pf2	381,972
PF1	403,431	PF2	428,777

428,777(0.9890) = 424,258

% Change PF = [(424,258-403,431)/403,431](100)

***% Change PF = + 5.16%**

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

Table 10: Unit 274

Mwt1	29.0042	Mwt2	28.9824
pf1	361,940	pf2	395,716
PF1	406,112	PF2	435,781

435,781(0.9834)= 428,547

% Change PF = [(428,547-406,112)/406,112](100)

***% Change PF = + 5.52%**

Table 11: Unit 311

Mwt1	28.9835	Mwt2	28.9518
pf1	432,919	pf2	484,582
PF1	699,463	PF2	747,433

747,433(0.9965)= 744,792

% Change PF = [(744,792-699,463)/699,463](100)

***% Change PF = + 6.48%**

Table 12: Unit 313

Mwt1	28.9848	Mwt2	28.9709
pf1	390,760	pf2	423,820
PF1	498,218	PF2	554,290

554,290(1.0023)= 555,591

% Change PF = [(555,591-498,218)/498,218](100)

***% Change PF = + 11.52%**

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

Figure 1
CARBON MASS BALANCE FORMULA

<u>ASSUMPTIONS:</u> C_8H_{15} and SG = 0.78
Time is constant
Load is constant

<u>DATA:</u>

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 ($^{\circ}F$)
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

<u>EQUATIONS:</u>

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

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

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

FUEL ECONOMY:
PERCENT INCREASE (OR DECREASE)

$$\frac{PF_2 - PF_1}{PF_1} \text{ x } 100$$

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.

Raw Data Sheets

CARBON MASS BALANCE FIELD DATA COMPARISON

Company: DTC

BASELINE DATA
Date 1-4-94
BP: 29.78-30.05 @ ______ °F
Fuel: ______ SG @ ______ °F
Ambient Temp: 50+ °F

TREATED DATA
Date: 10/26/93
BP: 30.27-30.47 @ ______ °F
Fuel: ______ SG @ ______ °F
Ambient Temp: 50-70 °F

Unit #	RPM	Exhaust Temp.	Exhaust Press.	CO	HC	CO_2	O_2	NO_x	Smoke
(B) 199	2000	408.40	1.150	.050	9.2	1.928	17.72		9.0
(T)		406.50	1.250	.043	7.5	1.738	18.08		8.0
(B) 204	1800	294.74	1.117	.030	8.1	1.411	18.78		7.75
(T)		293.70	1.067	.027	7.0	1.197	18.58		6.0
(B) 210	1600	267.06	0.983	.040	8.0	1.445	18.58		6.0
(T)		279.23	1.030	.030	6.2	1.342	18.55		5.0
(B) 240	1700	280.20	1.000	.030	6.0	1.400	18.52		6.5
(T)		287.50	1.050	.030	5.7	1.232	18.60		6.0
(B) 273	1900	305.07	1.067	.030	7.2	1.693	18.35		3.0
(T)		296.67	1.077	.033	8.0	1.575	18.35		2.0
(B) 274	1900	305.07	1.083	.030	8.5	1.668	18.42		3.0
(T)		283.10	1.100	.040	6.0	1.513	18.50		2.5
(B) 294	1800	304.03	0.850	.013	4.7	1.633	18.23		3.0
(T)		317.37	0.863	.010	4.2	1.593	18.43		1.75
(B) 311	1600	276.8	0.500	.020	4.8	1.400	18.98		2.75
(T)		279.9	0.562	.020	4.7	1.247	18.80		2.0

CARBON MASS BALANCE FIELD DATA COMPARISON

Company: DTC (Cont.)

BASELINE DATA	TREATED DATA
Date	Date:
BP: @ °F	BP: @ °F
Fuel: SG @ °F	Fuel: SG @ °F
Ambient Temp: °F	Ambient Temp: °F

Unit #	RPM	Exhaust Temp.	Exhaust Press.	CO	HC	CO_2	O_2	NO_x	Smoke
(B) 312	1570	278.53	0.700	.020	7.33	1.540	18.71		4.0
(T)		297.13	0.750	.012	6.67	1.303	18.73		4.0
(B) 313	1570	274.13	0.800	.020	5.80	1.553	18.40		4.5
(T)		297.23	0.800	.017	6.30	1.432	18.53		3.5
(B)									
(T)									
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