ALGAE-X®
Fuel Conditioning

ENVIRONMENT CANADA
AFC FUEL CATALYSTS URBAN BUS EVALUATION
FINAL ANALYSIS

EXECUTIVE REPORT

In 1996 Chassis Dynamometer testing was conducted and concluded on three Detroit Diesel 6v92 diesel engine powered urban buses by Environment Canada, Mobile Sources Emissions Division in Ottawa Ontario, Canada. A series of New York City Composites (NYCC) and Central Business District (CBD) cycles were conducted on each bus at zero hours, 400 hours and 1000 hours of normal in service operation in the city of Ottawa, Canada. Two of the three identical buses were tested and operated on fuel treated with AFC, which was mixed by lab technicians as specified by the product manufacturer. The third bus served as a control and operated on non-treated fuel. The fuel that was treated with AFC came from the same batch as the fuel used by the control bus.

The data generated from the two test cycles was evaluated six different ways for each cycle. This was done for the purpose of generating as much data as possible across as broad a spectrum of operating conditions as possible. The method of analysis gave results that are as random and impartial as possible. How the results are interpreted depends on the circumstances that they are compared to. The NYCC cycle is typical of heavy city driving and the CBD cycle is typical of lighter suburban driving. By cross comparing the results from each cycle the range of performance of a vehicle under certain conditions can be predicted. A summary of the fuel economy improvements and emission reductions is presented below. An explanation of how the results were determined follows.

Table 1
Summary of results

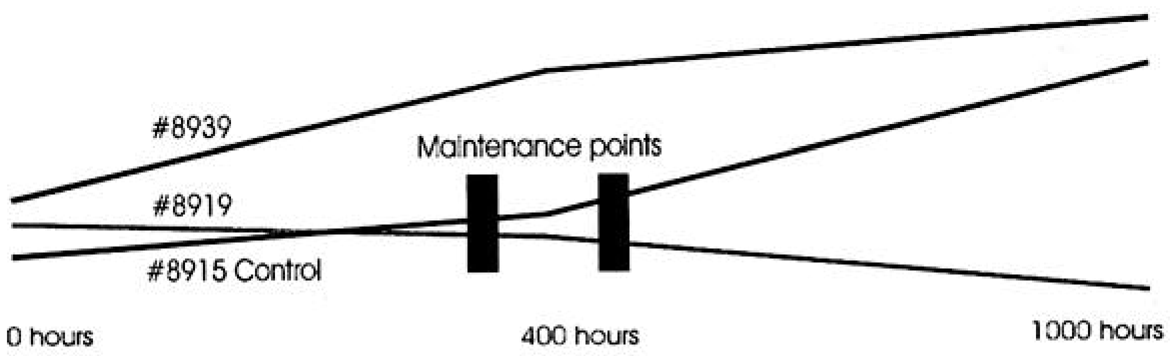
DATA SUBJECT	NYBC	CBD	AVERAGE
Fuel Economy	5%	7%	6%
CO_2 (carbon dioxide)	5%	10%	8%
NO_x (nitrogen oxides)	18%	21%	20%
PM (particulate mass)	6%	8%	7%
CO (carbon monoxide)	NI	8%	8%
THC (total hydrocarbons)	NI	2%	2%
Acetaldehyde	NA	NA	20%
Formaldehyde	NA	NA	5%
PAH (1-4)	NA	NA	99%
PAH (5-7)	NA	NA	50%
PAH (8-14)	NA	NA	Decreased

*All results are statistically significant at a 95% confidence level.

P.O. Box 4011, 1661 Estero Blvd, Fort Myers, FL 33932 Tel 877-463-0607 Fax 239-463-7855 www.algae-x.net

During the course of the test maintenance was performed on test bus #8919 and the control bus. There is no way to know for sure whether the maintenance procedures had a negative or positive effect, or none at all, on the performance of tile busses, however, there are some strong indications of the trends. After the maintenance was perforn1ed on test bus #8919, the range of the data became significantly wider between the two tests busses. This indicates a negative impact (emission readings went up, fuel economy went down) on the overall performance of that bus. However, there were some variations in the individual trends of the areas evaluated. The range of data between the control bus and the other test bus (#8939) became narrower indicating a positive impact (emission readings were reduced while fuel economy improved) on the overall performance of that bus. Again, with some variations in the individual trends of the areas evaluated. The following graph illustrates the overall resulting trends.

Graph 1



The results of this evaluation indicate that fuel economy consistently improved with the continual use of AFC treated fuel. The average increases for the test vehicles themselves during the testing period were 7.0% for the CBD cycle and 4.6% for the NYBC. This is in spite of any negative influence that the maintenance conducted on test bus #3919 might have had in lowering the averages. With the control bus factored in, the results indicated increases of up to 6.1% for the CBD and up to 5.5% for the NYBC. This was in spite of any positive influence that the maintenance conducted on the control bus might have had in reducing the difference.

In short, even with the trends of the outside variables going against producing positive results, there was a positive, statistially significant improvement at the 95% confidence level. There is no better indication that the improvements are real and significant. If the effects of the adverse factors are ignored, the results indicate a statistically significant improvement as high as 14% for two of the eight different test evaluation scenarios.

Generally, any percentage reduction in fuel consumption causes an equal percentage reduction in emissions. For example, if 10% less fuel is being burned then 10% fewer total emissions are being produced. However, the ratios of the individual gasses that comprise the reduced total can change in relation to themselves. For example, the different tests will show consistent improvements in fuel economy and a corresponding reduction in total emissions. However, the ratios of the individual gasses comprising the totals may be different for all three tests.

This variation makes it more difficult to pinpoint improvements. However, consistent improvements that show up can be considered significant with a high degree of confidence. This type of variation is prominent when combustion surfaces are being modified and AFC is an extremely effective surface modifier. Because of this, the emissions data needs to be analyzed in a slightly different way than that of the fuel economy.

With respect to the CO_2 exhaust emissions, the data indicated a statistically significant average reduction of 8% in this emission. This is consistent with the increase in fuel economy and corresponds with an improvement in combustion efficiency . This corresponds with field test measurements.

NOx is a highly variable emission due to the inability to control all of the variables that influence its production. Readings for NO_x will vary from day to day for a given piece of equipment regardless of its condition. However, the equipment design, condition, fuel etc. will influence the magnitude of those fluctuations. For NO_x, which is influenced more by engine environment conditions than by fuel consumption, the average emission levels increased for all the busses over time. This is not uncommon. However, the increases in the test busses were significantly less than the increases in the control bus. (This illustrates the importance of having a control) The effect that the maintenance had on these differences is unknown, but in this case the trends were very consistent between the test busses and the control bus indicating that there was very little or no effect. The statistically significant percentage differences in NO_x production between the control bus and the test busses were 18% for the NYBC and 21% for the CBD. This illustrates the capability of AFC to minimize the degree of fluctuation in NOx emissions. These differences correspond closely to field test predictions.

The particulate mass measurements on the test busses showed a statistically significant average decrease of 7% for this emission for three of four test sequences. The control bus showed the same trends but with a larger percentage decrease. The maintenance performed on test bus #8919 seems to have had a very negative impact on the amount of PM released, while the maintenance perfomed on the control bus resulted in a very positive impact on this emission. If the negative impact of the maintenance on the reduction of PM is taken into account the results indicate a significant reduction of 14% for the CBD cycle. This is more typical of what happens in the field.

CO was reduced by a statistically significant 8% for the CBD cycle while showing no improvement (NI) for the NYBC. There is no explanation for this difference other than that CO emissions are very low for diesel applications in the first place. The maintenance that was performed on the test bus did not seem to affect CO production. The same is true of the maintenance conducted on the control bus. The 8% reduction that was significant for the test busses is half the 16% that is typically seen in field tests.

THC's were reduced by a statistically significant average of 2% on the CBD, while showing no average improvement (NI) for the NYBC. However, there are strong indications that the maintenance conducted on test bus #8919 had a very negative impact on the production of this emission. Test bus #8939 showed significant reductions of 8% for the NYBC and 9% for the CBD. The maintenance conducted on the control bus seemed to have a positive effect on the readings for this emission. A 10% reduction is typical for this emission in field tests.

The carbonyls were measured independent of the testing cycles (NA) and consist primarily of formaldehyde and acetaldehyde. Formaldehyde, which comprises 50 to 90% of the total carbonyls, showed a statistically significant reduction of 5% over the control bus. Acetaldehyde showed a 20% reduction over the control bus and a 41% reduction for the test busses themselves. There was no way to determine how the maintenance conducted on the busses affected these emissions.

The polycyclic aromatic hydrocarbons (PAH) were also measured independent of the testing cycles (NA). 15% of the total PAH is released in gaseous form with the remaining 85% adhering to the particulate mass. During baseline testing 14 compounds were identified. At the 1000 hour point of the test tour, (4) of the PAH compounds were at the non-detectable level being reduced by greater than 99%. Of the remaining ten, three (3) were reduced by greater than 50%. The last seven (7) identified PAH compounds were all reduced significantly by varying degrees. This was consistent for both test busses with little or no variation in the trends. The reduction of PAH has a secondary effect of reducing the toxicity and reactivity of any particulate mass that is released.

In conclusion, based on the methodology and vehicles used for this test program, AFC treated fuel was shown to effectively improve fuel economy while reducing most of the exhaust stream compounds by significant amounts.

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DATA INTERPRETATION

The results support the following conclusions:

- For diesel vehicles operating in a light/fast city type environment, one could expect an improvement in fuel economy of about 6%. This also means a direct reduction of all emissions by the same percentage.

- For diesel vehicles operating in a heavy/slow city type environment, one could expect an improvement in fuel economy of about 4%. This also means a direct reduction of all emissions by the same percentage .

- For diesel vehicles operating in a light/fast suburban type environment, one could expect an improvement in fuel economy of about 14%. This also means a direct reduction of all emissions by the same percentage.

- For diesel vehicles operating in a heavy/slow suburban type environment, one could expect an improvement in fuel economy of about 10%. This also means a direct reduction of all emissions by the same percentage.

- For diesel vehicles operating in a light/fast city/suburban mix type environment, one could expect an improvement in fuel economy of about 10%. This also means a direct reduction of all emissions by the same percentage.

- For diesel vehicles operating in a heavy/slow city/suburban mix type environment, one could expect an improvement in fuel economy of about 7%. This also means a direct reduction of all emissions by the same percentage.

- For diesel vehicles operating in a heavy/slow city type environment, where smoke and particulate emissions are the worst, one could expect a reduction in PM of around 20% above and beyond any reductions due to reduced fuel consumption. Total Hydrocarbons and CO_2 reductions would be around 8% each, above and beyond any reductions due to reduced fuel consumption.

An overall average improvement in fuel economy would be expected to fall in the range of 8% and an over all reduction of emissions would be expected to fall in the range of 12%. However, these numbers are not representative of any particular type of driving environment.

COMBUSTION CHEMISTRY

AFC works on the chemical level of the combustion process and therefore works in exactly the same way, regardless of the type of liquid or solid fuel in which it is used. AFC interacts with the carbon-carbon and carbon-hydrogen bonds of fuel particles. It makes no difference whether the particle is a short carbon chain (gasoline), a medium length carbon chain (kerosene), or a long carbon chain (diesel). The AFC combustion catalysts interact with one carbon bond at a time. When the temperature of the combustion environment reaches a minimum of about 200°C, the AFC catalysts are activated and the chemical reaction begins to occur. The catalysts can't tell what kind of fuel they are in, or what type of engine they are in, or what type of combustion environment they are in. All they see are carbon-carbon and carbon-hydrogen bonds in an environment of 200°C or more. For a visual illustration of this process, please refer to the color bulletin titled "The Combustion Process". This process is the same for all hydrocarbon fuels regardless of whether it is being burned in an internal combustion engine including turbines or open flame type applications. AFC will improve the combustion efficiency, remove hard carbon deposits, and reduce fuel consumption and overall emissions in all types of applications and equipment. The trends will be the same regardless. The only thing that the type of equipment or type of fuel used will affect is the magnitude of the trends.

For example, AFC will improve fuel economy in a diesel application on the order of 7% while in a gasoline application the improvement will be on the order of 12%. Generally, the lighter the fuel the greater the improvement in fuel economy that will show up. Also, a dirtier engine will show greater improvement after it is cleaned up than a not so dirty engine. Another example is with particulate and smoke production. AFC will reduce combined smoke and particulate in diesel applications on the order of 40% while reducing them in gasoline applications on the order of about 15%. Generally, the heavier the fuel, the greater the reduction in smoke and particulate emissions. In yet another example CO reduction in gasoline is high, while CO reduction in diesel is lower partly due to the fact that CO emissions in diesel applications are naturally low in the first place. In all cases the trends are the same with only the degree of magnitude differing.

Once the chemistry of AFC is understood, it is not hard to predict with good accuracy the trends that one will see due to its use. The difficult part is predicting the magnitude of those trends. In most cases a ball park estimate can be given, but it is not until all the variables affecting the combustion environment are understood or controlled that a number can be declared. However, the trends will be the same regardless of the fuel type or the application.

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FINAL REPORT EXTRAPOLATION

The following summary lists the reductions in fuel consumption that one would expect to see when operating equipment in the operating environments listed below. The expectations represent the average of a range and are extrapolated from the results of Environment Canada's evaluation of the AFC combustion catalysts. Keep in mind that any reduction in fuel consumption equates to an equal reduction of total emissions by the same percentage.

THE MINING INDUSTRY

The typical operating conditions of an engine used in a mining environment resemble the heavy/slow city/suburban mix type operating conditions of the lab test. In this case expect to see an improvement in fuel economy of about 7%. In some cases the operating conditions resemble the heavy/slow suburban type operating conditions of the lab test. If so, expect to see an improvement in fuel economy of about 10%.

THE MARINE INDUSTRY

The typical operating conditions of an engine used in a marine environment resemble the heavy/slow suburban type operating conditions of the lab test. In this case expect to see an improvement in fuel economy of about 10%. In some cases the operating conditions resemble the light/fast suburban type operating conditions of the lab test. If so, expect to see an improvement in fuel economy of about 14%.

OVER THE ROAD TRUCKING

The typical operating conditions of an engine used in an over the road trucking environment resemble the heavy/slow suburban type operating conditions of the lab test. In this case expect to see an improvement in fuel economy of about 10%. Under heavy haul operating conditions, the performance resembles the heavy/slow city/suburban mix type operating conditions of the lab test. In this case expect to see an improvement in fuel economy of about 7%. In some cases the operating conditions resemble the light/fast suburban type operating conditions of the lab test. If so, expect to see an improvement in fuel economy of about 14%.

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RAILROADS

The typical operating conditions of an engine used in a rail type environment resemble the heavy/slow suburban type operating conditions of the lab test. In this case expect to see an improvement in fuel economy of about 10%. Yard or switch engines operate in an environment that resembles the heavy/slow city/suburban mix type operating conditions of the lab test. In this case expect to see an improvement in fuel economy of about 7%.

MUNICIPALITIES

The typical operating conditions of an engine used in a municipalities environment (i.e. garbage collection, school buses, etc.) resemble the heavy/slow city type operating conditions of the lab test. In this case expect to see an improvement in fuel economy of about 4%. In some cases the operating conditions resemble the heavy/slow city/suburban type operating conditions of the lab test. If so, expect to see an improvement in fuel economy of about 7%.

NOTE: Field tests indicate gasoline operated equipment generally achieves greater improvements in fuel economy than diesel powered equipment. Where applicable, gasoline powered equipment running under the conditions listed above will generally see a greater percentage reduction in fuel consumption than diesel powered equipment. The difference generally falls in the range of 50% to 80% greater for gasoline over diesel.