

# Optimal Control of Particulate Emissions in Diesel Engines

## *Abstract*

### *Introduction*

In the early years of the twenty-first century, the emphasis on fossil fuel emission reductions was focused on gaseous emissions. Nitrogen Oxides (NO<sub>x</sub>) were recognized as the precursors of ground smog and as such were detrimental to communities located near ports where the concentration of exhausts from diesel engines and/or boiler plants adversely affected the quality of life. As the new century progressed, the emphasis on emission reductions shifted to solid emissions. Particulates were recognized as health hazards that contributed to instances of respiratory ailments. Fossil fuel combustion – so fundamental to the economy of the nation – unfortunately produces both emissions. Thus, the development of after-treatment technologies to treat the gaseous and solid exhaust products of fossil fuel combustion chambers was pursued. Unfortunately, the imposition of after-treatment technology proved costly from both an application and a maintenance aspect. Furthermore, in some instances, the introduction of after-treatment technology caused a decrease in fuel efficiency.

In view of the foregoing, it is important to note that there is a technology that REDUCES the gaseous AND the solid emissions of fossil fuels. Furthermore, since it fundamentally alters the combustion of fossil fuels in a favorable manner, this technology can also INCREASE fuel efficiency. The technology that can deliver this “triple-crown” of dual emission reduction and enhanced fuel efficiency is EMULSIFIED FUEL TECHNOLOGY (EFT). In this paper, we shall consider EFT from several viewpoints. First we shall consider the constitution, production and characteristics of Emulsified Fuels. Then we shall consider the combustion of such fuels and the environmental benefits that can accrue to their utilization. Finally, we shall consider past applications of Emulsified Fuels and the future markets for this intriguing technology.

## *Experimental*

### *Constitution of Emulsified Fuels*

An emulsion is a mixture of two immiscible (i.e., not able to be blended) substances. In an emulsion, one substance - the dispersed phase - is uniformly distributed throughout the second substance - the continuous phase. For example, a fuel oil emulsion features water globules - the dispersed phase – uniformly distributed throughout the fuel oil – the continuous phase. An emulsion takes on the characteristics of the continuous phase. Hence, fuel oil emulsions exhibit characteristics of fuel oil NOT water.



**Figure 1. Photomicrograph of Water Particles in a Diesel Oil Emulsion**

Emulsions are inherently unstable. Over time they tend to “separate” into the stable states of the dispersed and continuous phase materials. Thus, a volume of fuel oil emulsion over time will separate into distinct volumes of water and oil. In order to maintain the composition of an emulsion, surface active agents, i.e., surfactants are incorporated into the production of an emulsion. In a fuel oil emulsion, these surfactant agents encase the globules of water distributed throughout the continuous oil phase and prevent the water globules from coming together and coalescing into larger globules and ultimately into a significant volume of “separated” water. Because of surface tension, the surfactants act to form a membrane that encases the water globules within the fuel oil emulsion and forces the globules into small spheroids of water that are distributed throughout the continuous fuel oil phase. A micrograph of such water spheroids contained within the light (diesel) oil continuous phase of a diesel oil emulsion is shown in Figure 1 above.

### *Production of Emulsified Fuels*

The production of an emulsion involves both chemical and mechanical operations. As stated previously, a surfactant is incorporated into the production of an emulsion to preserve its stability. The chemical nature of this surfactant is such that it is amenable to both the dispersed and continuous phase materials. The formulation of an emulsion surfactant agent must take into account the need to preserve the stability of the emulsion in both storage and pumping operations as well as the need to render harmless the emission products arising from the combustion of the emulsified fuel. In this regard, it is to be noted that both the additive and the light oil (diesel) emulsified fuel produced by Alternative Petroleum Technologies S.A. (APT). have been verified by the California Air Resources Board (CARB) and registered with the United States Environmental Protection Agency (USEPA).



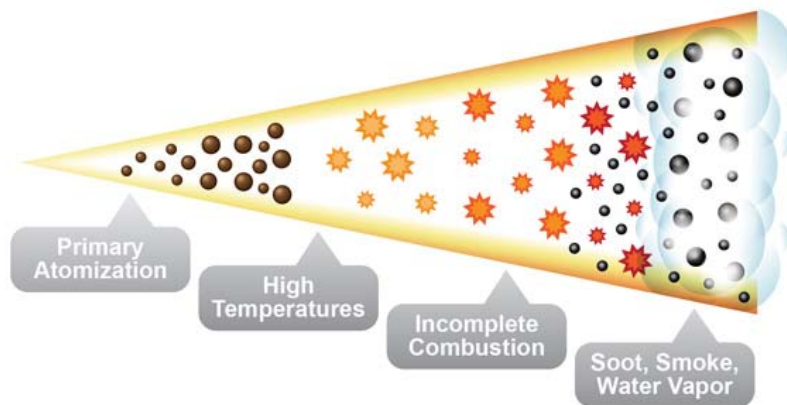
**Figure 2. Stationary & Mobile Blending Units**

The mechanical operation involved in the production of emulsified fuels is that of a high-value (HV) shearing operation. This HV shearing operation is accomplished in a computer-controlled Blending Unit that insures the dispersed phase (water) in an emulsified fuel is sufficiently shattered into micro-scale globules that will react with a proprietary surfactant agent to produce a maximum dispersion of water spheroids within the surrounding fuel oil phase. In conjunction with this HV shearing action, the proper amounts of water, surfactant and fuel oil must be metered into the shearing volume to preserve the homogeneity of the final emulsified fuel product. Examples of computer-controlled APT Blending Units – both stationary and mobile configurations - that produce light and heavy fuel oil emulsions are shown in Figure 2.

### *Characteristics of Emulsified Fuels*

While emulsified fuels take on the primary characteristics of the continuous phase material, emulsified fuels differ significantly in some respects from their base constituents. For example, light (diesel) oil emulsions appear white in color as compared to the amber color of base diesel oil. However, diesel oil emulsions do feel “oily” to the touch thus preserving some of the base characteristics of the continuous phase. In contrast, heavy oil emulsions appear black in color – like their base oil – but flow liberally at a somewhat lower ambient temperature than do their base (continuous phase) fuel oil. This lower viscosity aspect of fuel oil emulsions provides added savings in energy usage for their service as combustibles since less power is needed to pump fuel oil emulsions from storage tanks to burner fronts and less heat is also needed to preserve fuel oil emulsions in a proper pumping state within plant storage tank farms.

This aspect of emulsified fuel characteristics is especially pronounced with residual oil emulsions. Residual oil emulsions are made by emulsifying the very heavy liquid “bottom” oils from vacuum tower installations. Instead of “cutting” these vacuum tower bottom” oils by blending them with lighter distillate oils to ultimately make #6 fuel oil, emulsifying these “bottoms” replaces the expensive “cutter” oils with water and an emulsifying surfactant to produce a residual oil emulsion that flows like water (!) at an ambient temperature. Again, these residual oil emulsions can be readily pumped from storage tanks to burner fronts to produce an inexpensive alternative to fuel oil #6 for plant power production.



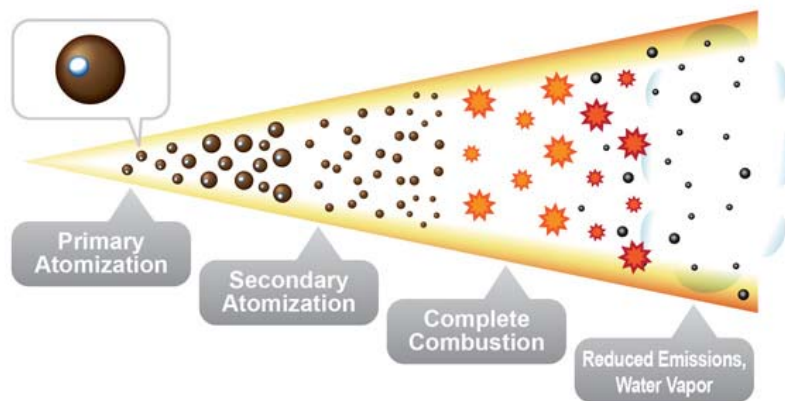
**Figure 3. Regular Fuel Oil Combustion**

## Combustion of Emulsified Fuels

Traditional combustion of hydrocarbon fuels in a power plant boiler requires the fuel to be first atomized (either mechanically or with steam or air) to breakup the fuel into small droplets that can be more readily ignited. Once these small fuel droplets enter the high temperature combustion zone of the boiler at the exit plane of the fuel nozzle, they begin to burn in a charring fashion, i.e., from the surface inward to the core of the droplet. Normally, this “char” burning of the fuel droplet is not completed within the high temperature combustion zone of the boiler. As a result, unburned fuel products (particulates) are expelled from the combustion zone and transported in the flow of exhaust gases from the combustion zone to the stack exit of the boiler.

Simultaneous with this generation of particulate emissions, the generation of gaseous emissions proceeds from the exposure of fuel-borne nitrogen and the nitrogen in combustion air to the high temperature refining atmosphere of the combustion zone. Depending upon the completion of the attending combustion, various concentrations of oxides of nitrogen ( $\text{NO}_x$ ) as well as carbon oxides ( $\text{CO}$  and  $\text{CO}_2$ ) exit the combustion zone and proceed to the stack exit plane. An illustration of this process is shown in Figure 3.

In contrast to this foregoing situation, the combustion of emulsified fuels features the introduction of water into the combustion zone along with the base fuel. Introduction of water into the combustion zone produces two profound effects upon the combustion of the emulsified fuel. First, upon expulsion from the exit plane of the burner nozzle, exposure of the globules of water in the emulsified fuel to the high temperature of the combustion zone causes an immediate evaporation of the water in the droplets to steam – a phenomenon known in the literature as a “micro-explosion” (1) occurs.



**Figure 4. Emulsified Fuel Combustion**

Each “micro-explosion” of a water droplet is accompanied by a significant increase in volume of the here-to-fore surfactant-encased water droplet and a subsequent shattering of the surrounding fuel oil medium into numerous auto-ignition centers of combustion. It is akin to the bursting of a balloon and the fracturing of the balloon surface into numerous pieces of balloon surface material. Each piece of balloon surface material immediately becomes a burning center and causes the surrounding medium to ignite. As such, the surface area of the surrounding material subject to burning is greatly increased and a more complete combustion of the surrounding material – the continuous fuel oil phase of the fuel emulsion – is generated. Hence, the chance of unburned particles of fuel oil escaping from this burning atmosphere is significantly decreased and thus the production of particulate emissions is stifled. An illustration of this process is shown in Figure 4.

## Results and Discussion

### Environmental Benefits

The introduction of water vapor into the combustion zone tends to decrease the temperature of the combustion zone due to the high heat capacity of the water medium. This decrease in combustion zone temperature leads to a less energetic oxidation of both fuel borne and combustion air nitrogen contents and therefore leads to an overall decline in  $\text{NO}_x$  generation.

As we have seen, the introduction of water - via the fuel emulsification process – leads to a twofold environmental benefit. By fundamentally affecting the fuel combustion process (2), emulsification leads to the reduction of BOTH solid (particulate) AND gaseous ( $\text{NO}_x$ ) emissions. Very rarely does a single technology have such a significant set of dual environmental benefits.

The introduction of water into the combustion process has an added benefit from an energy efficiency viewpoint. The added heat content of the water introduced into the combustion zone by an emulsified fuel means that the exhaust gases of the combustion process are more “energetic” than those of conventional fuels. Hence, as these more “energetic” combustion gases traverse the boiler heat transfer zones, they are able to transmit more heat by convection to the steam generating tubes resulting in an INCREASE in fuel efficiency.

This increase in fuel efficiency leads to the final benefit attributable to emulsified fuels – a reduction in hydrocarbon emissions. If indeed emulsified fuels can produce more steam output per fuel input, then the total amount of base (hydrocarbon) fuel input required to produce a required power output is less. If base (hydrocarbon) fuel usage is decreased, the oxides of Carbon resulting from this lessened requirement for base fuel combustion are LESS. Emulsified fuels can thus contribute significantly to the lessening of greenhouse gases generation resulting from existent hydrocarbon fuel combustion.

In summary, the introduction of water into the combustion process by the use of emulsified fuels results in the generation of an enhanced “triple crown” of benefits – the reduction of BOTH gaseous (NO<sub>x</sub>) and solid (Particulate) emissions, an increase in fuel efficiency AND the reduction of greenhouse gases. As such, emulsified fuel technology is one of the most effective – and cost-beneficial technologies – available to accommodate future requirements for hydrocarbon emission reductions, energy efficiency enhancement and greenhouse gas diminution.

### *Past Applications of Emulsified Fuels*

Past applications of Emulsified Fuel Technology (EFT) are now reviewed to validate the foregoing assertions on emissions and efficiency. These applications are divided into two major categories – Mobile EFT Tests and Stationary EFT Tests.

Mobile EFT tests include:

1. Test of DOE - Engine Timing (Lubrizol) (NO<sub>x</sub> & PM)
2. CATTs - DOE Truck Engine Dyno-Tests (EFF+)
3. CEC Tests of DOE in London, UK bus fleet (+AfterTreat)
4. TestSafe, Australia – DOE in Mining Engine
5. Shell Global tests of DOE in Australian Trucks (CO<sub>2</sub>)
6. SWRI Test of DOE in Bus Engine – Transient Emissions

Stationary EFT tests include:

1. Tests of FOE in 4 engines at Freeport, NY municipal power plant
2. Test of FOE in 2 dual-fuel diesel engines at Hofstra University
3. Test of FOE in power plant of South Oaks Hospital in Amityville, NY

### *Mobile Tests*

1. A Caterpillar 3406B (1986) manual-throttled diesel engine was tested by the Lubrizol Corporation (3) over the ISO standard Marine 4-mode steady-state cycle on a set of Low-Sulfur Diesel Oil Emulsion (LSDOE) fuels. Five fuels were included in the test program: baseline low sulfur (~150 ppm) diesel (LSD) fuel and four LSDOE fuels containing 5%, 10%, 15%, and 20% water (by volume) respectively. A minimum of three test series was undertaken for the baseline fuel configuration and also for each of the LSDOE fuel configurations. The engine was installed on the water-brake heavy-duty dynamometer test site at ERMD (the Environment Research and Measurement Division) of Environment Canada in Ottawa, Canada. The throttle and dynamometer controllers allowed for continuous steady-state engine operation.

The engine was mapped using the baseline LSD fuel to determine the rated speed and power of the engine, from which the Marine cycle was applied. Baseline emission tests were undertaken first with the LSD fuel. In addition to exhaust emissions, a record of engine performance data was also recorded. Following the baseline testing, the LSDOE fuel blends were tested in sequence using the same routine as the baseline testing.

**Optimization of engine timing combined with the use of LSDOE fuels was found to reduce engine NO<sub>x</sub> emissions by 48% and to reduce particulate emissions by 83%.**

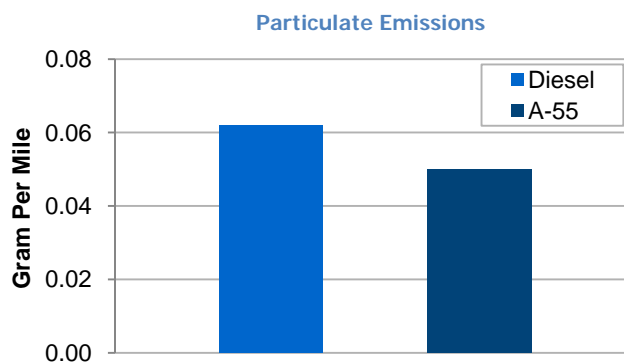
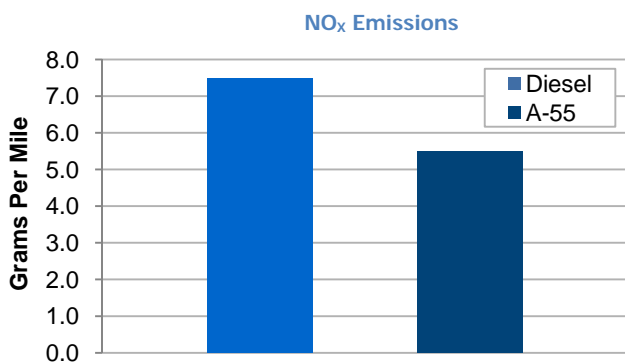
2. A Diesel Oil Emulsion (DOE) was tested in a pick-up truck with a Cummins 5.9L 24 Valve engine at the California Truck Testing Services (CATTs) facility in Richmond, California (4). The facility is a CARB and US Environmental Protection Agency (EPA) recognized laboratory for conducting vehicle certification and retrofit emission testing in light, medium and heavy duty vehicles on chassis and engine dynamometers. Engine emission and fuel consumption tests were undertaken on a Froude-Consine heavy-duty truck dynamometer. No modifications to the engines or vehicle were performed or required in order to run the DOE fuel. Significant reductions in NO<sub>x</sub> and Particulate Matter (PM) emissions were recorded as was a major increase in fuel economy.

The emission testing was done according to CFR 40, 86, App.1, the Urban Dynamometer Driving Cycle (UDDS). Unlike engine dynamometer testing, chassis dynamometer testing is more representative of actual in-use vehicle operation as it accounts for the losses and operation associated with the specified vehicles into which the engine is installed. The UDDS schedule has been developed for chassis dynamometer testing of heavy-duty vehicles. Typically, three tests are done on each fuel to ensure repeatability.

The vehicle's exhaust gases were captured using a Horiba emissions sampling system. This system incorporated a dilution tunnel, a secondary tunnel, a 3000-cfm constant volume sampler (CVS) and an emissions bench. The data recorded by this system were monitored by a computer and automatically treated to subsequently calculate engine emissions data.

The fuel manufactured for the testing contained 76% standard #2 on-road diesel fuel, 23% water and 1% proprietary Emulsion Additive. Because of the efficiency of diesel engines, CO emissions are extremely low. Notwithstanding, CO emissions were still reduced by 2.83% when operating on DOE fuels as compared to standard #2 on-road diesel fuel. Emission results from the CATTs tests (shown below) illustrate that DOE fuels (designated A-55 in the graphs) were able to reduce engine NO<sub>x</sub> emissions by 26.6% and engine PM emissions by 22.3%.





Tabular fuel use and mileage data from this CATTs testing is shown below.

FUEL	GAL	MI	MPG	H <sub>2</sub> O%	DO%	DO GAL	MPG-DO	MPG-DO %INC
DO	0.337	5.6	16.6	0	100	0.337	16.6	0.0%
DOE	0.376	5.6	14.9	23	76	0.286	19.6	15.2%

From this record, it is seen that 0.337 gallons of diesel oil (DO) produced 5.6 miles of travel on the test dynamometer. To produce this same mileage on the test dynamometer, 0.376 gallons of diesel oil emulsion (DOE) was used. Hence, more (0.376 – 0.337 = 0.039 gallons) “fuel” (i.e., “emulsified fuel”) was used to produce the same mileage (i.e., 5.6 miles) on the test dynamometer. However, there was less diesel oil in this emulsified fuel since it contained 23% water by volume. If one considers only the diesel oil content of the emulsified fuel, then only (0.76 x 0.376 =) 0.286 gallons of diesel oil (in the emulsified fuel) was used to produce 5.6 miles of travel on the test dynamometer. Hence, **a fuel efficiency increase of 15.2%** was registered in the diesel oil gallons (DO-GAL) figure recorded for the testing. It is instructive to consider fuel efficiency in this manner since the hydrocarbon fuel (i.e., diesel) content of an emulsified fuel product is the primary COST element of the product.

3. A water-blend fuel technology has been shown to substantially reduce engine emissions relative to ultra-low sulfur diesel (ULSD) fuels and requires no engine modifications in order to use the technology. To further evaluate the emissions performance of the technology, a trial was conducted by the Lubrizol Corporation at the Millbrook testing facility in Bedfordshire, England (5). The ultra-low sulfur diesel oil emulsion (ULSDOE) fuel that was tested contained 10% by weight of water, as well as proprietary additives to maintain emulsion stability. The trial also considered the impact of such ULSDOE fuels on existing/future exhaust emission control technology.

The vehicle selected for this work was an Olympian bus, with Euro 2 engine. No modifications were made to the engine other than to ensure that an appropriate exhaust system was in place to permit rapid changes to exhaust after-treatment when required. The catalytic converter utilized two, 46.5 cells/cm<sup>2</sup>, 5.05L Large Frontal area (LFA) substrates for a total catalyst volume of 10.1L. The catalyst had a loading of platinum on a molecular sieve that contained wash-coat which was stabilized against deterioration at elevated temperatures. The particulate trap used in this study was an 11¼ x 14 trap that featured an EX66 Cordierite substrate. The trap was sized to provide comparable levels of back-pressure to the original exhaust system. No tests on regeneration were made and the test time was minimized to limit the need for such regeneration.

On the Millbrook London Transport Bus (MLTB) cycle, the ULSDOE fuels tested achieved significant reductions in nitrogen oxides (NO<sub>x</sub>) and particulates over that attained with ULSD fuels. Speciation confirmed that the ULSDOE fuels tested also gave equivalent or lower levels of unregulated emissions. Further enhancements in total emissions control were achieved through the combination of ULSDOE fuel use with oxidation catalyst and particulate filter trap technologies. No detrimental effect was noted for these ULSDOE fuels with respect to the use of these additional exhaust emission control technologies.

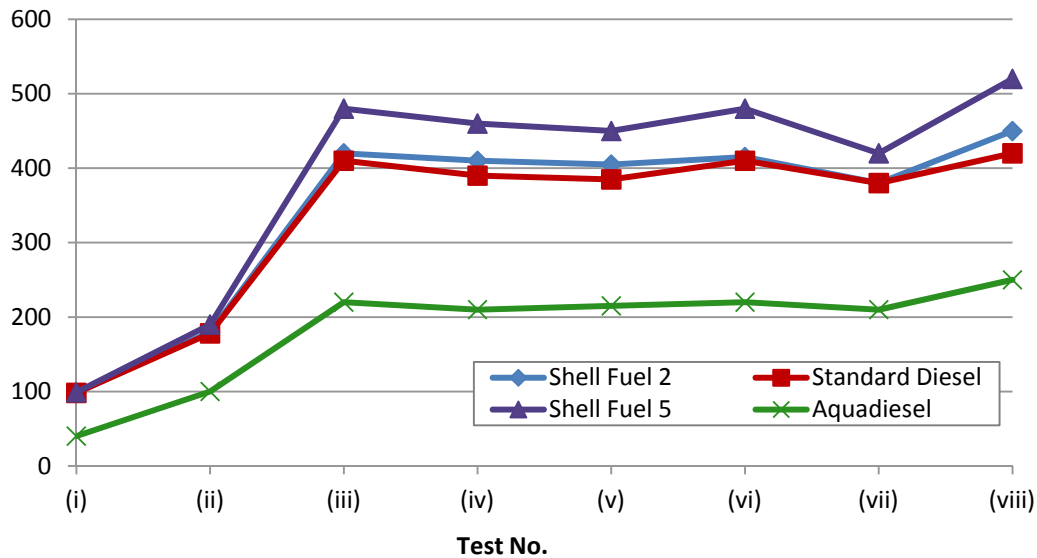
The procedures used for the sampling and analysis of engine emissions were approved by the California Air Resources Board (CARB). One hundred and sixty-nine CARB Non-Methane organic compounds (NMOG) were measured. Using US ozone forming factors, the ozone-forming potential of gaseous emissions from the ULSDOE fuels showed reductions of up to 29% relative to the ULSD fuel baseline data with comparable exhaust after-treatment installations. Formaldehyde emissions, one of the primary Hazardous Air Pollutants (HAPs), were reduced by 22% using ULSDOE fuel relative to ULSD fuel performance. This formaldehyde reduction improved to **up to 58%** when additional oxidation catalyst exhaust after-treatment technology was applied.

NO<sub>x</sub> and PM reductions with ULSDOE fuel relative to ULSD fuel performance with the same oxidation catalyst were on the order of 14 % and 38 % greater respectively. The reduction in NO<sub>x</sub> seen previously was maintained in the presence of an oxidation catalyst. The reduction in particulates relative to ULSD fuel without any exhaust after-treatment was at least the sum of the impacts of the oxidation catalyst and ULSDOE fuel run independently.

NO<sub>x</sub> reductions of 12-13 % were noted when using the water-blend fuel ULSDOE fuel with a particulate trap. PM reductions on the order of 38% were noted for part of the test cycle. In reality, however, because of the extremely low levels of PM emissions measured after the particulate filter installation, these reductions were considered to be differences that were compromised by the resolution limits of the instrumentation. **An overall determination of this study was the fact that oxidation catalysts and particulate traps are quite effective in reducing engine emissions and this effectiveness is not impaired by the use of ULSDOE fuels.**

4. Tests were performed by the Shell Oil Company of Australia on a CAT 3306 typical mining vehicle diesel engine (6). The engine did not have any exhaust after-treatment systems fitted to the engine exhaust. NO<sub>x</sub> reductions greater than 50% (see graph below) were recorded during the test program.

Fuel Tests – Shell Cat 3306 Engine Graph No. 2A – NO<sub>x</sub> Levels - PPM



- A fleet trial was conducted in Australia to support claims to greenhouse gas reductions attendant to the use of Diesel Oil Emulsions (DOE) fuels (7). The market trial of the Shell Oil Company DOE (“Aquadiesel”) was conducted from the Shell Newport terminal near Melbourne in 2002. The DOE fuel was manufactured from standard Shell diesel fuel using a blender and a surfactant supplied by Clean Fuels Technology (Australia) Pty Ltd, a subsidiary of Clean Fuels Technology Inc. of Reno, Nevada USA<sup>1</sup>. The product was distributed to four fleet operators in Melbourne and Bendigo, including a Shell fuel distribution tanker, which was also converted to use the DOE fuel. In total, 10 vehicles used the DOE fuel and accumulated 213,000 km during the trial period. The fleet operators maintained comprehensive fuel consumption records for both regular diesel and DOE fuel use in each vehicle.

The DOE fuel contained 13% water – by volume. When the calorific value of the DOE fuel was calculated from the known properties of its components, DOE fuel consumption was expected to increase by 16.7% (assuming that fuel consumption was proportional to fuel calorific value). Averaged over all ten vehicles, fuel volumes increased by only 11.8%. This result implied that there were efficiency savings and that CO<sub>2</sub> emissions could be reduced by use of DOE fuels.

The size of the attendant CO<sub>2</sub> reduction was calculated from determinations of the total consumption and the carbon content of the DOE fuel. With the carbon content of the DOE fuel calculated from the known properties of its components, it was shown that switching to Shell “Aquadiesel” fuel reduced tailpipe CO<sub>2</sub> emissions by 3.2% compared to the previous emissions from standard diesel fuel. There were additional CO<sub>2</sub> emissions associated with the production of “Aquadiesel” fuel: blending, surfactant manufacture, water purification, etc. Making reasoned estimates for the size of these factors, it was shown that switching to Shell “Aquadiesel” fuel reduced CO<sub>2</sub> emissions by 80 grams per liter of standard diesel fuel used previously – equivalent to 2.7% of diesel lifecycle CO<sub>2</sub> emissions.

- Transient test cell studies of a DDC 6V-92TA diesel engine were accomplished at the Southwest Research Institute facilities in San Antonio, TX (8). A comparison of the engine torque maps developed with regular diesel oil (DO) fuel and a diesel oil emulsion (DOE) fuel are shown in the figure below. Except in the very low speed range, the DOE fuel produced about 8% more torque than the regular DO fuel. This indicated that even though the DOE fuel had less energy per unit of volume than the regular DO fuel, the higher capacity fuel injectors and fuel pump installed on the engine as part of the test setup more than compensated for the fuel energy deficiency and actually delivered more energy into the engine cylinders. Subsequent hot-start transient testing indicated significant reductions in regulated emissions for test operations on DOE fuel as compared to matching operations on DO fuel. NO<sub>x</sub> emissions in DOE fuel tests were reduced by over 40% as compared to those in DO fuel tests. Likewise, PM emissions recorded with DOE fuel operations were 26% lower than those recorded with DO fuel operations.

<sup>1</sup> Clean Fuels Technology was a predecessor company of APT.

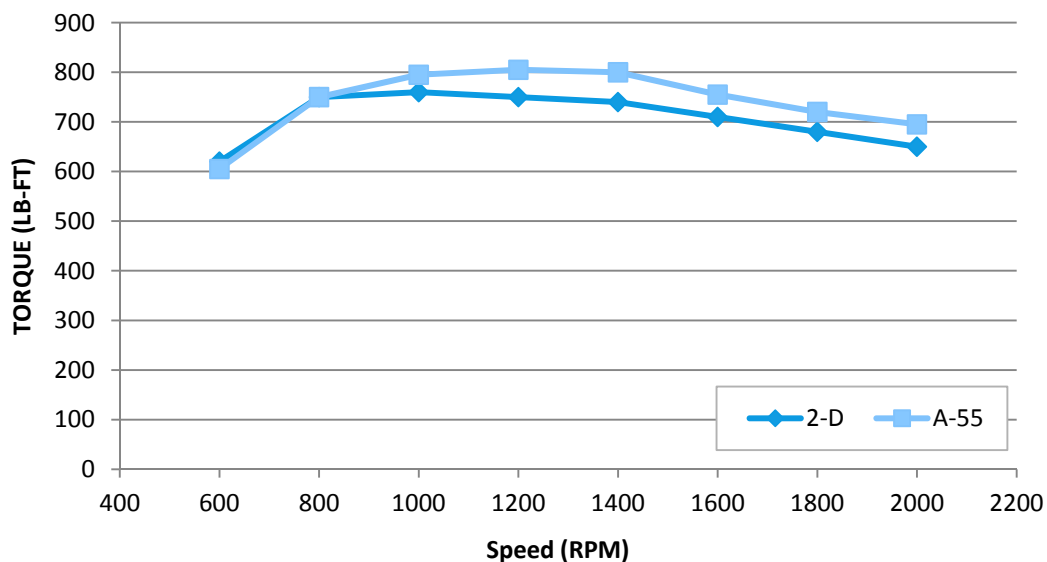


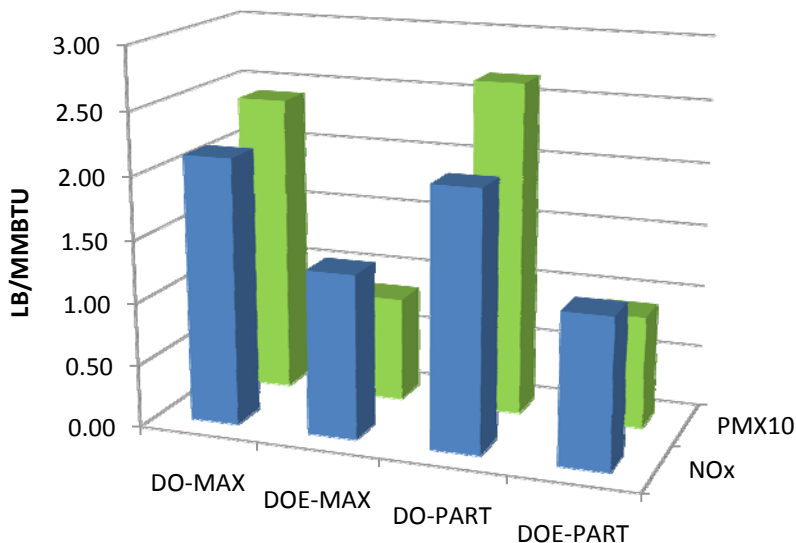
Figure 5. Transient Torque - Maps

**Stationary Tests**

- Freeport Power Plant The capacity of the stationary Engine 9 at the Freeport, NY Municipal Power plant was 1.5 MW. The maximum load for the test was 1.3 MW. The partial load for the test was 1 MW. Under maximum loading, nitrogen oxide (NO<sub>x</sub>) emission reductions were on the order of 33% and particulate (PM) emission reductions were on the order of 65%. Under partial loading, nitrogen oxide (NO<sub>x</sub>) emission reductions were on the order of 38% and related particulate (PM) emission reductions were on the order of 66%.

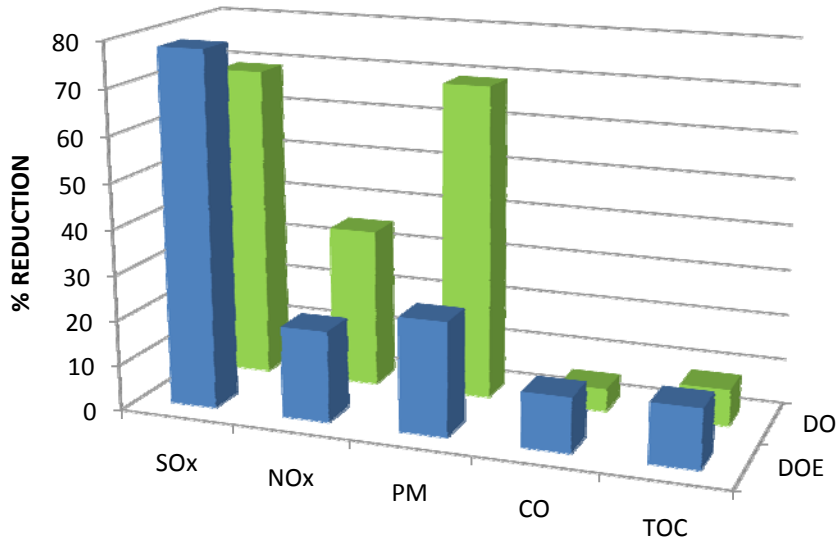
The results are typical of those found for the other three stationary diesel engines in the plant.

**Freeport Plant - Engine 9**



- Emission Reductions (in percent) for ALL of the exhaust emissions measured in tests on Engine #1 of the Hofstra University Power Plant indicates that Emulsified Fuels are very effective. This effectiveness is displayed not only in the comparison of operations of emulsified fuel versus diesel fuels but also in the operations of emulsified fuels versus dual fuel (DUF- a mix of 90% natural gas and 10% diesel oil). For example, SO<sub>x</sub> reductions for operations with an emulsified diesel fuel versus SO<sub>x</sub> reductions with a dual fuel – composed primarily of natural gas (i.e. 90%) - are on the order of 78%!

### Hofstra Eng-1 Emissions

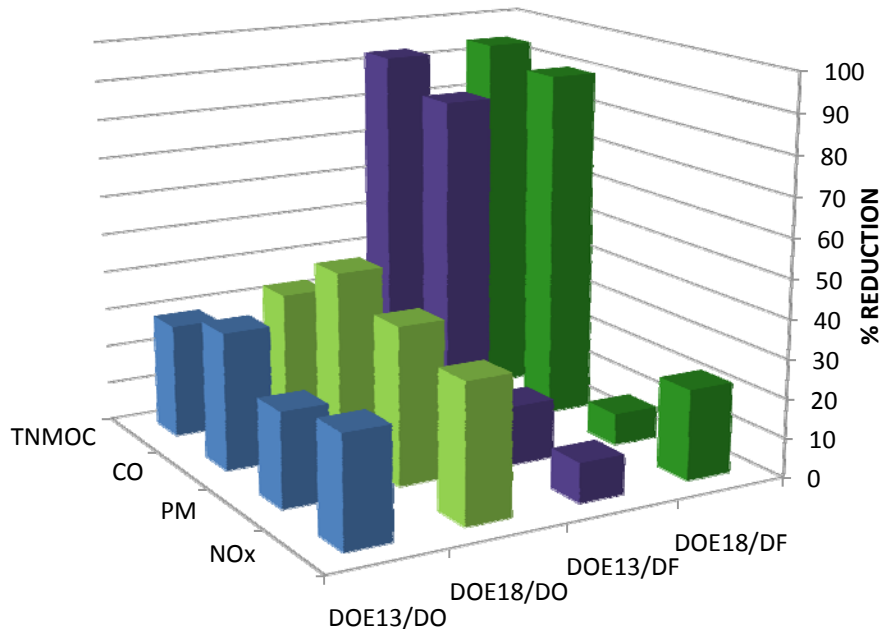


Moreover, PM reductions in the same comparative operating scenario are on the order of 25%. These emission reductions prevail for a fuel that is liquid (emulsified diesel fuel) in nature compared to a dual fuel that is comparatively gaseous (90% natural gas composition) in nature. Notably, the performance of Engine 2 in the Hofstra University Power Plant was even better than that shown here for the companion unit – Engine 1.

- South Oaks Hospital - Emissions testing at the South Oaks Hospital Power Plant in Amityville, NY compared stationary diesel engine operations on two Diesel Oil Emulsion (DOE) fuels – (13% water content and 18% water content – to operations on both a standard diesel oil (DO) and a dual fuel (DF) composed of 92% natural gas and 8% diesel oil at an operational loading of 650 KW.

Significant reductions in ALL emission levels were recorded. Use of DOE fuels had no appreciable impact on the engine exhaust turbocharger outlet temperature – it was reduced a maximum of 30F in operation. High load levels were achieved WITHOUT any engine modifications.

### South Oaks Emission Reductions





## Conclusions

As portrayed herein, Emulsified Fuel Technology (EFT) is a proven technology that summarily delivers on the promises of emissions reductions – BOTH gaseous AND solid emissions reductions – plus an increase in operational efficiency. Moreover, in addition to operational efficiency enhancements, EFT can contribute significantly to the ultimate lessening of overall system maintenance costs. This last advantage arises from the fact that emulsified fuels generate energetic steam gases in the combustion zone that sweep through the combustion and exhaust chambers of a boiler and effectively clean the heat transfer surfaces therein. Such “steam cleaning” actions give rise not only to a more immediate efficient operation but ultimately contribute to the diminishment of the time and effort that needs to be devoted to cleaning these surfaces in normal outage situations. Furthermore, the ability to lower fuel heating temperatures and atomizing steam pressures when using emulsified fuels also contributes to an increase in overall plant operational efficiency and thus directly to the enhancement of the bottom line of a power generation activity.

The applications of EFT are widespread. In addition to the fuel oil emulsion applications portrayed in this paper that are focused on boilers, EFT can be readily applied to light distillate oils – like diesel oils – to operate in internal combustion engines. At the other end of the spectrum, EFT can be applied to residual oils to produce usable combustion products from such diverse stocks as vacuum tower bottom oils and pitch blends. In all instances, EFT presents a significant opportunity to fully utilize hydrocarbon fuels – in all “flavors” - to their maximum operational potential without fear of contributing exceptionally to harmful emission levels. As such, EFT is an enabling technology that has a significant market potential as well as an enviable position in the quiver of modern technologies that are able to deliver an immediate impact on global warming and community health.

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