Improved Thermal Efficiency through Xmile, Enzyme Fuel Treatment Technology on Large Marine Diesel Engines

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Abstract

This paper sets out to demonstrate scientifically the real benefits of an organic microbiological alternative fuel treatment in the form of a complex enzyme formulation. When blended in liquefied fossil fuels there is a significant improvement in fuel consumption and an associated reduction in CO_2 emissions. The enzyme treatment, when dosed at one part per 10,000, affects fuel efficiency, exhaust gas temperature, and carbon monoxide (CO) emissions of marine diesel engines shown in two different ship examples. In the first case, fuel consumption and emissions were monitored over a 65 day period, 742 hours of operation, on a Stena Line cross-channel ferry burning marine gas oil. These tests showed the classic "conditioning" characteristic where no change was seen for 21 days, 240 hours of operation. Then, 7 days, 80 hours, of "clean-up" was observed with increased CO emissions but no reduction in fuel consumption. Finally, an improvement of 10.8% in specific fuel consumption (SFC) was seen after 28 days, 320 hours, of operation post-treatment, and these results have been sustained and verified one year later, approx. 4,000 hours of operation. In the second case, engine performance, fuel economy and emissions were recorded over a wide range of load points on the Teso Texel Island Ferry. This gave the opportunity for a more in-depth and accurate assessment of performance. Two engines were monitored: one with bio-diesel (EN 590 B5) and one with enzyme treated bio-diesel (EN 590 B5), with both operating together and at the same load condition. These tests showed a clear difference in thermal efficiency between the two engines with an average of 7.4% improvement in fuel consumption (and in CO_2), and 4.7% lower exhaust gas temperature on the engine with enzyme treated fuel. On this vessel, fuel consumption was also monitored over a four-month period and 1600 hours of operation. This extended test showed 7.9% reduction in fuel used by the two engines operating on enzyme treated bio-diesel fuel when compared to those on untreated fuel. In both these cases, there was clear evidence of improved fuel economy, supported by other measurements indicating improved thermal efficiency.

Introduction

Fuel treatment technologies or "chemical additive packages" are the norm and widely used by the petro-chemical industry to modify the properties of fuel in order to enhance performance and stabilise fuels. For example, tetraethyl-lead was added to gasoline for many years to improve octane rating, suppress knocking by lubricating valve to valve seat interface [1]*. A wide range of fuel additives with many different properties are now available and are widely used, [2], [3].

The series of work and careful real-time monitoring/testing presented here, seeks to address and demonstrate scientifically how microbiology in the form of a complex enzyme formulation in fuel can play a significant part in the conditioning of fuels for optimal sustained combustion efficiency, reinstating manufacturers ratings or, in some cases, achieving significantly below manufacturers ratings for SFC. Over the past 15 to 20 years there has been a significant improvement in the evolution of diesel engine technology to improve efficiency with typical values then of over 250 g/kWh [4] improved to better than 200 g/kWh more recently [5]. The two examples described here are taken from extensive research and were chosen as representing modern, state-of-the-art diesel engine technology [6], [9].

The Stena Line Trader Ship

The first set of tests shown was carried out on a cross-channel ferry operating between the Hook of Holland and Killingholme in England. It is owned and operated by Stena Line (7) and named "Trader", shown in Figure 1. This ship is a 212 m, 26.7 kilotonne vessel, built by FMV-Fossen,

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*Numbers in Parenthesis Indicate References

Norway. The main propulsion is provided by two B&W MAN engines with a total power output of 21.6 MW, Figure 2. The ship also has two auxiliary power engines running on marine gas oil (MGO) and providing the electrical power for the ship, see Figure 3. These are S16R series, V16 engines supplied by Mitsubishi, and each rated at 1,540 kW at 1800 rpm.

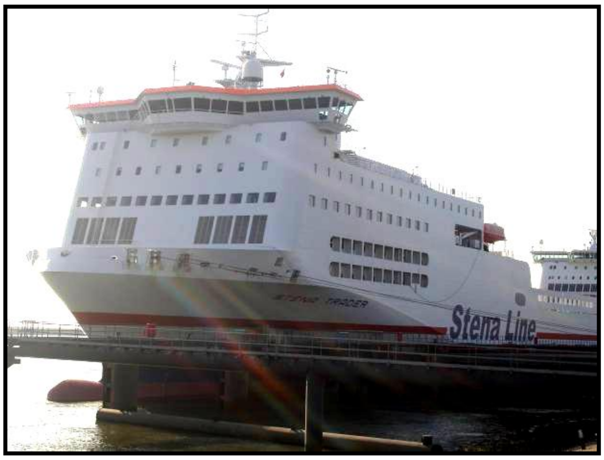

Figure 1: Stena Line Trader Cross Channel Ferry

Figure 2: Main Engine #1 of Trader Ferry

Figure 3: Auxiliary Engine #1 of Trader Ferry

The Teso Dr Wagemaker Texel Island Ferry

The second series of tests shown were carried out on a ferry operating between Den Helder and Texel Island in Holland and owned by Teso, (8). The ship, shown in Figure 4, is 130 m long, has a 5.1 kilotonne displacement and a load capacity of 1.8 kilotonnes. It is powered by four 3600 series 8-cylinder engines supplied by Caterpillar Corp each providing a power output of 2650 kW at 1000rpm, Figure 5.

The Teso ferry uses an electrical power drivetrain system, rather than a mechanically driven propeller. This constitutes a critical advantage for testing during the present study. An electrical generator is attached to each engine and acts as a dynamometer for the engine. Voltage and current measurements from the generator allows for accurate power measurements in real time. The drive system is instrumented with computerised data logging to record power and fuel consumption automatically and is thus ideal for testing and evaluation.

Figure 4: Teso Dr Wagemaker Texelaar Ferry

Figure 5: Main Engine #1 of Teso Ferry

The vessel has been operating since January 2006 and had accumulated approximately 15,000 hours of operation at the time of testing. The engines are normally run in pairs to provide the correct level of power during normal weather conditions. Occasionally three or all four engines are required during heavy seas and the engine operation is rotated to ensure roughly equal service from all engines. As a result, these engines had seen approximately 8,000 hours of operation.

Test Results for the Stena Line Trader

During the testing period, the average fuel consumption and sample exhaust emissions of the Trader engines were recorded on the Mitsubishi S16R auxiliary engines on a daily basis over a 65 day period. Marine gas oil (MGO) fuel used was logged from the on-board fuel meters and emissions were measured using a Kane 250 combustion analyser. A baseline was established over the first 14 days, 160 hours, of operation. During this time, untreated MGO fuel was used. The average specific fuel consumption (SFC) was stable at 213 +/- 5 g/kWh, Figure 6, and the specific CO emissions were 1.07 +/- 0.15 g/kWh, Figure 7.

Enzyme treated MGO fuel (one part in 10,000) was used starting on Day 14 and for the remainder of the test period. Initially, no change was seen in either fuel economy or CO emissions. A very slight decrease in SFC to 212 g/kWh was observed but this is not considered statistically significant. The engine performance remained stable for the next 20 days, 230 hours, of operation at which time there was a notable increase in specific CO to 1.36 g/kWh. This level was maintained for 7 days, 80 hours, after which the specific CO emission level dropped significantly to 0.76 g/kWh. At the same time there was a noticeable improvement in SFC to 190 +/- 3 g/kWh. This represents a decrease in fuel consumption of 10.8%. This improvement was maintained over the remainder of the test period, 274 hours, with a further reduction to an SFC of 186 g/kWh (12.7% improvement) and is considerably less than the manufacturer's SFC values at 75% load of 207 g/kWh, [9]. It is clear from these sets of results that there is a very significant improvement in fuel consumption when the enzyme treatment is applied.

It is also very interesting that the changes are not seen immediately but that some form of "clean-up" process is involved. There would appear to be a 21 day "conditioning" period between day 14 and day 35, with 240 hours of operation, when the enzyme treatment is preparing the engine there is no improvement in fuel economy. This is followed by the "clean-up" period, 80 hours of operation, when specific CO is higher than previously and when there is clearly a different form of combustion within the engine. It is assumed that these are the deposits within the engine, which are being gradually broken down and then consumed during normal combustion.

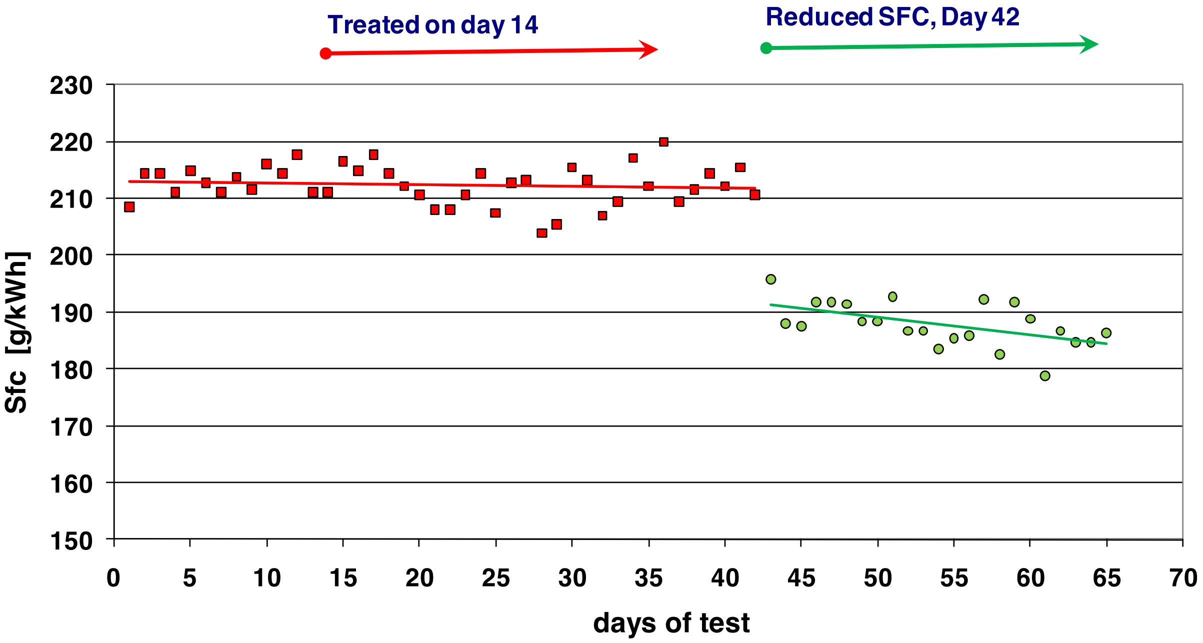

Figure 6: Specific Fuel Consumption for 65 day Period on the Stena Line Trader

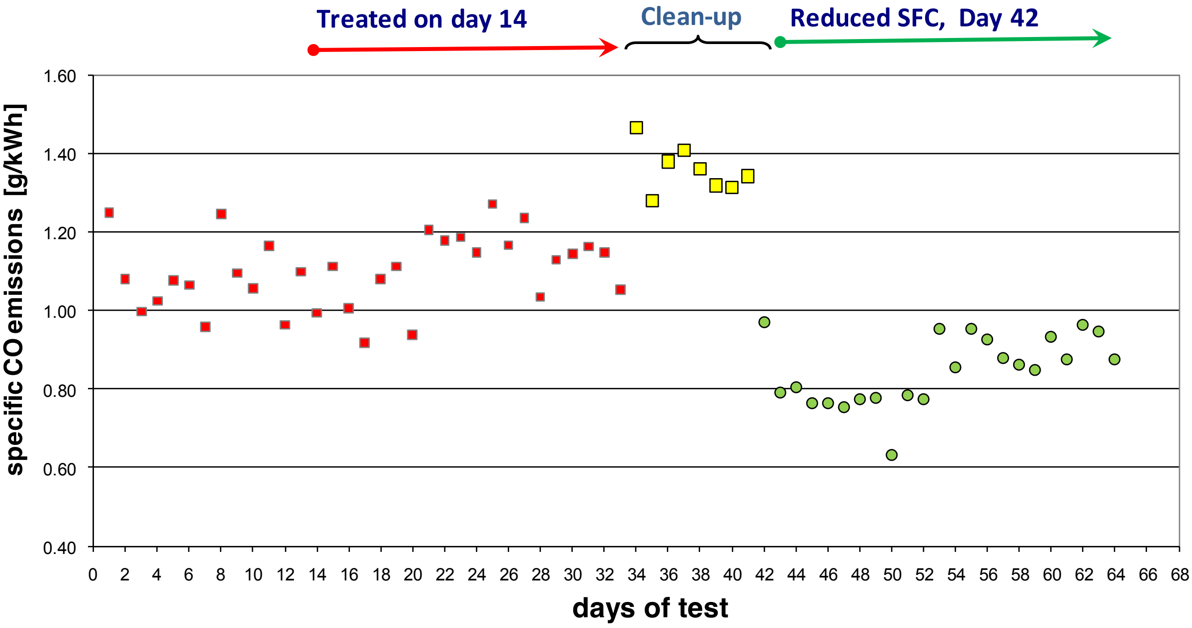

Figure 7: Specific CO Emissions for 65 day Period on the Stena Line Trader

Subsequently, there is the final stable period of operation, 274 hours, with improved efficiency and reduced fuel consumption. During this period the emissions also stabilise, with raw CO concentration in the exhaust gas returning to an average of 116 ppm, a slightly lower value of the original baseline value of 123 ppm, seen over the first 20 days of monitoring.

Test Results for the Teso Texel Island Ferry

A very different testing approach was taken on the Teso ferry, which has a total of four separate engines. These can be operated in any sequence but, during normal operation, only two engines are required to power the vessel. The other two engines are used as a backup, with all four engines only required during adverse weather conditions. An operational rota is applied to all engines to ensure even utilisation of all four engines. This was recorded on EN 590 specification diesel to ensure that all engines were very similar. Engine performance was very well matched with a maximum difference in full load power of only 2% and similarly a spread of 2% on specific fuel consumption. This was deemed adequate for test purposes and so any differences of greater that 2% would be regarded as significant.

The engines were operated for an extended period on diesel with two engines running on diesel treated with enzymes at one part in 10,000. During these tests, only overall fuel consumption was measured by recording fuel quantity during tank filling. This showed a significant difference over a nine month period and approx. 3,000 hours of operation. The two engines running on standard diesel consumed in excess of 10% more fuel that the two engines operating on enzyme treated diesel. At this point it was decided to conduct a more in-depth study by detailed monitoring over a typical full day of operation. However, the Teso Company had, by then, decided to switch to bio-diesel (B5) in an effort to reduce CO_2 emissions further, so the trials were conducted using bio-diesel. Before trials were commenced, a stabilisation period of one month (approx. 300 hours) of operation was employed to ensure that results would be significant and accurate.

As there are always two engines running in tandem, it was decided to run two engines on untreated bio-diesel fuel and two on enzyme treated bio-diesel fuel and to compare results instantaneously. The fuel tanks for two of the engines were treated directly with the enzyme treatment at a concentration of one part in 10,000, when filling.

The ferry operates at hourly intervals each direction, with approximately 15 minutes crossing time and 15 minutes turn around. During exit from the berth, almost full power is required to accelerate the vessel to cruising speed: these are the high power points, over 2000kW. When cruising across the channel the power requirement drops back to range 1200 to 1500kW. While berthed, the engines operate in the range up to 750kW, depending on the services required on the vessel. This gives a full range of operation from 10% load to full load and hence a range of fuel consumption.

Figure 8 shows a comparison of specific fuel consumption on engines #2 and #4 during a typical day of operation. The results are in the range from 190 to 450 g/kWh, with the best results seen at three-quarter load. At full load the values are clustered around 200 g/kWh, which matches closely with the manufacturers published values for these engines, [6]. There is significant scatter on the results so some analysis is required to highlight the differences and to demonstrate the significance of the results.

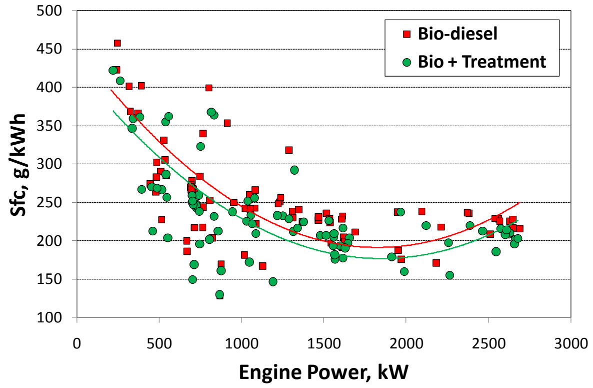

Figure 8: SFC Comparison for Teso Engines

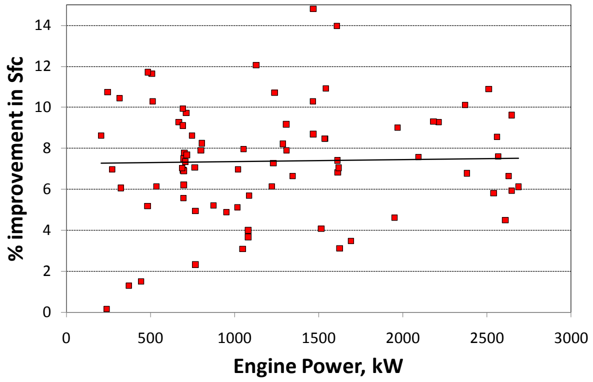

Figure 9: Improved SFC on Teso Engines

A curve fitting of the results in Figure 8 does show a difference between the SFC values for each engine, but the scatter makes this difficult to see. Figure 9 shows a comparison of the difference in SFC between the two engines at the same operating points. The #2 engine running on treated fuel always shows better SFC with an average improvement of 7.4% and a standard deviation of 4.3%.

This improved efficiency is further supported by comparing the recorded exhaust gas temperature. And, as shown in figure 10, the exhaust gas is always lower on the engine burning treated fuel, clearly indicating a better thermal efficiency. The difference in exhaust gas temperature is shown in Figure 11, with an average improvement of 4.7% and a standard deviation of 1.4%.

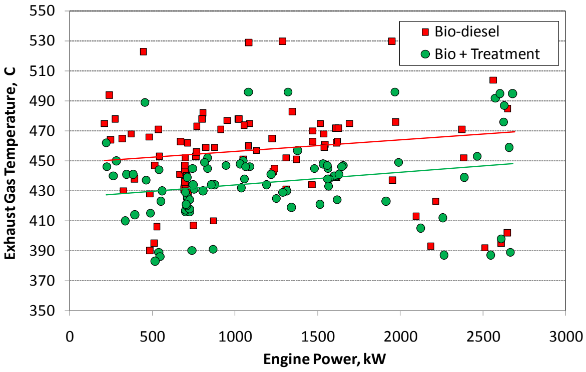

Figure 10: Exhaust Gas Temperature Comparison for Teso Engines

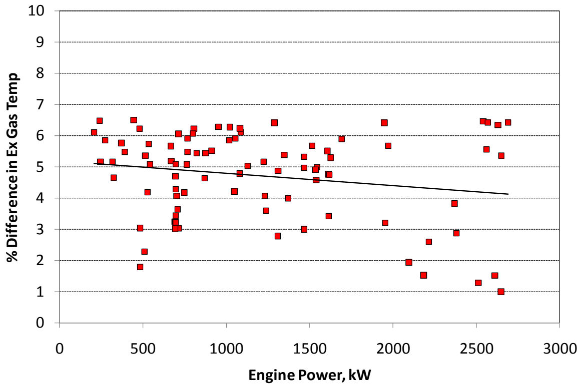

Figure 11: Difference in Exhaust Gas Temperatures on Teso Engines

These improvements are further confirmed by considering the results statistically. Figure 12 shows the spread of results for the both SFC and exhaust gas temperature, by plotting the distribution of the number of points against percentage improvement. The SFC results show a fairly normal distribution around the average value of 7.4%. The exhaust gas temperature shows an asymmetric distribution but is considered a good distribution as the peak frequency occurs close to the average value.

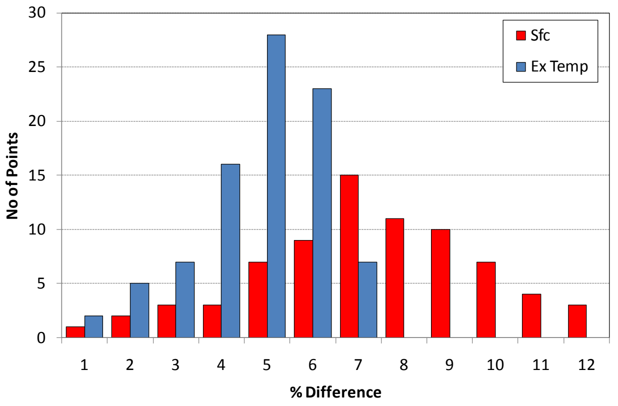

Figure 12: Spread of Difference on SFC and Exhaust Gas Temperatures

As both of these show a fairly normal distribution around a central average with significant improvements, then it is considered that these improvements are real and statistically significant. This is a key point and highlights the importance of a detailed testing plan, to show the differences. For example, due to the statistical scatter of results, about 4% of the points show 2% improvement or less. So if these were the only test points recorded, then no improvement would have been seen. On the other hand 8% of points show improvements of 10% or above.

Emissions Results for the Teso Texel Island Ferry

Exhaust emissions were also monitored on the Teso ferry over the same time period as the main testing plan. The test technique involved manual sampling using a handheld, portable analyser (Kane 900 Plus) as online monitoring of emissions was not available. As a result, much fewer results were recorded and so are less reliable than the more intensive fuel consumption results.

Figures 13 and 14 show the specific CO and specific NOx over a range of engine load, during normal operation. The first point of note is that there is no noticeable difference in emissions between the two engines under test. Specific CO, Figure 13, is very low at around 0.5 g/kWh over most of the load range of the engines, with a raw volumetric concentration around 60ppm.

Specific NOx, Figure 14, is much higher at about 15g/kWh with a raw concentration of around 1100ppm. Note that the difference in specific emissions is more emphasised for the NOx due to its higher molecular weight.

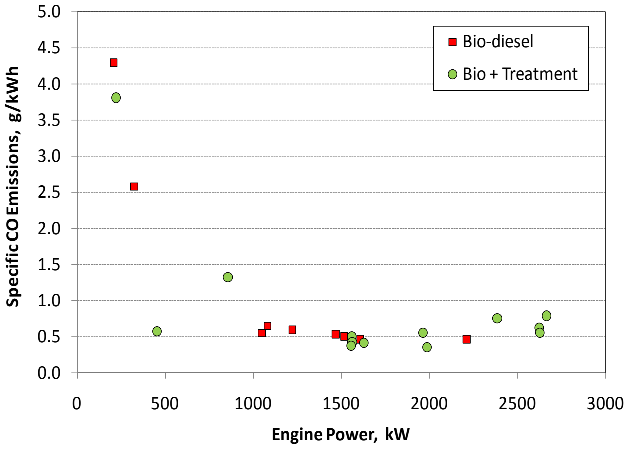

Figure 13: Specific CO Emissions for Teso

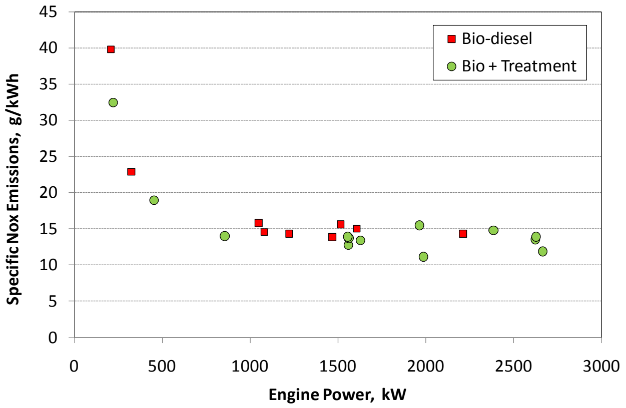

Figure 14: Specific NOx Emissions for Teso

Longer term Fuel Monitoring on the Teso

The final part of the study, as mentioned earlier, looked at the actual fuel consumption of the Teso vessel over a four month period, 1,600 hours of operation. Each engine has a separate fuel tank and so fuel consumption could be monitored by recording the bio-diesel fuel during tank filling. Table 1 shows the fuelling records for each engine, along with the hours of operation and the total power output, during this period. Engines #1 and #2 were operating on the treated EN 590 bio-diesel fuel.

Engine Number	Operating Hours	Output MWh	Fuel M3	SFC g/kWh
#1	972	912	251	236
#2	656	585	159	234
#3	1034	937	273	251
#4	879	801	244	262

Table 1: Long Term Fuel Consumption for Teso

At a first glance, the disparity in operating hours seems unusual but this can easily be explained. Although the engines are operated in pairs, they are also operated in different combinations, so no two engines see exactly the same operation. The operators choose which engines to run and do not always balance the operating times depending on day-to-day operating requirements.

As can be seen, engines #1 and #2 are showing a much lower SFC than engines #3 and #4. Engine #1 is 6.0% better than engine #3 and 10.0% better than engine #4. Engine #2 is 6.8% better than engine #3 and 10.7% better than engine #4. This gives an average value for engines #1 and #2 of 7.9% lower fuel consumed than engines #3 and #4. This is a critical finding that fully supports the level of improvement seen on the more detailed testing described above.

Conclusions

Based on the test results presented here, it can be concluded that the treating of marine gas oil and EN 590 B5 road diesel with the Xmile enzyme treatment in these vessels produced a significant improvement in specific fuel consumption and hence in overall thermal efficiency of these engines, with the associated reduction in CO_2 emissions.

On the Stena Line Trader ship using marine gas oil, an improvement of 10.8% in fuel consumption and hence CO_2 emissions were seen during a long term 65 day sea trial and 742 hours of operation. Significantly, this has been maintained after a further approx. 4,000 hours of operation. So this is considered a significant and sustainable reduction in SFC over the original untreated condition. Also, this level of performance shows up to 10.1% lower values than the manufacturers published ratings for specific fuel consumption using marine gas oil.

On the Teso Texel Island Ferry, an improvement of 7.4% was seen on the comparison between two identical engines operating in tandem and producing very similar levels of power output. This was further supported by long term fuel consumption monitoring over a 4-month period and an average of 885 hours of operation on each engines. An average improvement of 7.9% was seen between the two engines running with Xmile treated EN 590 bio diesel fuel and those on untreated EN 590 bio diesel fuel. The significance in these results was that the enzyme treated bio-diesel fuel reinstated the manufacturer's ratings for specific fuel consumption values which were originally calculated using marine gas oil.

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References

1. Bill Kovarik, "Charles F. Kettering and the 1921 Discovery of Tetraethyl Lead In the Context of Technological Alternatives". Originally presented to the Society of Automotive Engineers Fuels & Lubricants Conference, Baltmore, Md., 1994. *http://www.runet.edu/~wkovarik/papers/kettering.html.*
2. Joseph W. Roos, Doni G. Grande, Don P. Hollrah and Larry J. Cunningham. "Reformulating Gasoline for Lower Emissions Using the Fuel Additive MMT". SAE Paper 2002-01-2893, Oct 2002.
3. W. Rocco Pistillo, Darryl T. Grundle and Tara M. Kirschner-Jean. "Counteracting Detrimental EGR Effects with Diesel Fuel Additive". SAE Paper 2003-01-1915, May 2003.
4. A Govert, "Diesel Engine Fuel Economy Characteristics". SAE Paper 941730, Sept 1994. Hajime Muto, Hiroto Nakagawa, Takeo Yahagi and Tatusya Suzuki.
5. Kiyoshi Suginuma. "Hino J-Series Diesel Engines Developed for the U.S. 2004 Regulations With Superior Fuel Economy". SAE Paper 2004-01-1314, Mar 2004.
6. Caterpillar Marine Website, http://marine.cat.com/propulsion.
7. Stena Line Freight website, http://www.stenalinefreight.com/.
8. Teso company website, http://www.teso.nl/.
9. Seapower Australia website, source of technical data for Mitsubishi Marine Diesels. http://www.seapower.com.au/.