Catalyst Energy

Report on the Use of CombustAll™, a Fuel-Borne Catalyst, in Reducing Diesel Exhaust Emissions from Container-Handling Equipment in the Port of Vancouver

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1. Executive Summary

The purpose of the test program was to evaluate the effectiveness of the fuel-borne catalyst CombustAll™ in reducing components of diesel exhaust emissions, including particulate matter (PM), nitrogen oxides (NO_x) and carbon monoxide (CO). A series of emissions tests was carried out on eight pieces of cargo handling equipment at the Vanterm and Centerm container terminals operated by TSI Terminal Systems Inc. and P&O Ports Canada Inc. respectively. The test equipment included two rubber-tired gantries, two top picks, two tractors and two pulp clamps.

The tests showed that CombustAll™ significantly reduced PM, NO_x and CO emissions and, in addition, generated some small improvements in combustion efficiency.

The following table summarizes the changes in emissions caused by introduction of CombustAll™ into the fuel supply:

	PM Emissions (%)	NO_x Emissions (%)	CO Emissions (%)
Rubber-Tired Gantries			
Vanterm Unit 7	**-66**	**-26**	**-12**
Vanterm Unit 18	**+1**[1]	**-29**	**-41**
Top Picks			
Centerm Unit 9509	**- 18**	**NA**[2]	**- 2**
Centerm Unit 9523	**- 31**	**NA**	**- 100**
Tractors			
Centerm Unit 134	**- 49**	**NA**	**- 10**
Centerm Unit 1158	**- 61**	**NA**	**- 25**
Pulp Clamps			
Centerm Unit 1616	**- 17**	**NA**	**- 34**
Centerm Unit 8030	**+ 21**[1]	**NA**	**- 18**

[1] Units 18 and 8030 showed very low PM emissions in the baseline test (i.e. before CombustAll™ was added to the fuel) and slight increases in PM emissions after CombustAll™ was added to the fuel. This is a temporary phenomenon sometimes observed in low PM emission engines, when CombustAll™ causes flaking of carbon deposits from the engine manifold and the upstream end of the exhaust stack. For example, the PM emissions in Unit 8030 increased from 2.96% opacity to 3.59% opacity with the addition of CombustAll™, an increase in absolute terms of only 0.63%. In relative terms, it represents an increase of 21%.

[2] NO_x emissions are not reported for some units due to very wide variation in the baseline tests. See discussion on page 9.

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2. Introduction

The Vancouver Port Authority (VPA) and local container terminal operators want to reduce the amount of fossil fuel emissions from their shore-based diesel equipment used for cargo handling. In December 2003, a Memorandum of Understanding (MOU) was signed by the VPA, TSI Terminal Systems Inc. (TSI), operator of the Vanterm container terminal, P&O Ports Canada Inc. (P&O), operator of the Centerm container terminal, and Catalyst Energy Inc. (CEI). CEI is the manufacturer of CombustAll™, a fuel-borne catalyst that reduces harmful emissions from diesel fuel.

The MOU provided for a series of emissions tests to be carried out on equipment at Vanterm and Centerm to test the effectiveness of CombustAll™ in reducing diesel exhaust emissions such as particulate matter (PM), nitrogen oxide (NO_x), carbon monoxide (CO) and volatile organic compounds (VOC).

This report describes emissions tests performed on two rubber-tired gantries, two top picks, two tractors and two pulp clamps (see photos, Appendix B). These tests were conducted between February 2004 and May 2004.

Funding for the test program was provided by the Vancouver Port Authority. The VPA contracted the services of two qualified emissions testing companies, Detroit Diesel Allison B.C. Ltd. (DDA) and Canadian Engineered Products and Sales Ltd. (Cannepp). CEI provided the CombustAll™ product and project management services to organize the testing program. TSI and P&O generously made equipment available for testing in spite of very busy production schedules.

3. Scope of Testing Program and Methodology

The scope of the test program included two rubber-tired gantries (Vanterm Units 7 and 18), two top picks (Centerm Units 9509 and 9523), two tractors (Centerm Units 134 and 1158) and two pulp clamps (Centerm Units 1616 and 8030). Units 18, 9523 and 1158 are equipped with newer engine designs using electronic controls. The tests focused on emissions of PM, NO_x, CO and VOC because these are the subject of product claims made by CEI for CombustAll™.

The methodology required that baseline data (Test 1) be gathered before adding CombustAll™ to the fuel system. CombustAll™ was then added to the equipment fuel tanks and to the main fuel supply tanks simultaneously. Consequently, all the diesel-powered equipment at Vanterm and Centerm used treated fuel for the duration of the project, although only the eight units noted above were tested. Several follow-up tests (Tests 2, 3 and 4) were conducted at various intervals after CombustAll™ was added to the fuel supply to measure the effect on emissions over time.

DDA carried out the tests for opacity, a measure of PM emissions, using a Wager Model 6500 digital smoke meter (see photo, Appendix B), which was placed at the end of the exhaust stack. The smoke meter passes a light beam through the exhaust gas flow and measures the portion of light reaching a sensor on the other side.

The opacity tests were performed using the EPA-approved method developed by the Society of Automotive Engineers Recommended Practice J1667, *Snap Acceleration Smoke Test Procedure for Heavy-Duty Diesel Vehicles*.

The snap acceleration test, also known as the snap idle test, is performed on the vehicle while it is standing still and in neutral. The accelerator is depressed rapidly to the floor and held there until the engine reaches maximum governed speed. A smoke meter is placed at the end of the tail pipe or exhaust stack, and the opacity of the smoke (i.e. the degree to which the smoke obscures a beam of light shining through it, expressed as a per cent of light reduction or per cent opacity) is measured.

Opacity data were deemed acceptable if three consecutive measurements were obtained within a 5% variation. The three data points were then used to calculate an average.

Cannepp performed the gas emissions tests using an Enerac 2000 exhaust gas analyzer (see photo, Appendix B). The Enerac is a highly accurate instrument that can measure gas components within a few parts per million (ppm). This instrument is widely used in the U.S. for compliance monitoring and it is used locally to monitor boiler stack emissions in the Greater Vancouver Regional District (GVRD). Exhaust gas samples were taken from a port in the exhaust pipe a few feet downstream from the engine manifold. The Enerac unit was recalibrated before each emissions test.

Diesel exhaust emissions have a natural variation even when the engine is running in a steady state mode. Therefore, it is important to establish an emissions sampling regime that captures enough data to allow the calculation of sample means (average) and mean differences within a statistical framework to produce conclusions with a high level of confidence. The statistical control should prevent false conclusions when comparing sample means with small differences where the underlying data displays high variation (relative to the mean difference).

To establish statistical control, a mean or average was calculated from a series of 10 individual gas samples (i.e. a data series) taken at 4 minute intervals. Comparisons between tests are based on the means. The data series with and without CombustAll™ in the fuel were tested for statistical significance using the t-Test. The t-Test assesses whether the means of two groups are statistically different from each other.

In all cases in this report, t-values for mean differences are significant at the 95% or higher confidence level. This means, for example, a statement that "CombustAll reduces NO_x emissions by 20%" is essentially certain to be accurate and the probability that the results were produced by chance is negligible.

4. Fuel Borne Catalysts

Fuel-borne catalysts (FBC) are soluble chemicals added to fuel usually with the stated purpose of reducing emissions. Although FBC's exist in a wide variety of chemical formulations, the term "FBC" is used in this report to refer specifically to CombustAll™ and to similar products available in Europe. In the European application, the FBC is present in treated fuel at about five times the concentration of CombustAll™ and it is used primarily to regenerate diesel particulate filters (DPF).

CombustAll™-type FBC's have gained commercial acceptance in Europe where they have been used for several years in approximately 2,000 construction vehicles, city buses, garbage trucks and forklifts and building and cleaning machinery. Over this period of time, considerable experience has been gained in measuring the effect of the FBC (in conjunction with DPF's) on diesel emissions as well as the impact on engine operating conditions and fuel properties.

No Harm – Engine Effects

As a main consideration, operators of diesel equipment need assurance that the use of FBC's will do no harm to engines since there is potentially a high level of capital investment at risk.

European research from independent testing agencies has shown that this type of FBC will cause no harm to diesel engines. Published reports indicate that engine wear measurements in test vehicles at 90,000 km and 350,000 km showed no significant differences to cylinder liners, piston ring side clearance, gaps and weights. Furthermore, no degradation to engine oil or changes to lubricant quality in the 90,000 km test were seen. The "no engine wear" finding is consistent with a test done on a CombustAll™-type FBC at the Battelle Research Institute[1].

In Canada, Upper Lakes Shipping (ULS) has been using a CombustAll™-type FBC for about 14 years in its diesel-engined Great Lake freighters. Over that period, ULS reports the FBC has caused no engine problems whatsoever. ULS's reason for using the FBC is interesting; individual ship engineers use the product because it keeps their engines cleaner (i.e. the FBC burns off carbon deposits in the engine cylinders and exhaust system). They don't use it specifically to reduce emissions

No Harm – Fuel Properties

CombustAll™ has no effect on the properties of diesel fuel. The addition of the FBC does not change fuel properties such as cetane number, pour point, fuel stability, lubricity and emulsion forming tendency.

The catalyst chemicals in CombustAll™ are completely soluble in diesel fuel. Their presence in fuel - only a few parts per million - ensures there is no settling out in fuel tanks. CombustAll™ does not affect the long-term storage properties of fuel.

No Harm – Health Effects

The catalyst chemicals in CombustAll™ are non-toxic and fully biodegradable and their combustion byproducts represent no threat to human health.

Extensive epidemiological and health effect tests performed by independent agencies in Europe have demonstrated that CombustAll™-type FBC's pose no health risk to humans. It is important to note that, in many European countries, regulatory agencies must approve fuel additives as a public safety measure. The following agencies have approved CombustAll™-type FBC's: the German Federal Environmental Agency, the Swiss Federal Office of Environment, the French Ministry of Environment, the U.K. Department of Health and the Swedish EPA-MTC Centre.

In fact, FBC's can make an important contribution to reducing health risks associated with exposure to diesel exhaust, particularly by decreasing PM emissions. Since it is outside the scope of this report to examine the health impacts of diesel exhaust, interested readers are referred to an excellent report prepared by Dr. Sheela Basrur, Medical Officer of Toronto Public Health[9].

Effect of FBC's on Particulate Matter (PM)

The burning of diesel fuel in the engine cylinder does not occur instantaneously under stoichiometric conditions (i.e. that condition at which the proportion of the air-to-fuel is such that all combustible products will be completely burned with no oxygen remaining in the combustion air). Instead, there is a sequence of co-existing but different chemical reactions that occurs after injection of the fuel aerosol depending on whether combustion is occurring in a fuel-rich or fuel-lean zone of the cylinder. Particulate matter, or diesel soot, forms by the pyrolysis of fuel molecules in fuel-rich zones, typically at the core of the aerosol spray where there is a relative lack of oxygen.

As soot particles form and agglomerate and further air-fuel mixing takes place, the soot reacts with oxygen and is burned. The final rate of soot release into the exhaust system is the difference between the rate of formation and the rate of burning.

Laboratory testing at the Battelle Research Institute[1] suggests that CombustAll™-type FBC's act in the later stages of combustion, so it seems likely that CombustAll™ promotes burning or oxidation of soot as opposed to retarding its formation. This is supported by other research[7] showing that FBC's lower the ignition temperature of soot by about 100 degrees C. down to about 350 degrees C. and allow for shorter burn-out times.

The carbon content of particulate matter not only represents a health hazard but is also a form of lost energy, which can be utilized in the combustion chamber with the introduction of CombustAll™.

Effect of FBC's on Nitrogen Oxide (NO_x) Emissions

After soot or PM emissions, the major air-pollution problem for diesel engines is controlling NO_x emissions. Governments around the world are imposing ever tighter NO_x emissions limits, partly because multilateral efforts such as the Kyoto Accord have identified NO_x as a greenhouse gas.

NO_x formation in diesel engines is a strong linear function of combustion temperature. High combustion temperature causes some oxygen molecules in air to break up into atoms. These, in turn, attack the nitrogen molecules in air to form NO which makes up about 90% of NO_x emissions. Virtually all the nitrogen in NO_x emissions comes from atmospheric nitrogen; there is very little fuel-bound nitrogen in diesel fuel.

Nitrogen conversion starts at about 1,000 degrees C., and increases significantly above 1,300 degrees C. with rising temperature. From then on, the NO_x formation rate more than doubles for every increase of approximately 100 degrees C. The residence time at such high temperatures is also an important factor in determining NO_x quantities.

Although research in recent years has made great progress in modelling NO_x formation at all locations in the engine cylinder during the combustion cycle, not enough is known to define conclusively the process by which FBC's reduce NO_x formation.

In previous research done by CEI on ship engines[2, 3], it was observed that NO_x emissions declined steadily with continued use of CombustAll™. This suggests that CombustAll™ is affecting NO_x formation through non-stoichiometric means that are making semi-permanent changes in the engine cylinders. It is likely that NO_x formation is being reduced as CombustAll™ attacks carbon deposits in the engine cylinder. Carbon deposits act as insulators that interfere with the heat sink properties of the cylinder surfaces. Therefore, the carbon deposits act as hot spots, which play a role in the formation of NO_x.

Observations about NO_x Data

Collecting reliable NO_x emissions data from the Centerm equipment proved to be difficult. A major concern is evidence of high variation in NO_x emissions from the test units before CombustAll™ was added to the fuel (baseline tests were taken on February 11 and again on April 5, before the fuel was treated). For example, in top pick Unit 9523, NO_x emissions increased by 12% between the two baseline tests even though the stack temperature remained constant. In pulp clamp Unit 8030, NO_x emissions actually increased by 21% between the baseline tests even though the stack temperature fell by 47 degrees F., exactly the reverse of expectations.

Unlike most of the other engines we have tested, such as ship engines or constant revolutions per minute (rpm) genset engines, which are in a steady state mode most of the time, the nature of the duty cycle for the top picks, tractors and pulp clamps at Centerm is a nearly continual transient phase. There are a number of factors internal to diesel engines that can effect NO_x emissions, such as the fuel-air ratio, nozzle opening pressure, injection timing and aerosol swirl. Changes in these parameters over time are more likely under heavy transient use than with steady state use and can affect flame temperature, which is the primary determinant of NO_x emissions.

These observations were discussed with technical representatives from Cummins Inc., the manufacturer of the engines in the all of test units. The Cummins reps agreed it is likely that transient cycle engines would display higher variation in NO_x emissions, but apparently, there is little or no empirical data relating different duty cycles to changes in an engine's emission profile over time.

The transient nature of the duty cycle for the test equipment at Centerm is the most likely factor in the underlying variation in NO_x emissions data. Unfortunately, the variation observed is in the same order of magnitude as the improvements that CombustAll™ has produced in other tests. Therefore no conclusions can be made about the effect of CombustAll™ on NO_x emissions from the Centerm equipment.

Effects of FBC's on Carbon Monoxide (CO) Emissions

Carbon monoxide (CO) is a product of incomplete combustion of fuel hydrocarbons. Its formation in the diesel engine results mainly from the excess air ratio, the temperature of combustion and the uniformity of the fuel aerosol mixture in the engine cylinder. In general, CO emissions from diesel engines will be low due to high oxygen concentrations and an efficient combustion process. However, in poorly maintained engines or at low power ranges, the proportion of CO in the exhaust may increase considerably.

CombustAll™ improves combustion efficiency by catalyzing the oxidation of hydrocarbon molecules further to completion. In this process, carbon molecules are promoted to the more highly oxidized state of CO_2 rather than CO.

In tests performed at Battelle[1], a CombustAll™-type FBC reduced CO emissions from a clean diesel engine by 10%. CombustAll™ tests in the tug boat Evco Crest[2] and in a diesel bus operated by the Town of Markham[4] showed greater reductions of 20% and 40% respectively.

Effects of FBC's on Volatile Organic Compounds (VOC)

Volatile organic compounds are complex unburned hydrocarbons in gaseous or liquid phase that escape in the exhaust stream. They represent both a health and environmental hazard and a loss of energy that could be extracted in the combustion chamber.

Some of these hydrocarbons, such as benzopyrene, are well known carcinogens, which are distributed in the atmosphere by adsorption onto particulate matter. Methane is another VOC component, which is a greenhouse gas implicated in global warming.

CombustAll™ has been shown to be highly effective in reducing VOC compounds. Field tests on the Evco Crest[2] and the Canadian Explorer[3] showed that CombustAll™ reduced VOC emissions to zero.

However, none of the tests in this project, either before or after the addition of CombustAll™ to the fuel, detected any VOC's in the exhaust gas and so, other than this brief reference, this report will not discuss VOC's further.

5. Test Results and Analysis

In the following graphs, the blue bar is the baseline test (Test 1) showing the data acquired before CombustAll™ was added to the fuel supply. The green bars show data acquired at intervals after CombustAll™ was introduced to the fuel supply. The numbers at the top of the green bars indicate the number of operating hours on the engine since the fuel was treated. Numbers in the green bars show the per cent reduction in emissions with the use of CombustAll™. Where a data bar is marked "NMR" (no meaningful result), it means the data was excluded from the analysis because it didn't meet statistical criteria (95% confidence level) or some other criteria related to test mode consistency.

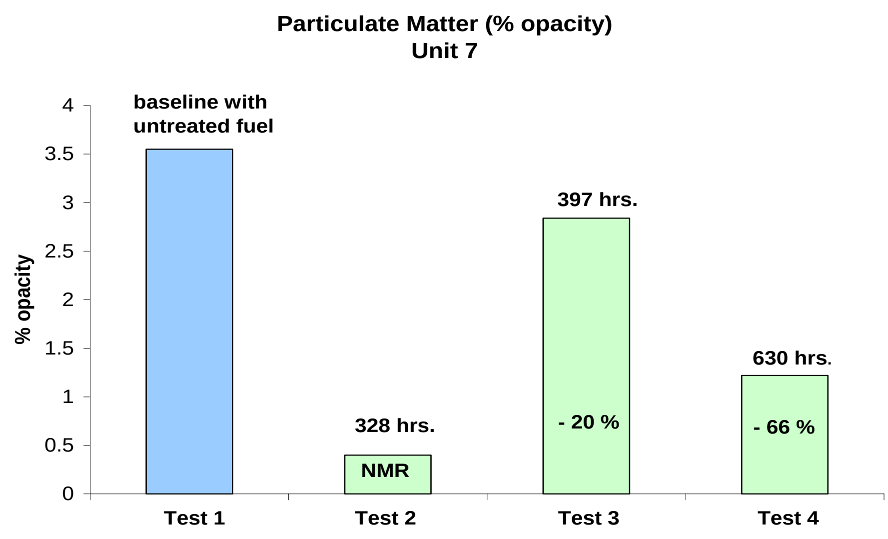
Vanterm Unit 7 (RTG)

RTG Unit 7 has a Cummins Model KTA-1150-G2 diesel engine rated at 600 brake horsepower (bhp) @ 1800 rpm. This engine was manufactured in December 1991 and has a mechanically controlled fuel injection system. RTG engines run at constant rpm to power electric motors that hoist containers and move the unit.

The opacity and emissions tests were conducted while Unit 7 was in the run mode at a constant rpm of 1850. The snap idle method was not used for the opacity test due to the constant rpm characteristic of the engine. Instead, a simple opacity reading was taken on the steady exhaust stream.

Particulate Matter (PM)

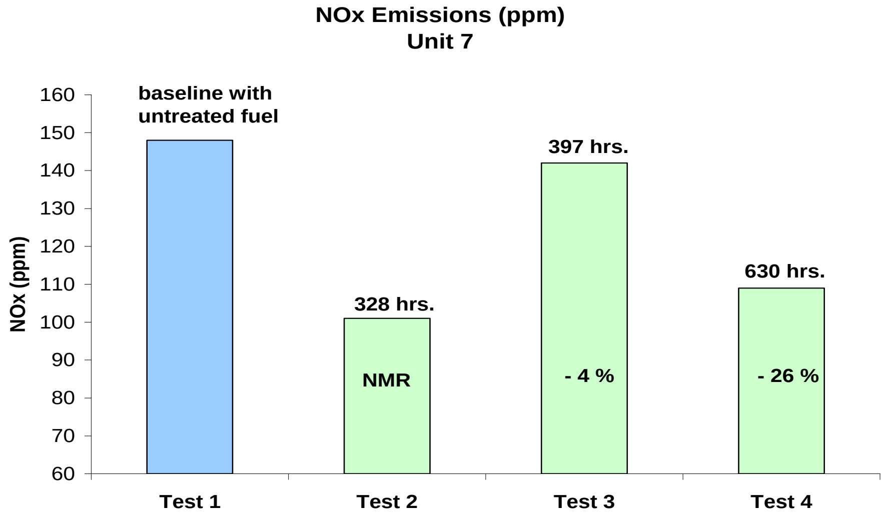
The opacity tests showed that CombustAll™ reduced PM emissions by 66% at the end of the test series after the engine accumulated 630 hours of operating time with CombustAll™ in the fuel. The change was apparent to the naked eye; the exhaust stream was visible in the baseline test but invisible in Test 4.



The Test 2 data was acquired when there was shower activity in the area and we cannot rule out the possibility that the high relative humidity affected the result even though we are not aware of any research linking humidity to PM emission levels.

NO_x Emissions

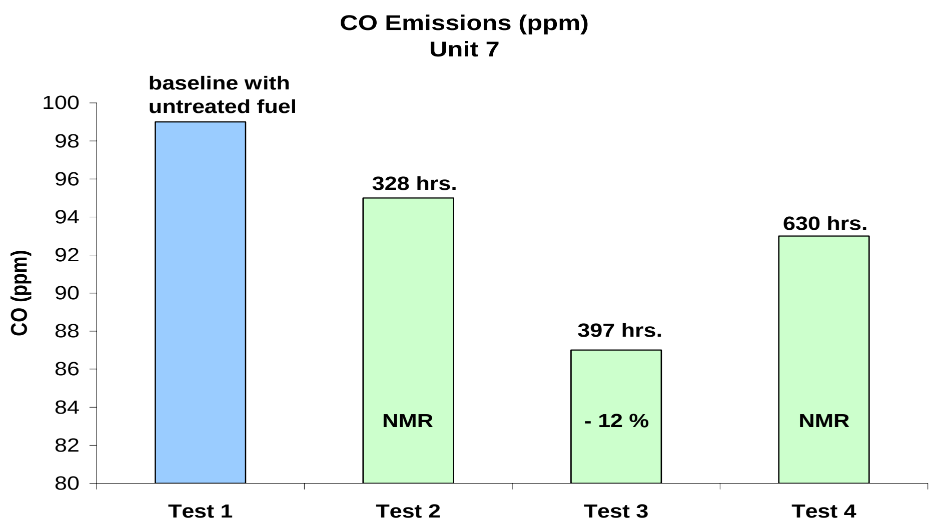
The test data showed a 26% reduction in NO_x emissions at the end of the test period. The downward trend from Test 1 to Test 3 to Test 4 is consistent with other field tests[3], which show NO_x declining over time with CombustAll™ use. CombustAll™ likely caused this phenomenon by eroding carbon deposit "hot spots" in the combustion chamber, which contribute to NO_x generation.



The Test 2 data is marked "NMR" due to shower activity that occurred during the test. There is a known relationship between relative humidity and NO_x emissions[7, 11]. High moisture content in combustion air suppresses NO_x production by absorbing energy and lowering flame temperatures.

CO Emissions

The following graph shows that CombustAll™ reduced CO emissions by up to 12% (Test 3). The variation in the Test1 baseline data was relatively high, which meant the small apparent changes recorded in Tests 2 and 4 in the range of 5 ppm or less were rejected at the 95% confidence level in the t-Test. The Test 2 and 4 bars are accordingly marked NMR.



Combustion Efficiency

The decreases in PM and CO emissions indicate that the addition of CombustAll™ to the fuel improved the combustion efficiency of the Unit 7 engine. The change was small, about 1%.

Conclusion

The test data showed that the addition of CombustAll™ to the fuel made the following changes to the emissions from RTG Unit 7:

- **PM was reduced by 66%.**
- **NO_x was reduced by 26%.**
- **CO was reduced by 12%.**
- **Combustion efficiency was improved slightly.**

Vanterm Unit 18 (RTG)

RTG Unit 18 has a Cummins Model KTA19-G4 (750) diesel engine rated at 755 bhp @ 1800 rpm. This engine was built in April 2000 and has an electronically controlled fuel injection system. RTG engines run at constant rpm to power electric motors that hoist containers and move the unit.

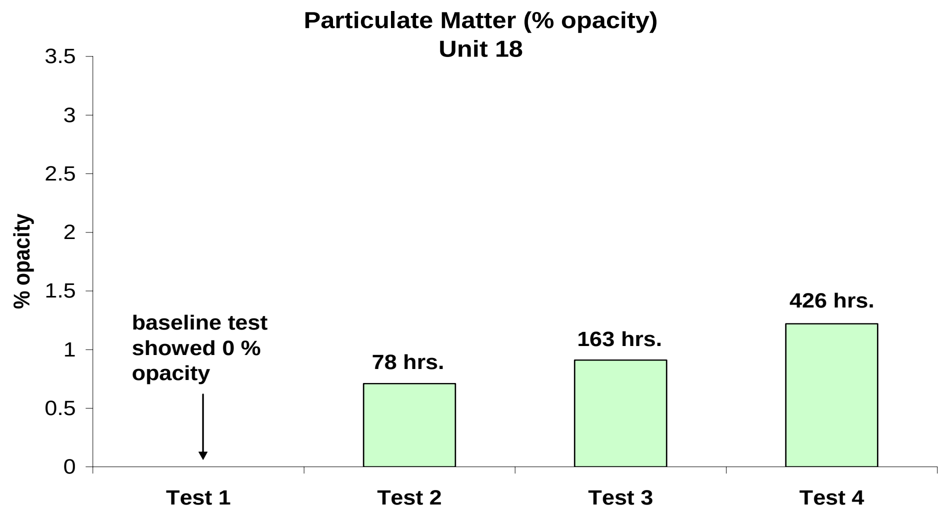
The opacity and emissions tests were conducted while Unit 18 was in the run mode at a constant rpm of 1,800. The snap idle method was not used for the opacity test due to the constant rpm characteristic of the engine. Instead, a simple opacity reading was taken on the steady exhaust stream.

Particulate Matter (PM)

The baseline opacity data for Unit 18 showed zero emissions of particulate matter, indicating that the newer, electronically controlled engines can be effective in reducing soot emissions. There was no opportunity, therefore, for CombustAll™ to make any improvement to PM emissions in this engine.

The test data showed a very slight increase in opacity, about 1%, with the use of CombustAll™. This phenomenon (i.e. a small increase in opacity) is sometimes seen in engines with low PM emissions, where CombustAll™ causes flaking of carbon deposits from the engine manifold and the upstream end of the exhaust stack. The flaking action will decrease over time as CombustAll™ cleans the exhaust system surfaces.

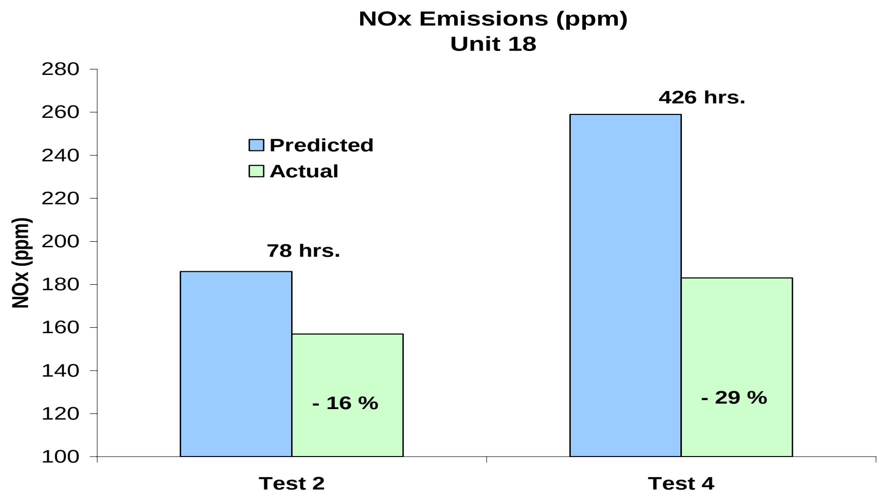
There was no visible smoke either before or after the addition of CombustAll™ to the fuel.



NO_x Emissions

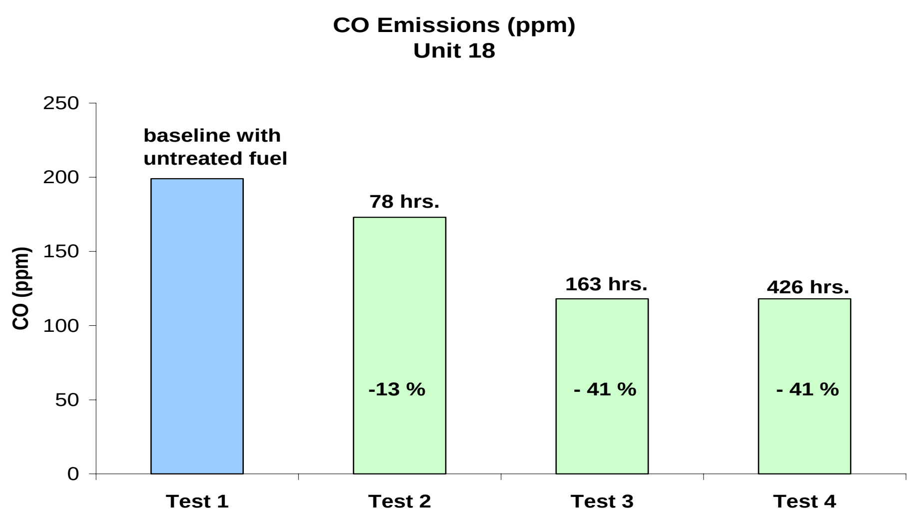
There is a very strong linear relationship between combustion temperature and NO_x formation. The temperature variation between the tests meant it was impossible to compare directly the unadjusted NO_x data from one test to another. Instead, a linear regression model was developed from NO_x data taken before CombustAll™ was added to the fuel. This allowed us to project NO_x emission levels for different temperature levels using untreated fuel. We then compared these projections with the actual observations using treated fuel. The following graph compares predicted vs. actual values for Test 2 and Test 4 (Test 3 was not included because the NO_x data series showed very high internal variation).

The Test 2 and Test 4 results show NO_x reductions of 16% and 29 % respectively. However, there was shower activity around the time Test 2 was performed so high relative humidity probably affected the result. The Test 4 result is the more meaningful figure.



CO Emissions

CO emissions were reduced by 41% at the end of the test series.



Combustion Efficiency

The decreases in CO emissions indicate that the addition of CombustAll™ to the fuel improved the combustion efficiency of the Unit 18 engine although the change was small, about 0.5%.

Conclusion

The test data showed that the addition of CombustAll™ to the fuel made the following changes to the emissions from RTG Unit 18:

- **PM increased slightly by 1% (due to soot flaking from exhaust stack and engine manifold).**
- **NO_x was reduced by 29%.**
- **CO was reduced by 41%.**
- **Combustion efficiency was improved slightly.**

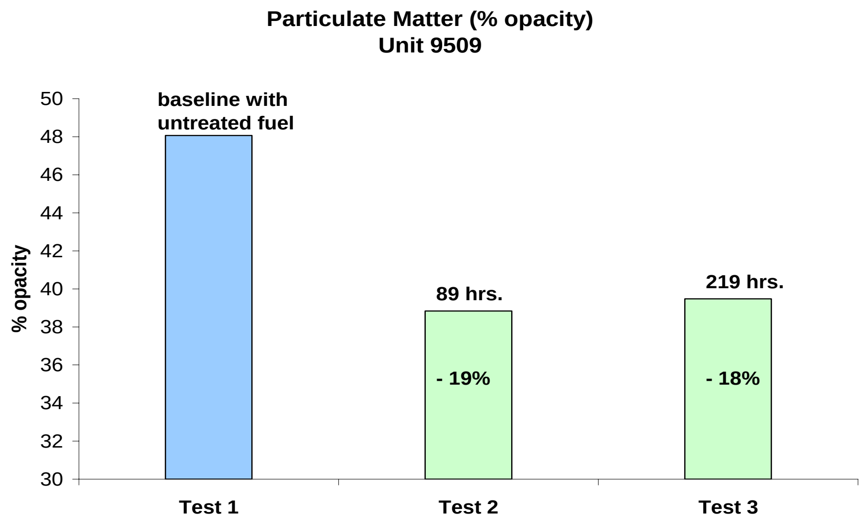
The emissions reductions also demonstrate that CombustAll™ is effective in modern design, electronically controlled diesel engines.

Centerm Unit 9509 (Top Pick)

Unit 9509 has a mechanically controlled Cummins Model L10-C250 diesel engine rated at 225 bhp @ 2100 rpm. The emissions tests were conducted while the engine was in the maximum idle mode limited by the governor.

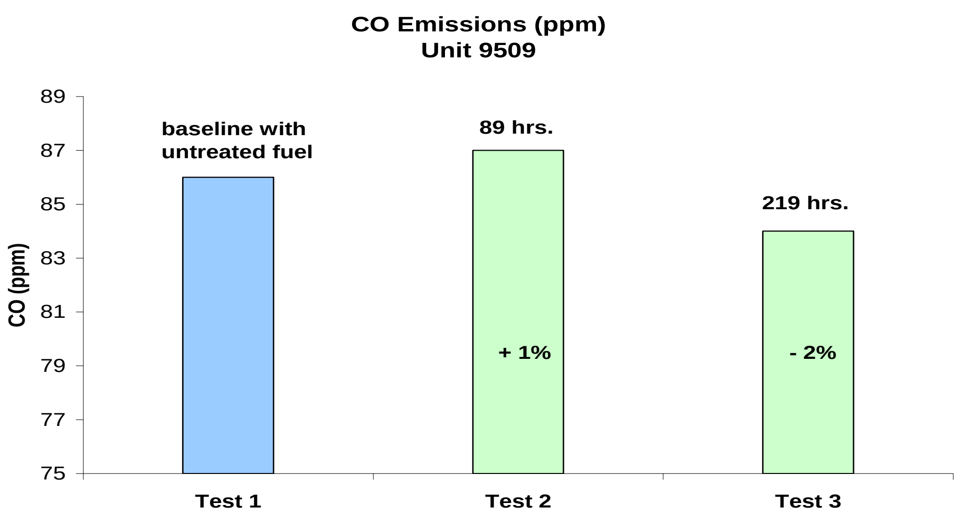
Particulate Matter (PM)

The opacity tests showed that CombustAll™ reduced PM emissions by 18% at the end of the test series after the engine accumulated 219 hours of operating time with CombustAll™ in the fuel. If this had been an on-road vehicle, it would have failed the Vancouver Air Care limit of 40% opacity, but the use of CombustAll™ would have improved PM emissions enough to earn a pass rating.



CO Emissions

The following graph shows that CombustAll™ reduced CO emissions by 2% in Test 3.



Combustion Efficiency

The decreases in PM and CO emissions indicate that the addition of CombustAll™ to the fuel improved the combustion efficiency of the Unit 9509 engine although the change was small, about 1%.

Conclusion

The test data showed that the addition of CombustAll™ to the fuel made the following changes to the emissions from Top Pick Unit 9509:

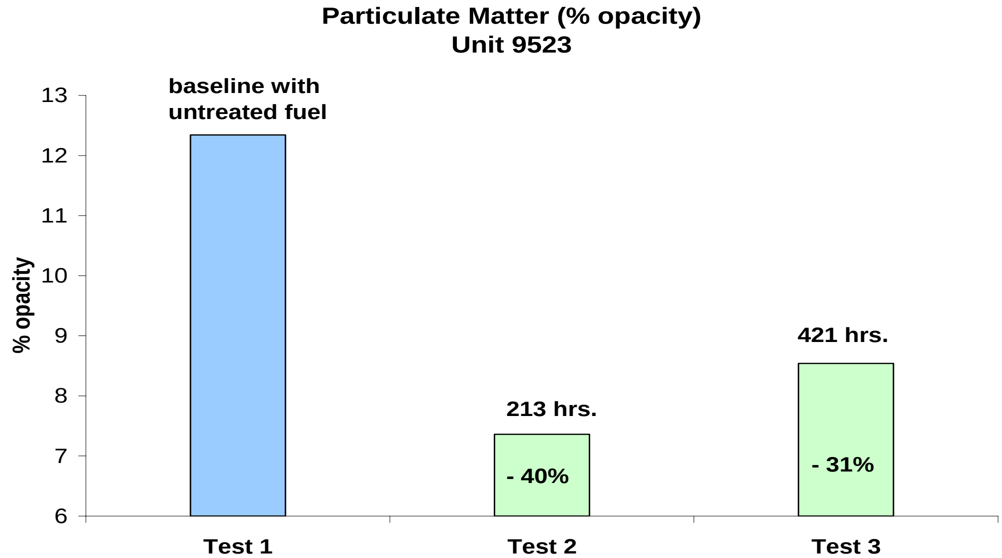
- **PM was reduced by 18%.**
- **CO was reduced by 2%.**
- **Combustion efficiency was improved slightly.**

Centerm Unit 9523 (Top Pick)

Top Pick Unit 9523 has an electronically controlled Cummins Model QSM11-C349E diesel engine rated at 330 bhp @ 2100 rpm. The emissions tests were conducted while the engine was operated at maximum rpm limited by the governor and loaded in a hydraulic "stall" mode.

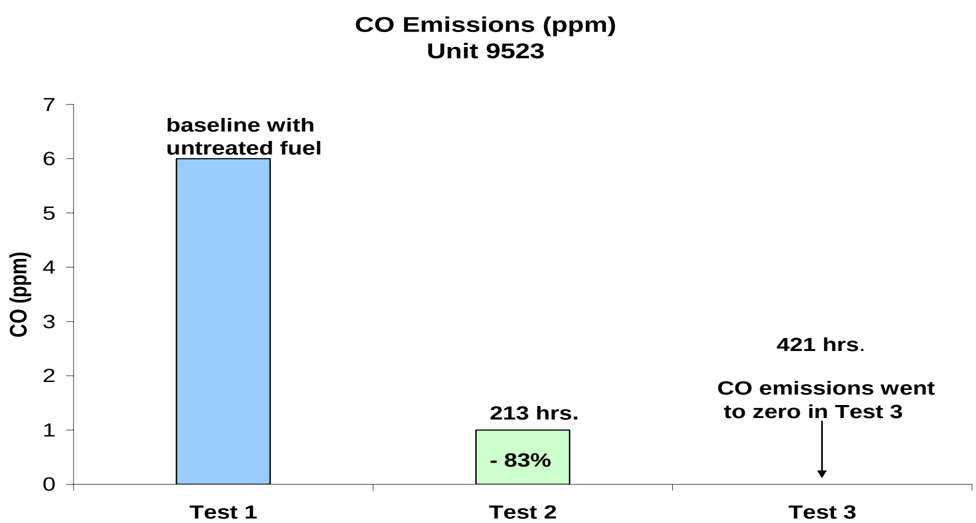
Particulate Matter (PM)

The test data showed that particulate matter was reduced by 31% in Test 3 after 421 hours of operation. These results are significant since they show that CombustAll™ is effective in modern, electronically controlled engines under load.



CO Emissions

The modern electronic engine controls in Unit 9523 are effective in limiting CO emissions to relatively low levels. However, the addition of CombustAll™ to the fuel further reduced emissions to the point that the engine was emitting zero CO by the end of Test 3 after 421 hours of operation.



Combustion Efficiency

The decreases in PM and CO emissions indicate that the addition of CombustAll™ to the fuel improved the combustion efficiency of the Unit 9523 engine. The amount of O_2 in the exhaust gas decreased, consistent with an improvement in combustion efficiency of 1.3%

Conclusion

The test data showed that the addition of CombustAll™ to the fuel made the following changes to the emissions from Top Pick Unit 9523:

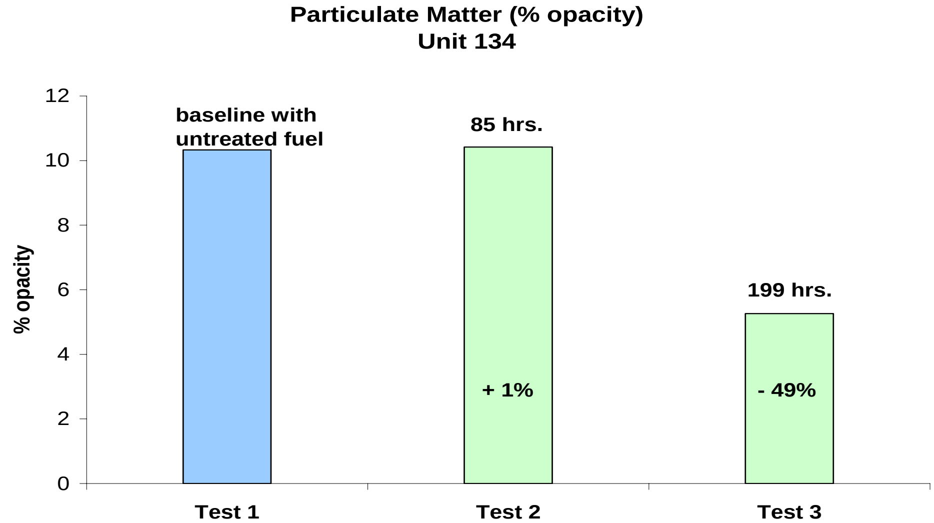
- **PM was reduced by 31%.**
- **CO was reduced by 100%.**
- **Combustion efficiency was improved by 1.3%.**

Centerm Unit 134 (Tractor)

Tractor Unit 134 has a mechanically controlled Cummins Model C8.3-C215 diesel engine rated at 215 bhp @ 2500 rpm. The emission tests were conducted while the engine was in maximum idle mode limited by the governor.

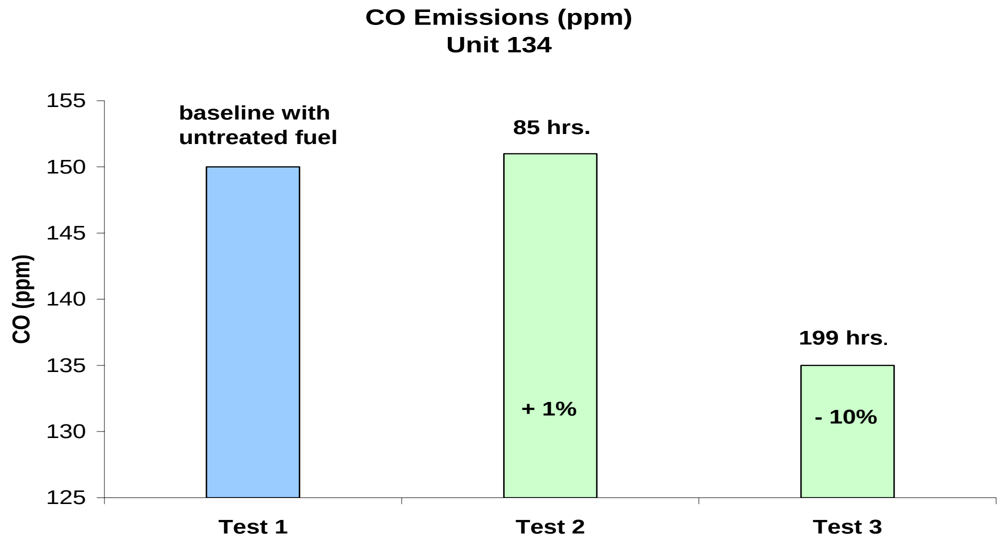
Particulate Matter (PM)

CombustAll™ reduced PM emissions by 49% at the conclusion of Test 3 after 199 hours of operation.



CO Emissions

CO emissions fell by 10% at the conclusion of Test 3 after 199 hours of operation.



Combustion Efficiency

The decreases in PM and CO emissions indicate that the addition of CombustAll™ to the fuel improved the combustion efficiency of the Unit 134 engine. The change was small, about 1%.

Conclusion

The test data showed that the addition of CombustAll™ to the fuel made the following changes to the emissions from Tractor Unit 134:

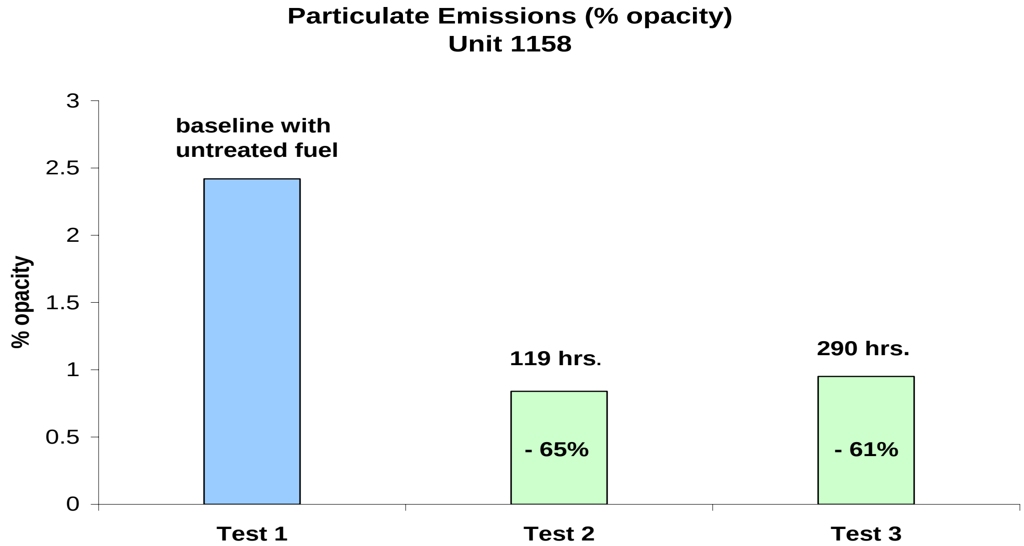
- **PM was reduced by 49%.**
- **CO was reduced by 10%.**
- **Combustion efficiency was improved slightly.**

Centerm Unit 1158 (Tractor)

Tractor Unit 1158 has an electronically controlled Cummins Model ISC-225E diesel engine rated at 225 bhp @ 2200 rpm. The emissions tests were conducted while the engine was in maximum idle mode limited by the governor.

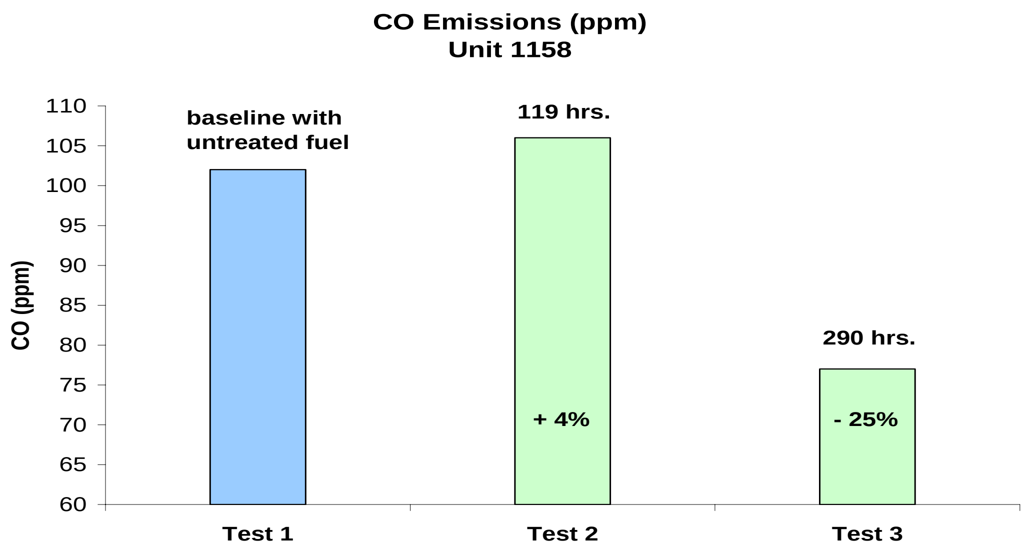
Particulate Matter (PM)

At the conclusion of Test 3, after 290 hours of operation, CombustAll™ reduced PM emissions by 61%.



CO Emissions

CombustAll™ reduced CO emissions by 25% at the end of Test 3 after 290 hours of operation.



Combustion Efficiency

The decreases in PM and CO emissions indicate that the addition of CombustAll™ to the fuel improved the combustion efficiency of the Unit 1158 engine. The change was small, about 1%.

Conclusion

The test data showed that the addition of CombustAll™ to the fuel made the following changes to the emissions from Top Pick Unit 9509:

- **PM was reduced by 61%.**
- **CO was reduced by 25%.**
- **Combustion efficiency was improved slightly.**

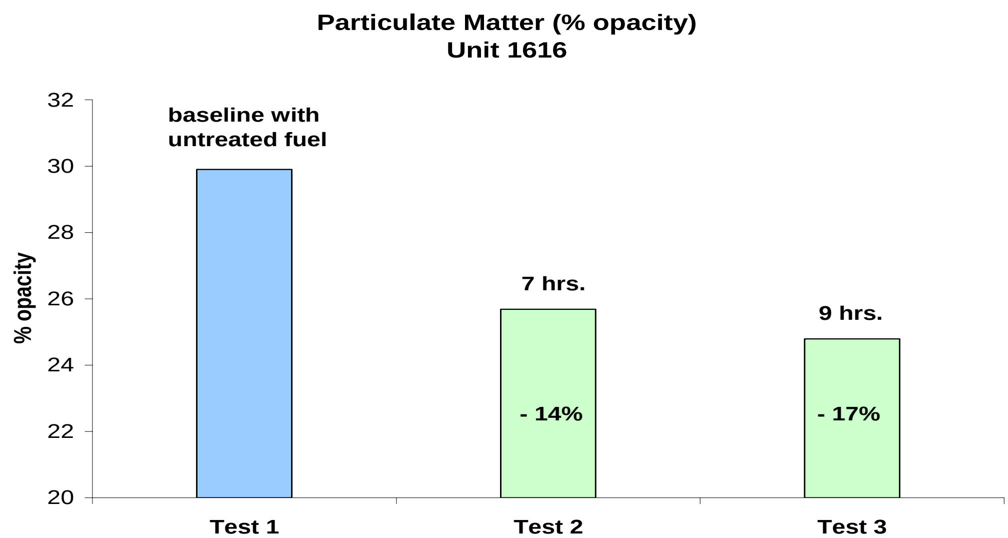
Centerm Unit 1616 (Pulp Clamp)

Pulp Clamp Unit 1616 has a mechanically controlled Cummins Model B3.9-C110 diesel engine rated at 100 bhp @ 2200 rpm. The emissions tests were conducted while the engine was in maximum idle mode limited by the governor.

This unit received little use during the test program, accumulating only 9 hours of operation by the end of Test 3. The decreases in PM and CO emissions show that CombustAll™ begins to affect the emissions profile immediately after it is introduced to the fuel tank.

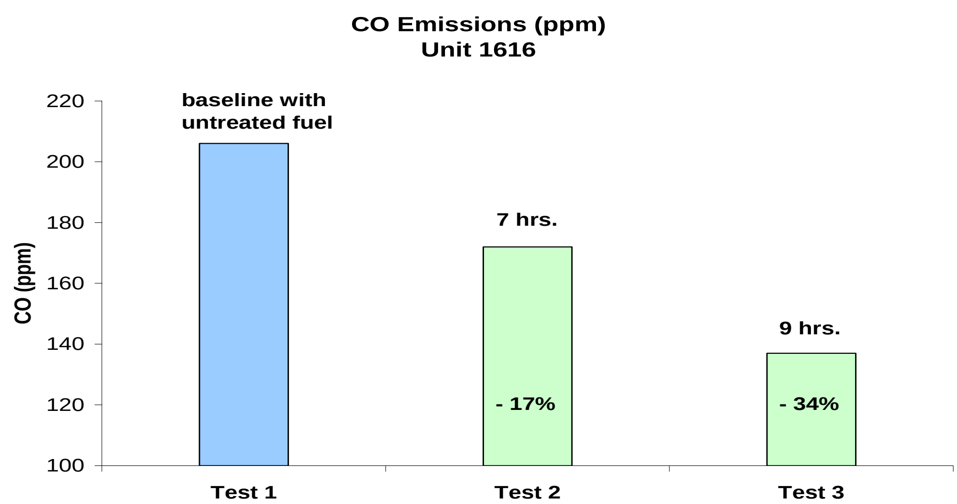
Particulate Matter (PM)

At the conclusion of Test 3 after 9 hours of operation, CombustAll™ reduced PM emissions by 17%.



CO Emissions

CO emissions fell by 34% at the end of Test 3 after nine hours of operation.



Combustion Efficiency

The decreases in PM and CO emissions indicate that the addition of CombustAll™ to the fuel improved the combustion efficiency of the Unit 1616 engine. The change was small, about 1%.

Conclusion

The test data showed that the addition of CombustAll™ to the fuel made the following changes to the emissions from Pulp Clamp Unit 1616:

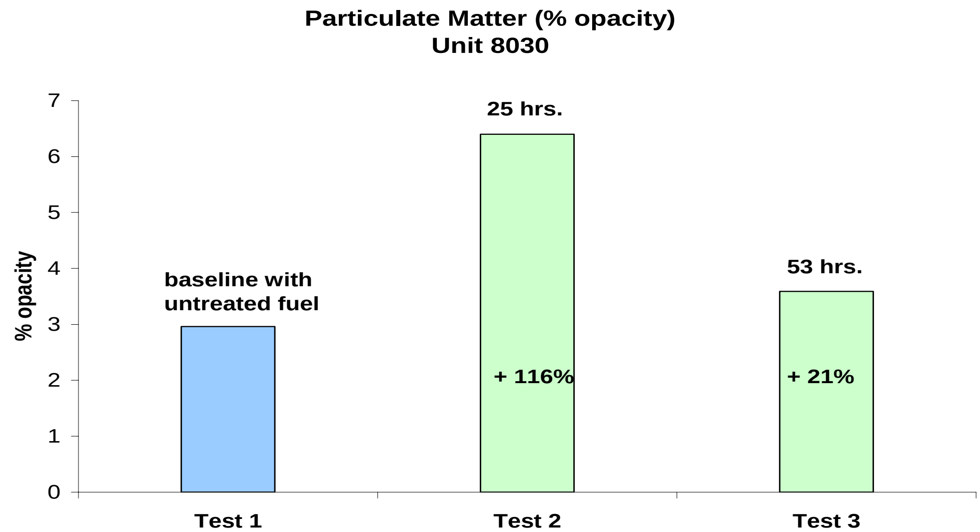
- **PM was reduced by 17%.**
- **CO was reduced by 34%.**
- **Combustion efficiency was improved slightly.**

Centerm Unit 8030 (Pulp Clamp)

Pulp Clamp Unit 8030 has a mechanically controlled Cummins Model BT3.9-C100 diesel engine rated at 100 bhp @ 2200 rpm. The emissions tests were conducted while the engine was in maximum idle mode limited by the governor.

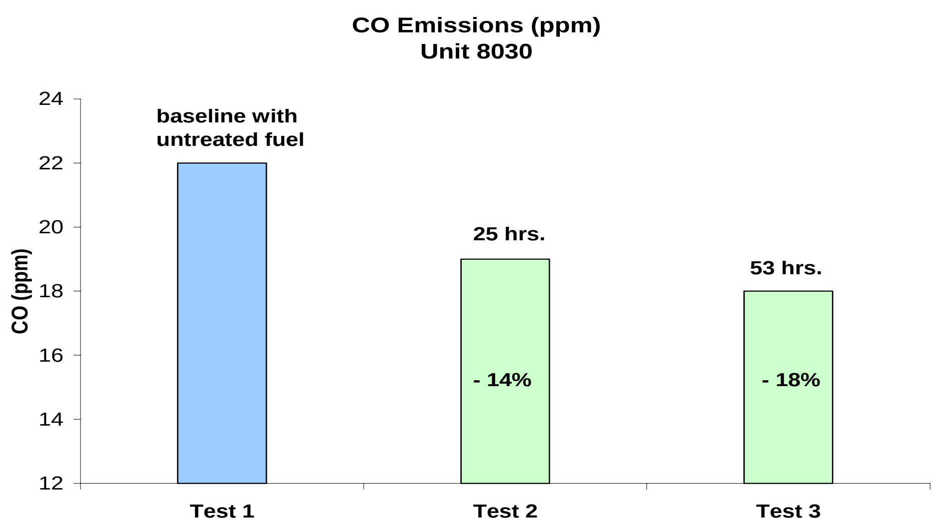
Particulate Matter (PM)

At the end of Test 3, PM emissions showed an increase of 21% after 53 hours of operation. However, while this is a large difference in relative terms, in absolute terms it represents a very small change of only 0.63% as the opacity increased from 2.96% to 3.59%. This result is often seen in engines where the PM emissions are already low before the addition of CombustAll™. Since CombustAll™ lowers the temperature at which soot can be burned, it attacks carbon deposits in the engine manifold and the upstream end of the exhaust stack. This is a temporary phenomenon, when the flaking of carbon deposits in the exhaust system can mask the effect of CombustAll™ in the engine cylinders.



CO Emissions

CombustAll™ reduced CO emissions by 18% at the end of Test 3 after 53 hours of operation.



Combustion Efficiency

The decreases in PM and CO emissions indicate that the addition of CombustAll™ to the fuel improved the combustion efficiency of the Unit 8030 engine. The change was small, about 1%.

Conclusion

The test data showed that the addition of CombustAll™ to the fuel made the following changes to the emissions from Pulp Clamp Unit 8030:

- **PM was increased by 21% (or 0.63% absolute).**
- **CO was reduced by 18%.**
- **Combustion efficiency was improved slightly.**

6. References

1. *Private Report on the Use of a Fuel-Borne Catalyst in a Diesel Engine,* Battelle Research Institute, Columbus Ohio Division.
2. *Test Report: Evco Crest*, Catalyst Energy Inc., 2002.
3. *Test Report: Canadian Explorer*, Catalyst Energy Inc., 2002.
4. *Test Report: Town of Markham Diesel Bus,* Catalyst Energy Inc., 2002
5. *Test Report on the Use of CombustAll™, a Fuel Borne Catalyst, in Reducing Diesel Exhaust Emissions from Rubber-Tired Gantries at the TSI Vanterm Container Port*, Catalyst Energy Inc., April 2004.
6. *Test Report on the Use of CombustAll™, a Fuel Borne Catalyst, in Reducing Diesel Exhaust Emissions from Top Picks, Tractors and Pulp Clamps at the P&O Centerm Container Port,* Catalyst Energy Inc., June 2004.
7. *Public Meeting to Consider Approval of Revisions to the State's On-Road Motor Vehicle Emissions Inventory: Technical Support Document*, California Environmental Protection Agency, Air Resources Board, May 2000.
8. *Rulemaking Informal: 2002-03-28 Appendix B. Diesel Engine Emission Control Technologies,* California Air Resources Board.
9. *Estimating the Health Impact of Exposure to Diesel Exhaust in Toronto*, Dr. Sheela Basrur, Medical Officer of Health, Toronto Public Health, June 2002. http://www.city.toronto.on.ca/health/pdf/de_summary.pdf
10. *Practical Diesel Engine Combustion Analysis*, Bertrand Hsu, Society of Automotive Engineers, 2002.
11. *Humidity and Temperature Correction Factors for NOx Emissions from Diesel Engines*, Final Report for Southwest Research Institute Project No. 03.30.10.06599, June 2003.

Appendix A: Engine Information

Rubber-Tired Gantries

Vanterm Unit No.	**7**	**18**
Equipment Make	MGM	ZPMC
Engine Make	Cummins	Cummins
Engine Model	KTA-1150-G2	KTA19-G4 (750)
Engine Serial Number	37140851	37192651
Engine Build Date	December, 1991	April, 2000
Rated Power (bhp@rpm)	600@1800 rpm	755@1800 rpm
Engine Controls	mechanical	electronic

Top Picks

Centerm Unit No.	**9509**	**9523**
Equipment Make	Taylor	Fantuzzi Reggiane
Engine Make	Cummins	Cummins
Engine Model	L10-C250	QSM11-C349E
Engine Serial Number	60404874	35064460
Engine Build Date	November, 2000	July, 2002
Rated Power (bhp@rpm)	225 @ 2100 rpm	330 @ 2100 rpm
Engine Controls	mechanical	electronic

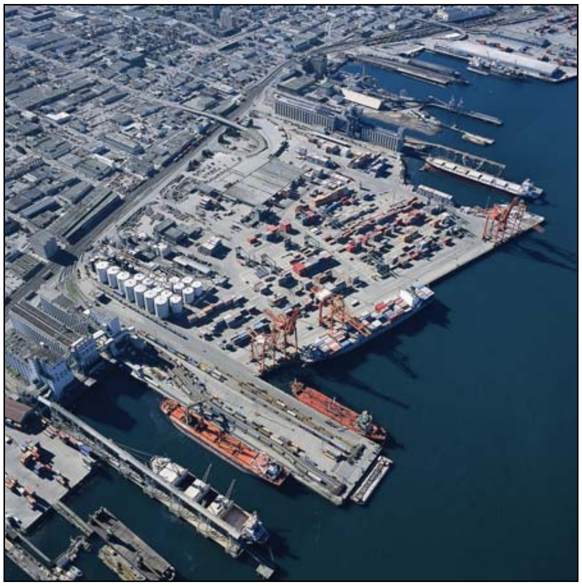
Tractors

Centerm Unit No.	**134**	**1158**
Equipment Make	Capacity	Ottawa
Engine Make	Cummins	Cummins
Engine Model	C8.3-C215	ISC-225E
Serial Number	45573710	46248322
Engine Build Date	August, 1997	August, 2002
Rated Power (bhp@rpm)	215 @ 2500 rpm	225 @ 2200 rpm
Engine Controls	mechanical	electronic

Pulp Clamps

Centerm Unit No.	**1616**	**8030**
Equipment Make	Taylor	Taylor
Engine Make	Cummins	Cummins
Engine Model	B3.9-C110	BT3.9-C100
Serial Number	45678350	48508423
Engine Build Date	March, 1998	April, 2002
Rated Power (bhp@rpm)	100 @ 2200 rpm	100 @ 2200 rpm
Engine Controls	mechanical	mechanical

Appendix B: Photos



TSI Vanterm Operation

P&O Ports Centerm Operation

RTG unit at Vanterm

Tractor unit at Centerm

Pulp Clamps at Centerm

Top Picks at Centerm

Enerac 2000 gas analyzer

Wager 6500 smoke meter