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EVALUATION OF FPC-1 FUEL PERFORMANCE CATALYST

AT

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FLORIDA OPERATION

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I. INTRODUCTION

FPC-1 Fuel Performance Catalyst is the designation of a unique catalyst developed to enhance the combustion of all liquid hydrocarbon fuels. The catalyst has undergone extensive testing at independent and university affiliated laboratories in light duty gasoline and diesel powered vehicles. These test procedures have included the EPA standardized, Federal Test Procedures (FTP), hot and cold cycles, the Highway Fuel Economy Test (HFET), (both use carbon mass balance procedures), the SAE J-1082 Interstate and Suburban Fuel Economy Tests, the Coordinated Research Council Cold Start Driveability Test and steady-state engine dynamometer testing.

These tests have provided documentation which show the FPC-1 catalyst creates the following benefits:

1) Increased fuel efficiency (or improved fuel economy).

2) Reduced emissions of harmful pollutants and smoke.

3) Improved driveability (engine performance).

This report will discuss the results of an extensive three phase engine performance evaluation using this unique fuel combustion catalyst. The test was conducted by Greyhound Lines, Inc., Phoenix, Arizona, at their Eastern Division, Florida Operation, in cooperation with J.R.C. Enterprises Inc., Tempe, Arizona, and UHI Corporation, Provo, Utah, the FPC-1 manufacturer. An explanation of the test procedures used to determine the effect of the catalyst on fuel economy, harmful emissions and engine performance characteristics will be documented and the results summarized.

II. TESTS

The tests were conducted in three phases. First, a preliminary fuel economy test; second, a carbon mass balance and harmful emissions analysis; and finally, a long term mileage comparison.

Phase I - Preliminary Single Engine Test

In meetings held between Mr. J.A. Malcomb, Senior Vice President, Maintenance/Engineering, Greyhound Lines Inc., J.R. Challis, President, J.R.C. Enterprises Inc., and S. Craig Flinders, Sales Manager, UHI Corporation, a trial test was established to verify the economic benefit provided by the FPC-1 catalyst. The study was conducted on an 8V-71 D.D.A. powered inter-branch transport operating out of the Chicago area. The truck was monitored for approximately eight months, from January 1983 to August of the same year.

Although the data from this study was not published, Mr. Malcomb reported the test truck demonstrated a significant improvement in fuel economy with the catalyst treated fuel. The success of this single engine trial provided the impetus for a more conclusive, wider range test using a larger test fleet.

Long Term Testing

A group of fifteen (15) Greyhound buses was selected by Mr. Malcomb as the test fleet for the next two phases of testing. These buses (designated Pool 23) operating primarily out of Miami, Florida, were selected as the test fleet for the following reasons;

a) All Pool 23 buses were restricted to operate within the state of Florida (serving the Walt Disney World service routes) allowing a specific geographic area for controlled fueling, thereby, assuring the use of FPC-1 treated fuel in the test fleet.

b) The Pool 23 buses provided a good cross section of the Greyhound Lines fleet.

c) Because the Pool 23 fleet had a designated service schedule (Walt Disney Route), it was felt that consistency in routing and loads could best be achieved for baseline and treated comparisons.

d) The Greyhound Lines, Eastern Division, Florida Operation, offered a most reliable personnel team to implement the test procedures and oversee the test program.

A Baseline MPG average was established from the Greyhound monthly mpg reports for an seven (7) month period beginning December, 1983 through June 1984. This baseline was then compared to a FPC-1 treated fuel period beginning August 1984, and ending April 1985.

In conjunction with the extended fuel consumption comparison, a carbon mass balance method of determining fuel economy was also conducted on the Pool 23 buses. The carbon mass balance test is covered in Phase II; the MPG comparison in Phase III.

Phase II - Carbon Mass Balance

History and Development

Until late 1973, vehicle fuel economy had been determined primarily by using various test track or road test procedures. In September. 1973, the U.S. Environmental Protection Agency (EPA) introduced a method of determining vehicle fuel economy in conjunction with its chassis dynamometer emissions test. This method determines fuel consumption based upon vehicle exhaust emissions through a "carbon balance" calculation rather than a direct measurement of fuel consumed.

Starting in 1974, the carbon balance method was used solely in the EPA, CVS cold start emissions test cycle (LA-4 Cycle). In 1975, the cycle was modified adding a hot start (FTP). Later, a highway test was also developed (HFET).

A series of tests done by Ford Motor Company compared the traditional fuel measurement techniques (volumetric or gravimetric) to the carbon balance method. The results, published in SAE Technical Paper Series 75002 (EXHIBIT A) entitled "Improving the Measurement of Chassis Dynamometer Fuel Economy", confirmed

"fuel economy results obtained by carbon mass balance calculation of carbon containing components in the vehicle exhaust are at least as accurate and repeatable as those obtained by direct fuel measurement of fuel consumed."

It is from this concept that UHI Corporation derived the exhaust gas analysis technique of determining fuel consumption changes used by J.R.C. Enterprises, Inc. and UHI personnel in this test with Greyhound Lines, Inc.

Although not as controlled a test as obtainable in a laboratory using a chassis dynamometer, the method used has consistently proven to be far more accurate than monthly mpg fleet records.

The technique uses state-of-the-art NDIR instruments that measure carbon dioxide (CO_2), carbon monoxide (CO), oxygen (O_2), and unburned hydrocarbons (HC).

Test Procedure

During a four (4) day period from July 21 through July 24, 1984, all Pool 23 buses were brought to the Miami Maintenance Center for baseline "carbon mass exhaust gas testing". Each bus engine was operated at a fixed RPM and load that could be easily reproduced. Numerous exhaust gas readings were taken on each bus with a Sun Electric MGA-90 Multiple Gas Analyzer and the mean percentage of the carbon dioxide (CO_2), carbon monoxide (CO), and oxygen (O_2), and the mean parts per million hydrocarbons (HC) determined.

Exhaust airflow rate and exhaust temperature were also recorded using a Davis high speed anemometer and an IMC digital thermocouple. All readings were taken and resultant averages calculated under the supervision of Mr. Lee Hopkins, Manager of Maintenance Center and/or Greyhound personnel designated by Mr. Hopkins.

Copies of all data were submitted to Mr. Hopkins upon test completion each day. Fuel treatment with FPC-1 Fuel Performance Catalyst was then accomplished as will be detailed in the PHASE III - MPG comparison section later.

During a second four (4) day period from October 5 through October 8, 1984, after all Pool 23 buses had exceeded the 150 hour or 6000 mile recommended break-in period, carbon mass test procedures were duplicated as in baseline testing.

Again, all readings were taken and the resultant averages calculated under the supervision of Mr. Hopkins.

The carbon balance data is compiled and compared in the following exhibits;

EXHIBIT B - illustrates the actual Carbon Balance Formula.

EXHIBIT C - depicts the Carbon Mass Balance test results on the 4900 series buses only.

EXHIBIT D - the 6600 series buses only, and

EXHIBIT E - the cumulative (all Pool 23 buses) results.

The results of the PHASE II - Carbon Mass Balance study confirm fuel economy improvements with FPC-1 treated fuel in excess of 10% over baseline cumulatively (EXHIBIT C), 14.09% for the 6600 series buses only (EXHIBIT D), and 9.74% for the 4900 series only (EXHIBIT E).

It might also be noted that potential engine failures can oftentimes be identified by this method of exhaust analysis. For example, during both baseline and treated testing, bus 4990 showed unusually high exhaust temperature and exhaust emission levels when compared to the other fourteen (14) test buses. The high emission levels of bus 4990 corresponded with its then high fuel consumption trend. The bus subsequently required repair for turbo charger and after cooler problems and, as a result, was dropped from the test data used in all comparisons.

How FPC-1 Affects Exhaust Emissions

In order to fully understand the correlation between emission levels and internal combustion engine operation, and the effect of the FPC-1 catalyst on these parameters, it must be understood how the different exhaust gases react to the combustion cycle in terms of time and mechanical efficiency.

Excessive hydrocarbons (HC) levels are a result of inefficient combustion which takes place when the fuel is burned without enough air to allow complete combustion.

Oxygen (O_2) and carbon dioxide (CO_2) levels are an excellent indicator of a lean running engine. If O_2 levels are high, and CO_2 levels are low, the engine is running lean. Conversely, if the O_2 levels are low, and the CO_2 levels are high, then the engine is running rich.

In most cases, HC and CO levels can be altered by increasing or decreasing the amount of time the engine configuration allows for combustion to take place. For instance, modern slow speed diesel engines run more efficiently than do modern high speed diesel engines. The slow speed diesel engine has considerably more time to burn the fuel.

SAE Technical Paper #831204, entitled "The Effects of an Iron Based Fuel Catalyst Upon Diesel Fleet Operation", explains that the FPC-1 active ingredient decreases the amount of time necessary for combustion to take place. As a result, "pressure is higher and more work can be accomplished for the same energy supplied." Further, HC and CO levels will be reduced. In the case of Greyhound Lines, Inc., there was a 94% reduction in CO and a 92% reduction in HC.

These results qualitatively demonstrate an improvement in fuel combustion under the operating conditions outlined. Regarding O_2 and CO_2 levels, the Greyhound test fleet showed a definite leaning out. The baseline fleet average showed levels of CO_2 to be 5.2% with O_2 levels of 12.97%. This compares to the leaning affect of the treated period in which the CO_2 levels were 4.73% with O_2 levels of 13.70%.

The actual fuel usage records correlate directly with the above mentioned emissions data. Bus #4990 has had a significantly lower mpg performance than any other bus in the test fleet. With the mechanical problems that #4990 experienced, it is not surprising that the HC and CO levels were significantly higher than the fleet average. These "mechanical inefficiencies" caused emission level increases in bus #4990 with baseline CO levels of 0.513% as compared to the fleet average of 0.008%, and HC levels of 13 ppm as compared to the fleet average of 9.7 ppm. All of the above data was taken under identical loads and engine temperatures.

Additional evidence to indicate improved combustion was demonstrated when smoke and solid particulate levels were monitored. A letter from Lee Hopkins with accompanying photos provide visual documentation into the reduction of solid particulate's. Further, Messrs. Lee Hopkins and H.B. Swann acknowledge the elimination of complaints of heavy smoke during the treated portion of the test.

Phase III - Fifteen Month Road Test / MPG Comparison

Based upon Greyhound Lines monthly fuel consumption records from December, 1983, through July, 1984, Baseline MPG averages were established for the entire Pool 23 fleet. The fuel tanks at the fueling facilities in Miami, Orlando, St. Petersburg, and Jacksonville were treated by J.R. Challis, J.R.C. Enterprises, on July 25, 26, and 27, 1984, at a one part FPC-1 to 1600 parts diesel fuel ratio.

The Greyhound personnel at each location were instructed in the treatment ratios and procedures for future treatments during the ongoing test period. A reporting system was also established to provide a record of all fuel deliveries and the FPC-1 used for each fuel delivery. Fuel consumption data was collected in the usual manner throughout the test period and submitted on a monthly basis to Mr. Malcomb and subsequently to Mr. Challis.

It became apparent early in the treated segment of the Greyhound test that, although fuel consumption had improved, the monthly mpg data was far more erratic than during the baseline period. Total mileage accumulated by the fleet also decreased by an average of 30,000 miles per month or 2,000 miles per bus.

Consequently, in May of 1985, Mr. Craig Flinders and Mr. Kim LeBaron, representatives of UHI Corporation, met with Mr. Lee Hopkins, Manager of the Greyhound Maintenance Center in Miami, to investigate the possible cause of the change in the data.

After investigation, Mr. Hopkins records revealed that the Pool 23 fleet had experienced a significant change in routing shortly after the treated test period began. The greatest change occurred with the 6600 series portion of the test fleet which, during the baseline period of mpg recording, had run exclusively the Walt Disney World route from Miami to Orlando and back. These 6600 series buses were taken off this route in October of 1984 and put into charter service. Mr. Hopkins reported that since the routing change, the 6600 fleet had experienced major increases in stop-and-go driving and idle time over that of the baseline period.

The same was confirmed by Mr. T.J. Shelby at the Orlando facility. Mr. Shelby added that the 6600 buses were carrying heavier loads on charter service than while running to and from Disney World. For these reasons, Mr. Hopkins recommended the 6600 fleet be dropped from the test.

It was also discovered that the 4900 fleet had also experienced operation changes as indicated again by the reduction in miles driven. However, Mr. Hopkins' records showed these changes far less significant and having only minimal impact on the fuel consumption figures. The

4900 fleet experienced enough common factors in both baseline and treated segments to provide an accurate comparison.

Mr Hopkins also reported that the buses maintained good mechanically working order except unit 4990 which suffered turbo charger and after cooler problems throughout the test program. Mr. Hopkins recommended unit 4990 also be dropped from the test fleet.

In early October, UHI discovered a container compatibility problem in one batch of FPC-1 which resulted in product contamination. UHI recalled the entire batch, five drums of which had been shipped to Greyhound locations. Although replacement product was provided, shipping problems prevented the arrival of the replacement product in time to treat fuel shipments delivered to the Miami Maintenance Center (the facility that predominantly fuels and maintains the Pool 23 fleet) in mid and late October.

Although it is impossible to determine the exact affect of this break in regular treatment, experience has confirmed that fuel economy will drop off and that the "break-in" period required to bring about the full effects of FPC-1 must be repeated.

However, this does provide the opportunity to do an A-B-A (treated-return to baseline-treated analysis) comparison. Such a comparison shows large reductions in fuel economy during October (4.70 mpg) and November (4.90 mpg) when the fleet was operating on untreated and diluted fuel, and substantial gains in fuel economy after the fuel was again fully treated with FPC-1 and break-in completed (5.43 mpg in December). Therefore, Mr. Hopkins has recommended that the October and November data be dropped from the test.

The mileage and fuel consumption figures for the Pool 23 fleet are compiled on the table in Exhibit I of this report. The table demonstrates the data for both baseline and treated fuel periods under three separate headings. These include; 4900 series buses only, 6600 series buses only, and All Pool 23 buses. The ten 4900 series buses experienced a 9.47% improvement in fuel economy with FPC-1 treated fuel. The five 6600 series buses experienced a 2.59% decrease in fuel economy and the entire Pool 23 fleet averaged a 5.57% improvement in fuel economy while using FPC-1 treated fuel.

III. Summary

In even the most controlled field evaluations it is impossible to control all the variables. This test was no exception. However, the test was monitored over a significant period of time (15 months), and enough data has been accumulated on 15 buses to provide a meaningful fuel economy comparison between the baseline and treated segments of the evaluation.

The following list summarizes the adjustments recommended by Greyhound managers that would add to the reliability of the test results and conclusions:

1) 6600 Fleet: The entire 6600 fleet be eliminated from the data base due to dramatic route and load changes.

2) Bus #4990: Bus #4990 be eliminated from the data base because of mechanical problems during the treated fuel segment of the test.

3) October/November: The months of October and November be eliminated from the data base because the fuel was not fully treated.

None of these adjustments have been made in the final analysis of the data and all data is shown on the exhibits contained in the report and in Exhibit J, the Fuel Cost Savings Analysis. However, if the above recommendations were carried out, the test would show that Greyhound experienced a 9.5% improvement in fuel economy with FPC-1 treated fuel. This percentage improvement agrees with the carbon mass balance calculations on the 4900 series fleet of +9.74% and the total fleet carbon mass calculation of +11.24%.

IV. Conclusion

Fuel economy derived from monthly fuel usage reports shows a minimum improvement in fuel economy with FPC-1 treated fuel of 5.57%. Carbon balance testing reveals a minimum improvement of 9.74% . Based upon the results of the Greyhound evaluation, it is estimated that annual net fuel savings could be between 2.04 million and 4.9 million dollars.