Trial of Emulsified Fuel Fuelling of Arahura Generator Engine “ME2”

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1. Executive Summary

Engine trials were carried out on one of the Arahura’s generator engines to consider the use of a water in M80 emulsified fuel, following successful tests of the same in 2013. The aim of this trial was to evaluate the performance of the engine over a longer timeframe, which necessitated on-board production of the emulsified fuel and other factors – which effectively amounted to a trial of the logistics of the fuel’s use as well. This report concerns the engine performance testing component of the trial.

The generator engine was instrumented so that its specific fuel consumption could be determined (requiring the metering of fuel consumed and electrical energy generated) and the data from this and the standard engine instrumentation were used to assess the performance of the engine over various series of one-hour tests on M80 (the standard fuel) and on emulsified fuel. The end-to-end trial comprised a total of 1250 hours of engine operation over which 36 such one-hour tests were conducted, around 80 tonne of emulsified fuel was consumed[1], and a similar order of standard M80 fuel was consumed.

Comparison of test results from testing the generator engine on M80 and on emulsified fuel found that:

1. Use of emulsified fuel brought about an improvement in specific fuel consumption of around 3%. It is possible that a greater improvement in specific fuel consumption could have been found had the comparison been made in like-for-like engine conditions and arrangements.
2. It appears that the use of emulsified fuel also brought about an improvement in the base engine performance, through cleaning or other, which resulted in an improvement in the specific fuel consumption performance of the engine of around 2% when returned to standard M80 operation at the end of the trial.
3. There were no significant differences in the cylinder pressure diagrams at same engine loads indicating that there were no concerning changes to the combustion profile.
4. There were no significant differences in exhaust emissions. It is possible that an improvement in emissions could have been found under moderate to higher loads had the comparison been made in like-for-like engine conditions and arrangements.

[1] Based on production of 82,979 litres, less around 2 tonnes reprocessed.

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2. Background

Engine trials on one of the Arahura's generator engines conducted in 2013 found up to a 5.5% decrease in specific fuel consumption with the use of an emulsified fuel and water mixture (see report *Emulsified Fuel Tests on Arahura Generator Engine,* Andrew Campbell, 10 August 2013). The tests involved were relatively simple[2] and conducted over a single day of tests each for M80 and for an emulsified fuel made from the M80. Based on the positive results, Interislander set about a more extensive trial, which is the subject of this report.

This more extensive trial began in late 2014 and finished in May 2015. It comprised:

- On-board manufacture of the emulsified fuel (using centrifuged M80 delivered to the emulsifying unit using existing fuel reticulation lines);
- Day-tank storage of the emulsified fuel;
- Transfer of the emulsified fuel from the day tank to the test engine using existing fuel reticulation lines;
- Use in generator engine ME2;
- The comparison of the operation of the generator engine when using standard M80 fuel as against emulsified fuel, which included engine performance testing over discrete periods of around one hour;
- Visual inspection of the injectors, bore and piston crown, and turbocharger.

This report concerns the timed engine performance testing of the generator engine and comparison of the results obtained.

2.1. Use of Emulsified Fuels

The emulsified fuel made and used on board comprised an emulsification of M80 (the standard fuel used by the Arahura), around 8% water (using town water available on the ship), and a dose of around 0.6% emulsifying agent (the latter functioning to keep the water in a sufficiently stable emulsion so that it was carried to the engine with as little separation as possible from the emulsion). The equipment used to make the emulsified fuel (essentially metering pumps and an emulsifying pump), the emulsifying "recipe", and the emulsifying agent were supplied to the Interislander by Blended Fuel Systems New Zealand.

The theory behind the use of emulsified fuel-water mixtures was detailed in the earlier mentioned report. In brief, emulsified fuel injected into the combustion chamber forms droplets which contain spheres of water within them. The emulsified fuel droplets heat up due to the high temperatures in the combustion chamber and this causes the included spheres of water to "flash boil", which shatters the fuel droplets into smaller droplets (effectively causing "secondary atomisation"). This can provide better conditions for the various combustion-related reactions to take place, which can result in earlier and more complete reactions, and accordingly improved fuel economy.

However, there is also the theoretical potential at lower loads for such "steam raising" to lower temperatures in the cylinder, to the point where combustion reactions are slowed and a worse fuel

[2] In that electricity generated was calculated from the control room's analogue generator power output meter and fuel consumption was based on reading from a sight glass on the generator engine's day tank.

economy results. (This is why the performance of the generator engine was evaluated at a number of different loads).

2.2. Engine Performance Testing

The original intention of the trial had been to operate the generator engine under normal service on standard M80 fuel and separately on emulsified fuel, each for a period of 6-8 weeks, and to compare the overall specific fuel consumption (SFC) for each fuel over those periods. However, there are many factors that can change SFC and the change directly attributable to a difference in fuel type could be lost in the noise of variations expected due to other factors[3]. So it was decided to carry out numerous additional steady-load tests of around one hour's duration during the respective trial periods so that more specific engine performance comparisons could be made.

As it happened, there were several instrument and engine failures during the trial and the results from the steady-load tests were used to recover much of the test data (and this recovery would not have been possible had simple 6-week trials been conducted). Also because of the instrument failures, further testing was carried out after the generator engine was returned to M80 at the end of the emulsified fuel trial period in order to provide further checks on the data and on the calibration of the instruments.

3. Test Methodology

John Fraser, Maintenance Engineer on the Arahura, was assigned to the trial and made responsible for carrying out much of the trial's engine test-related work, as well as for assisting with the inspection of the engine before and after use on emulsified fuel, taking cylinder pressure records, taking fuel samples, and other related tasks.

The timed engine performance tests essentially comprised maintaining the generator engine at a target power output for a (timed) period of around one hour, and recording readings of the following at the start and at the end of the timed period:

- The engine's fuel meter (cumulative total);
- The generator's kilowatt-hour output meter (cumulative total);
- Engine power, as indicated by the control room's (analogue) meter;
- Engine speed, as indicated by control room's (analogue) meter.
- Engine hours, as indicated by the engine-mounted hour meter;
- Charge air pressure, fuel pressure and turbocharger speed, as indicated by (analogue) meters at the engine console;
- Temperatures of the inlet air casing, post-compressor chamber, intercooler water outlet pipe, fuel inlet pipe to the injection gallery, and engine water outlet pipe, as indicated by infrared thermometer (Scotchtrak Model IR1600L, Serial Number 29076).
- Exhaust temperature at the six exhaust outlets plus the post-turbocharger outlet, as indicated by the engine monitoring system's pyrometers.

[3] For example, there was a risk that longer periods of low-load operation on emulsified fuel could result in high SFC, to the point that improvements found at other loads might not be seen.

The engine test data was recorded using Form FRM-KR1.2 (8 Dec 2014). This form was developed during trials of the test methodology carried out on 27 November 2014. A completed sample of this form is attached at Annex A.

For this form, the tester recorded the kilowatt-hour meter and fuel meter readings exactly 60 seconds apart (at both the start and end of each timed test), providing time for the tester to get from one location to another (these meters were in different rooms). This method simplified the recording task and only required one test person to be involved. No difference in calculated SFC was expected for this method (at the level of significance that the calculated results were provided) compared with a method that required the simultaneous recording of fuel and kilowatt-hour meters.

The raw SFC was calculated from this data by dividing the indicated amount of fuel consumed by the indicated amount of electricity generated. The corrected SFC was calculated from this by adjustments to take into account of the amount of water in the fuel and the state of kilowatt-hour meter calibration (the meter had different states of calibration during the trial, which is further discussed below) so that the SFC performance of the engine could be compared on a like-for-like energy input basis.

Separate to this, stack emissions testing was carried out on 27 November 2015 for emulsified fuel operation, and on 30 May 2015 for M80 operation (after the generator engine had been returned to M80 operation at the end of the trial). Emissions testing comprised stabilising the engine at a target power output and sampling the gases at around 200mm from the top of the engine's stack and analysing these for carbon monoxide, carbon dioxide, hydrocarbons, oxides of nitrogen and oxygen using an IR 5-gas analyser (Emission System Inc. supplied by BFSNZ) and for smoke (using a Bosch type EFAW smokemeter). For this, the engine was stepped through the target indicated power outputs of 300kW, 400kW, 500kW, 600kW and 700kW for each fuel, over a 30-minute period (to provide consistency in the test method for the two sets of tests).

Note that the 5-gas analyser was not calibrated but was zeroed before measuring and recording the results[4]. Five pulls of stack gases were also drawn through the same filter used for smoke testing, a method found to provide results that were easier to compare across the fuels[5].

The first set of formal tests on M80 began on 11 February 2015 and finished on 11 March 2015. Fifteen test data sets from timed engine testing were achieved in this time for power outputs ranging from 400kW to 750kW. The formal tests on emulsified fuel began on 9 April 2015 and finished on 5 May 2015. Fifteen test data sets from timed engine testing were achieved in this time for power outputs ranging from 300kW to 750kW.

Due to concerns over the calibration of the kilowatt-hour meter, a second set of six tests was conducted on M80 on 28 and 29 May 2015, for power outputs ranging from 400kW to 700kW.

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[4] And this was deemed acceptable because of the expense required to calibrate the gas analyser, the robustness of the infrared instrumentation, the near-near cell condition, and the relative importance of the results.

[5] That is, rather than just one pull which is the standard method. One pull did not provide any noticeable change in colouration of the filter.

3.1. Instrument Calibration

It is normal practice in test work to know or otherwise verify the calibration of any equipment used. However, to do so for all of the equipment involved with operation of the generator engine was not practical – the engine was still in normal service and such would have caused significant disruption and would have been very expensive. Hence it was decided to take the engine's own meters and instrumentation at face value, but to carefully consider the metering of fuel consumption; the metering of the electricity generated, and the determination of the water content of the emulsified fuel – the three most important parameters to be considered (as these directly related to the determination of SFC and SFC was in turn an important determinant of the economics of the generator's operation).

3.2. Engine Fuel Consumption

It was at first deemed too difficult to calibrate the engine's fuel flow meter (noting that there are two sensors involved – one metering fuel to the engine, and one metering fuel from the engine, with a display reporting the difference). The VAF meters used (Model VAF 149 FCM 2) were temperature-compensated, avoiding the need to correct the results for differences in fuel temperature[6]. In consideration of the high quality of these meters (VAF is a reputable brand known to the marine sector, and their good design is acknowledged – these were not simple turbine flow meters), their state (they were brand new at the start of the project) and the expectation that the meter calibration would not change during the trial, it was decided that it was acceptable not to calibrate the fuel meters.

However, the engine supply-side fuel sensor developed a fault during the trial[7] necessitating disassembly, cleaning and re-assembly. One part was lost and not replaced on reassembly. Because of this, a way to check the engine fuel meters was devised and this calibration check was carried out on 26 June 2015, after the engine testing component of the trial had finished. This found that the calibration of the fuel meters either side of the engine appeared to be within expected norms[8].

Numerous other checks were also used to test for possible changes in the calibration of the fuel meters[9] and no indication of changes in calibration were found apart from two 300kW tests carried out on 23 March 2015, when there was a known fuel meter fault (the reason for the disassembly mentioned above).

3.3. Kilowatt-hour meter

A (new) kilowatt-hour meter was installed at the beginning of the trial to measure the electrical energy generated by the generator. Results from the first tests indicated that the meter was reading around 20% higher than expected based on the generator power output indicated by the control

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[6] Fuel expands with increasing temperature which changes the fuel's energy density, and would change the indicated SFC unless fuel metering is corrected for temperature.

[7] Test results on 23 March 2015 were found to be inconsistent. It was later reported that the indicated fuel flowrate was quite erratic at much the same time, which can occur if the meter's vane is not spinning freely (say due to dirt or other). Maintenance was carried out on the engine supply-side fuel meter on or shortly after 11 March 2015.

[8] The average volumetric result of five tests was within 1% of the indicated result, which was within the errors of the calibration test method used.

[9] Including checks that there were no unaccounted-for, time-dependent changes in SFC results.

room’s analogue power meter. The control room power meter appeared to be the more correct as the engine was not capable of operating at the higher power indicated by the kilowatt-hour meter.

The vessel’s Chief Electrician was questioned on the fitting and calibration of the kilowatt-hour meter. He reported that the meter had been fitted correctly and that there were no means for adjusting the calibration of the meter. It was therefore concluded that the meter would stay at the same state of calibration. No practical option was devised to calibrate the meter. This situation was deemed acceptable as it appeared that there was no alternative.

Nonetheless, the kilowatt-hour meter did reset itself at least twice during the trial: once near to the end of the M80 trial (on 1 April 2015), after which time the meter indicated kilowatt-hour data that was more-or-less consistent with the control room’s power meter; and once near the end of the trial (on 27 May 2015), after which the meter still indicated kilowatt-hour data that was more-or-less consistent with the control room’s power meter.

Comparison of the power as indicated by the kilowatt-hour meter and the control room’s meter found a very good correlation (R^2 above 0.99), albeit with three different calibrations. The very high R^2 values provided confidence in calibrating the kilowatt-hour meter data using the data from the control room power meter, resulting in three correction factors to be used to take account of the kilowatt-hour meter’s three different states of calibration. The derivation of these three correction factors plus supporting information for this is provided in Appendix B.

3.4. Water Content Determination of the Emulsified Fuel.

Appendix C provides detail on the determination of the water content of the emulsified fuel. This determination was found to be difficult until an appropriate sampling method was devised – it appeared that the emulsion was separating sufficiency within four to eight hours from sampling that the result became more dependent upon how that sample was subsequently handled.

Consideration of the calibration of the emulsifying unit and consideration of the results from water content testing of a sample taken at the engine concluded that the water content of the emulsified fuel was around:

8.3% for the emulsified fuel produced and used up to and including 9 April 2015[10].
8.0% for the emulsified fuel produced and used after 9 April 2015.

When plotted against engine (generator) power output, the SFC results from M80 tests were relatively tightly clustered along a line. The results from emulsified fuel tests were more scattered which suggested that there were small differences in the water content of the emulsified fuel despite the stability of the emulsifying unit’s calibration results. This scatter suggested a possible variation in the water content of around ± 0.3%. This was inside the accuracy of the analytic test methods used to determine water content, when sampling and sample stability is taken into account, and hence a more accurate determination of water content would not have been achieved with further sampling and testing (without introducing significant additional and costly measures, that is).

[10] There was actually only one data set involved in the dataset up to and including 9 April 2015.

4. Trial Results

4.1. General Engine Operation

The generator engine was largely in normal service during the trial (that is, apart for the time during timed engine performance tests, the use of emulsified fuel, the use of newly serviced injectors at the start of the M80 trial and at the start of the emulsified fuel use, and the additional visual inspections carried out related to the trial).

The following non-routine maintenance work was carried out during the trial:

1. The turbocharger was replaced as a result of a housing crack that caused flooding of the engine with coolant on 23 April 2015 (midway through the trial on emulsified fuel).
2. Cylinder head #4 and the injector quill to cylinder #4 was replaced as a result of findings during a routine 1000-hour engine check carried out on 16 May 2015.

These maintenance requirements were unrelated to the use of emulsified fuel. However, it is important to consider whether the repairs carried out resulted in a change in engine performance.

For the cylinder head and injector quill replacement, the engine would be expected to be returned to before-failure condition. The only potential difference would be lowering the deposits on the combustion side of the cylinder head, but it is expected that this would not significantly alter the performance of the engine. A change in engine performance was looked for around this repair but no unaccounted-for change in engine performance was found.

The replacement of the turbocharger had the potential to alter the boost, should the new turbocharger have different performance. This was checked for by plotting boost versus generator output for the emulsified fuel tests (which were performed on either side of the turbocharger change). This found that the boost pressure reduced up to 10% with the change in turbocharger (as shown by the difference between the emulsified fuel test data before 23 April [orange trendline] and after 23 April [yellow trendline] in Figure 1).

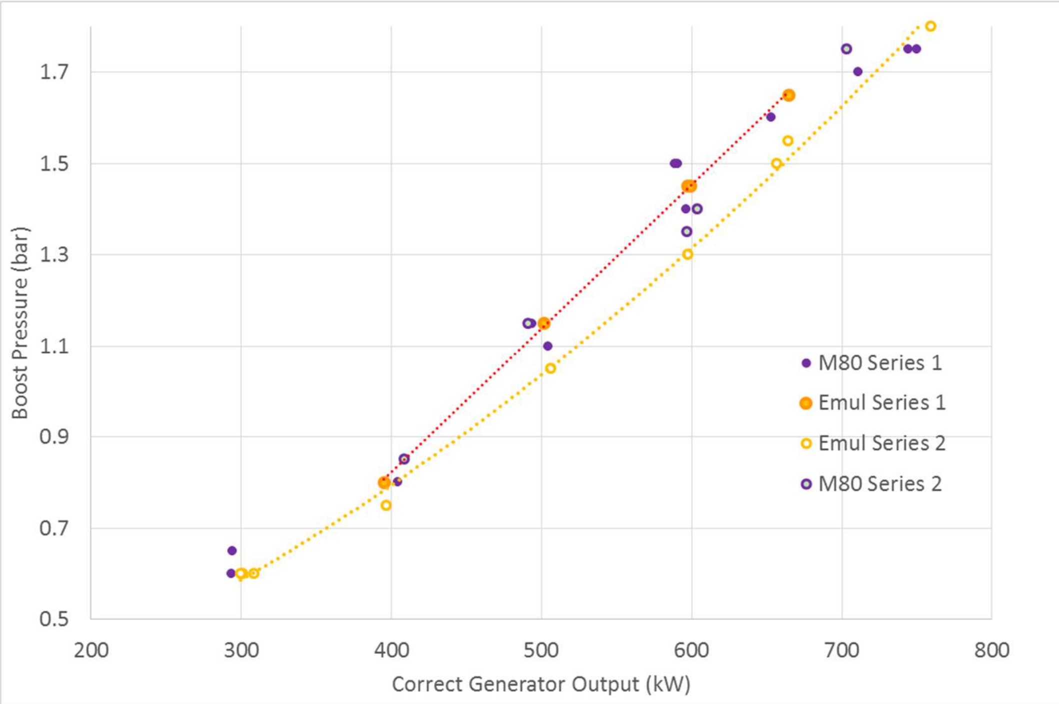

Figure 1: Boost Pressure Versus Corrected Generator Output for all Tests, with Trendlines Provided for the Emulsified Fuel for Before Turbocharger Change (Orange) and After the Turbocharger Change (Yellow).

The boost pressures from the M80 data sets are also provided in Figure 2 for comparison. The solid purple circles are from tests prior to the emulsified fuel tests and the hollow circles from afterward (excluding the obvious outliers). The M80 data exhibits slightly more scatter than the emulsified fuel data. There are a number of possible reasons for this[11]. The more important feature of this, which is not illustrated but was checked for, was that there did not appear to be any time-dependent change in boost pressure or other engine performance indicators across the first series of M80 data (i.e., indicating another change in engine state). However, there was a significant difference found in engine performance on return to M80 operation after the use of emulsified fuel.

In order to capture these differences – the change in engine performance with the change in turbocharger, and the change in performance upon return to M80 operation — the test data was divided into four subsets:

1. M80 1st Series (for tests leading up to the switch to emulsified fuel use);
2. Emulsified fuel 1st Series (for tests before 23 April 2015, which had higher boost pressure);
3. Emulsified fuel 2nd Series (for tests after 23 April 2015, which had lower boost pressure); and
4. M80 2nd Series (for tests at the end of the trial, which may have mixed boost pressure).

[11] Including the small variability in engine load that could result in small differences in instantaneous engine performance data, such as boost, noting that such data was recorded at the start and at the end of a timed run only.

4.2. Specific Fuel Consumption

The specific fuel consumption (SFC) results would be one of the more important results for Interislander to consider for SFC in a key parameter when considering the economics (and viability) of an alternative fuel option.

Figure 2 provides a plot of the corrected and converted[12] SFC results plotted against corrected[13] generator power output, for the four sets of test data. This figure shows:

- The SFC results for the M80 Series 1 data are relatively closely clustered along one sloping, linear trend line (with improved SFC with increasing load, as is expected). This relatively close clustering indicates that the testing technique was reasonably robust in terms of accuracy – all non-outlier[14] results were within ±0.7% of the simple trendline average.
- The SFC results for the M80 Series 2 data are also relatively closely clustered along a trendline of similar slope to that of the M80 Series 1 data. The lower position on the plot indicates an improvement in the corrected SFC of around 3%. As this happened to be similar to the indicated improvement in performance of operation on emulsified fuel, the data was carefully checked to ensure that the improvement indicated was real and not simply a result of some other factor, such as applying incorrect calibration factors. This more detailed check resulted in a small refinement of the calibration factors used for the kilowatt-hour meter[15], but the use of these refined factors did not materially change the results – the improvement found in SFC was still 3%. As this was greater than the uncertainty in the results, this is a real improvement in SFC over the original M80 tests.
- The emulsified fuel SFC results were noticeably more scattered than for M80. This scatter calls into question the consistency of the amount of water in the emulsified fuel, as there are few other reasons for this scatter (after all, the low scatter found for two separate series of M80 results had indicated that the base test method was reasonable robust). The determination of water content was rechecked because of this uncertainty and small refinements to the values for water content were made. This iteration did not change the results. However, it is acknowledged that the determination of water content of the emulsified fuel is relatively weak. This is discussed in more detail hereafter.
- The trend line for the combined emulsified fuel data ran alongside that for the M80 Series 2 results which indicates an average improvement in the (energy-content adjusted) emulsified fuel SFC results of around 3%. A trend is shown of a small improvement in SFC (of the order of 1% in the range of 500-650kW) with the new turbocharger, a trend that is better illustrated in Figure 3, which looks at SFC as a function of indicated boost pressure. However, the scatter of the results in Figure 2 indicates that the SFC difference between the two series of emulsified fuel tests is not significant.

  Upon applying the SFC-boost trend to the M80 data, possibly around one-third of the improvement in SFC found on return to M80 fuelling was due to the change in turbocharger.

[12] Using correction factors applied to the kilowatt-hour meter data plus converting the emulsified fuel data so that the comparison could be made on an equivalent energy basis.
[13] Using correction factors applied to the kilowatt-hour meter data.
[14] That is, removing those where there were obvious large errors in the data.
[15] Resulting in the use of two different calibration factors for the kilowatt-hour meter when the kilowatt-hour meter results were consistent with the control room kilowatt meter, rather than one, amongst others.

This still leaves a non-turbocharger-related improvement in engine performance of to the order of 2% for the M80 Series 2 results compared with M80 operation at the beginning of the trial.

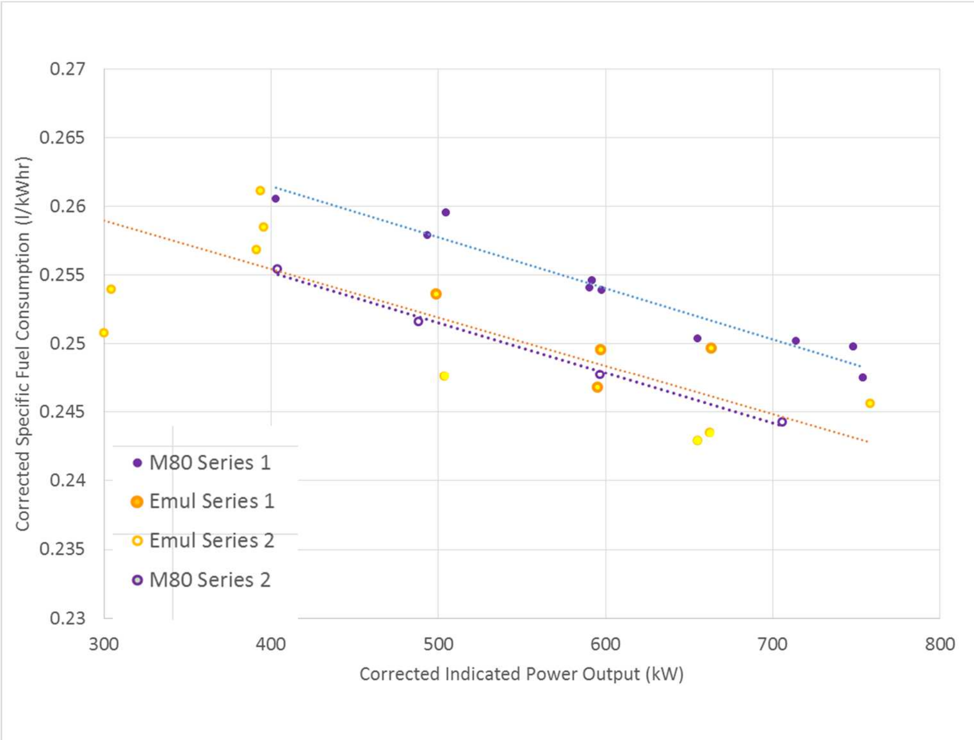

Figure 2: Corrected Specific Fuel Consumption Versus Corrected Generator Output for M80 and Emulsified Fuel Operation

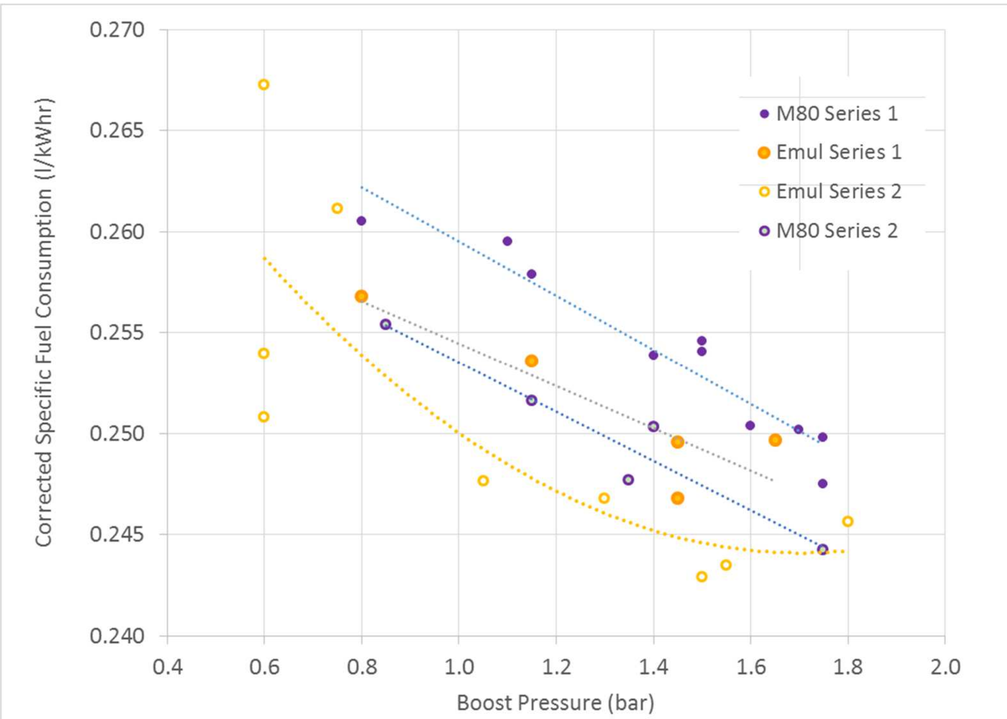

Figure 3: Specific Fuel Consumption versus Boost Pressure for M80 and Emulsified Fuel Tests

Further checks were carried out on the SFC results due to the relatively small changes in SFC found and the amount of manipulation carried out in order to obtain useable data around the various instrument failures. These checks included testing the sensitivity of the various calibration and correction factors used. These checks concluded that the 3% improvement in SFC with emulsified fuel use and the order of 2% non-turbocharger-related improvement in SFC for M80 operation after the use of emulsified fuel were both real changes in engine performance and significant.

Comparison of Average Specific Fuel Consumption Data

Use of the totalised results from the kilowatt-hour and fuel meters allowed the SFC to be calculated for engine operation for the periods between and including the timed test runs. The results of these calculations are illustrated in Figure 4. As shown, the SFC results for the original M80 tests consistently exhibited the worst (highest) SFC results and emulsified fuel operation provided the best SFC performance when comparing like-for-like turbocharger operation. The inconsistency with the low SFC result for the first emulsified fuel series in the timed tests (orange bar, far right set) was due to the higher average power of the timed tests during this test series, providing a lower average SFC result (noting that SFC reduces with increased engine load, all-else-equal).

The average power output of the generator over the trial period was around 500kW and this did not differ significantly during the trial periods that produced the different series of data.

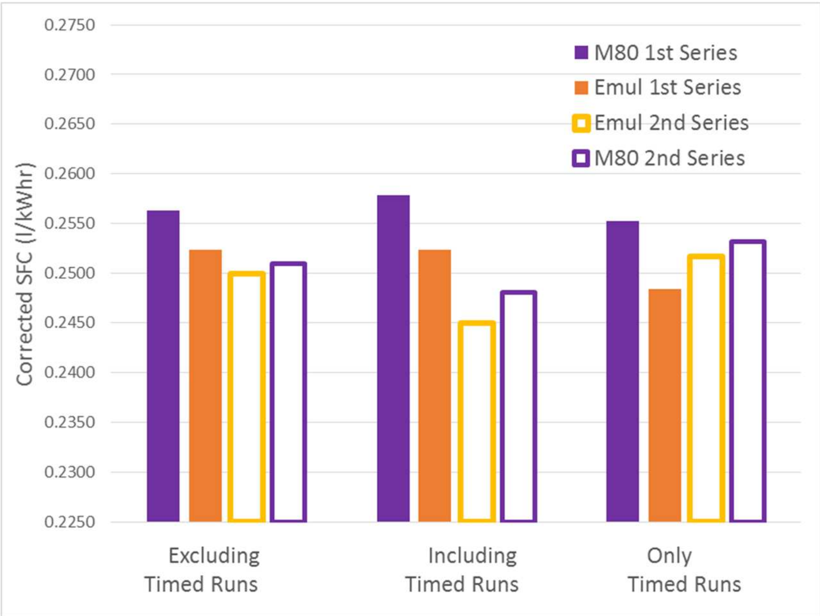

Figure 4: Specific Fuel Consumption for the Timed Tests and the Periods of Engine Operation Between Timed Tests, for the Different Series of Data.

4.3. Other Engine Parameters

4.3.1. Exhaust Temperature

An improvement in SFC should coincide with lower exhaust temperatures, all else equal, as less energy should remain in the exhaust gases. Figure 4 plots average exhaust temperature versus indicated engine power for the four data series, and shows:

- The exhaust temperatures of the post-emulsified fuel M80 tests are lower than the first series of M80 tests, corroborating the lower SFC results. This is despite lower airflow through the engine (as evidenced by lower boost for reasonably similar boost temperatures, which would normally cause an increase in exhaust temperature, all else equal. Note that lower boost is also an indication of less energy remaining in the exhaust gases, as there is less energy driving the turbocharger turbine).
- The exhaust temperatures for the emulsified fuel tests tended to be lower for tests conducted after the change in turbocharger. This matches the slight improvement in SFC found for these tests compared with the tests carried out before the turbocharger change (and again, despite lower boost which would normally be expected to cause an increase in exhaust temperature).
- On average, the exhaust temperatures for the emulsified fuel tests were to the order of 10^{o}C lower than for the M80 Series 1 tests. A decrease in exhaust temperature of only around 2-3^{o}C is expected to be due to the evaporation of water in the emulsified fuel (based on thermodynamic calculations) and hence the greater decrease in exhaust temperature supports the improved SFC results obtained for the use of emulsified fuel (i.e., less energy has been lost to the exhaust resulting in improved SFC).
- The slightly lower exhaust temperatures of the M80 Series 2 tests compared with those of the emulsified fuel tests are inconsistent with this result. However this inconsistency is not considered to be significant as the temperatures involved are still relatively similar.

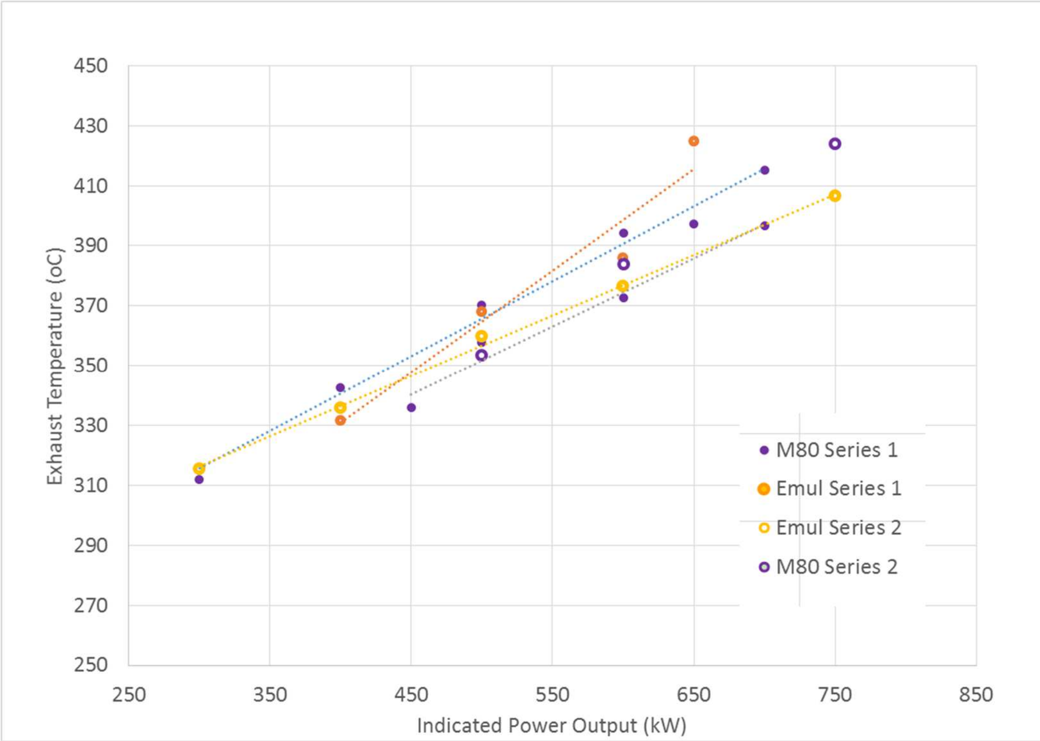

Figure 4: Average Exhaust Temperature Versus Indicated Engine Power for the Different Data Sets.

4.3.2. Inlet Air-Related Parameters

The pre-intercooler (boost) air temperatures, turbocharger speed and other parameters were consistent with expectations (for example, pre-intercooler air temperature and turbocharger speed were higher with increased exhaust temperature, etc.).

4.3.3. Cylinder Pressure

Cylinder pressure diagrams are the equivalent to the monitoring of the heart-lung machine in the human body. The expectation is that changes in engine performance will also be matched by changes in cylinder pressure diagram. Diagrams were taken at the very beginning of the emulsified fuel trial and at the end of the trial, once the engine was returned to M80.

No significant difference was found in the pressure diagrams. Figure 5 provides the comparison of the pressure diagrams at 500kW, as an example to illustrate this. Each trace shown is the average of the diagrams obtained from the six cylinders and these average traces more-or-less lie on top of one another. The average indicated peak pressure was 90-91 bar for each fuel and there was no discernible difference in the peak rate of pressure increase (i.e., the pressure diagrams had the same slope during the combustion phase immediately after combustion initialisation). This indicates that the use of emulsified fuel does not create concerning changes to the cylinder pressure (i.e., and therefore does not result in unusual stresses on engine components, etc.).

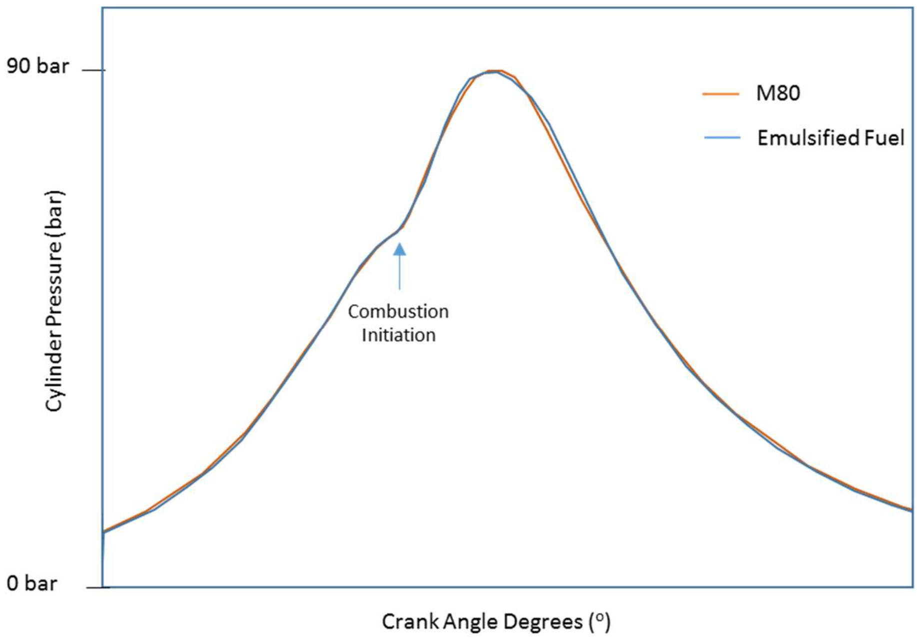

Figure 5: Comparison of Cylinder Pressure Diagrams Taken During M80 and Emulsified Fuel Operation at 500kW.

It is difficult to read anything further into the pressure diagrams than this. It is important to note that the emulsified fuel pressure diagrams were taken soon after the switch to emulsified fuel. Around 30 tonnes of emulsified fuel had been consumed by the time formal testing on emulsified fuel began. As the use of emulsified fuel appears to have brought about a change in base engine performance, the engine test results may not align with the pressure diagrams (taken earlier at the same engine load). And the turbocharger change that took place before the M80 pressure diagrams were taken could also have resulted in a change in pressure diagram. In all, there are too many variables involved for a meaningful comparison to be made, other than to say that there appears from the pressure diagrams to be no discernible difference between emulsified fuel and M80 operation.

Note that the Maintenance Engineer involved in the trial reported that the engine combustion sounded less harsh for operation on emulsified fuel. This is not borne out by the differences seen in the pressure diagrams. However, it is possible that these diagrams do not show a second order of pressure fluctuation which may be audible to the human ear.

4.3.4. Exhaust Emissions

Stack emissions testing was carried out at the beginning of the trial for emulsified fuel, and at the end of the trial period for M80. As with the taking of cylinder pressure diagrams, these two instances were separated by a turbocharger change and an apparent change in the base performance of the engine (brought about by some form of engine cleaning, or other), which needs to be taken into consideration.

The emissions results are provided in Table 1. Comparison between M80 and emulsified fuel data did not show any significant differences apart from in the smoke result, with a slightly lighter smoke filter found for operation under high load on emulsified fuel, and a slightly darker filter for operation on emulsified fuel under low load (the differences in shade only noticeable by placing cut disks beside one another). It is expected that the same trend would have been found had the turbocharger not been changed, such are the differences in boost involved.

Engine Power	300 kW	400 kW	500 kW	600 kW	700 kW
Emulsified Fuel					
HC (ppm)	0	5	0	1	5
CO (%)	0.04	0.01	0.01	0.01	0.02
CO_2 (%)	4.9	5.1	5.1	5.1	5.7
O_2 (%)	14.6	13.9	14	14.2	13.3
NOx (ppm)	616	651	624	577	658
Air-Fuel Ratio	44.83	42.92	43.12	43.65	38.36
Comparison of Bosch smoke filters	Emul slightly darker	same	same	Emul slightly lighter	Emul slightly lighter
M80					
HC (ppm)	6	5	7	5	1
CO (%)	0.02	0.01	0	0.01	0.01
CO_2 (%)	4.8	5	5.1	5.7	6
O_2 (%)	14.8	14.3	14.1	13.4	13.2
NOx (ppm)	593	649	646	672	699
Air-Fuel Ratio	45.71	44.1	43.36	38.51	37.33

Table 1: Exhaust Emissions Results For Emulsified Fuel and M80 Operation (noting that there were differences in the base test arrangement between the fuels)

The 2013 tests found differences in smoke and oxides of nitrogen (NOx). The close results for these recent tests are thought to be due to improvement found with the second series of M80 tests, using as the M80 reference, in this case. The emulsified fuel stack emissions testing was also carried out at the very beginning of the use of emulsified fuel and therefore would not reflect the change in base engine performance either. Thus comparison is hardly on a like-for-like basis.

But as with the consideration of cylinder pressure, it can be concluded that there were no concerning differences found in the stack emissions. Discussed in the next Section, the temperature of the emulsified fuel was around 15°C lower than that for the emulsified fuel and there was potential for improvements to be detected for emulsified fuel operation under moderate to higher load operation had the comparison been across like-for-like engine condition and arrangement.

4.4. Comparison with 2013 Test Results.

A check of the results from the emulsified fuel and M80 tests carried out in 2013 found similar trends in the changes in engine performance (that is, for operation under moderate load, use of emulsified fuel brought about a decrease in exhaust temperature and an improvement in SFC). However, the changes realised in the most recent testing were only around half those found in the 2013 testing. For example, the indicated improvement in SFC was around 5.5% in 2013 whereas it was around 3% in the recent testing, and the drop in exhaust temperature was around 30˚C in 2013 and around 15˚C in the recent tests (and noting that the variation in the differences is consistent, which supports the integrity of the results[16]).

The following considers reasons for this change:

1. In the recent testing, the temperature of the emulsified fuel was consistently around 15˚C cooler than for M80 whereas the fuel temperature was around the same for both the emulsified fuel and M80 tests in 2013. The lower temperature has the potential to slightly reduce the amount the fuel atomises on injection. From my experience with the use of M80 in boilers, lifting the temperature from 70^{o}C to 90^{o}C does provide a noticeable change in the spray pattern. Thus, although the presence of the emulsion is expected to cause increased atomisation, this effect is possibly offset by the greater droplet size to begin with. Therefore the slightly lower temperature of the emulsified fuel may not have provided a like-for-like comparison of performance for the M80 and emulsified fuels.

   Checking the reason for this difference in temperature, it was originally believed that the temperature chosen for M80 operation was agreed between Interislander and BFSNZ. However it now appears that the lower temperature was chosen by Interislander to reduce the energy used to heat the fuel.

   It is difficult without carrying out further testing to determine if this would have brought about a significant difference in the actual performance of the engine.

2. In the recent tests, refurbished injectors were used prior to the M80 testing and prior to the emulsified fuel testing, whereas the injectors were not changed in the testing carried out in 2013. It is possible that the greater improvement found in the 2013 testing was partly due to a base of poorly performing injectors, with the secondary atomisation of the emulsified fuel enabling greater recovery from this performance. Again, it is difficult to determine if this would have brought about a significant difference in the actual performance without carrying out further testing.

   Together, these two differences do have the potential to account for the differences found between the 2013 and recent tests, although no certainty can be reached without further testing.

[16] That is, they are not a result of measurement errors.

5. Conclusions

In conclusion, comparison of test results from testing the generator engine on the Arahura when using emulsified fuel and on M80 has found that:

1. Use of emulsified fuel brought about an improvement in specific fuel consumption of to the order of 3%. It is possible that further improvement may have been realised had the engine been tested in a like-for-like manner.
2. It appears that the use of emulsified fuel also brought about an improvement in the base engine performance, through cleaning of the engine or other, which resulted in an improvement of to the order of 2% in the specific fuel consumption performance of the engine, when returned to M80 operation at the end of the trial.
3. There were no significant differences in cylinder pressure diagram, indicating that there were no concerning changes to the combustion profile.
4. There were no significant differences in exhaust emissions. It was possible that an improvement in emissions could have been found under moderate to higher loads had the comparison been across a like-for-like engine condition and arrangement.

Appendix A: Form FRM-KR1.2, Filled Out for One of the Timed Tests Carried Out During the Trial

FRM-KR1.2 Date 8 Dec 2014				
M8 and Emulsion Engine Performance Data Recording Sheet				
Recorder	Initials	JF —	—	
Date	DD/MM	30/04/15 —	—	
Time start of recording	HH:MM	15:50		
Fuel (M8 of FOE?)	Fuel	M80 FOE	M80 FOE	M80 FOE
Snapshot or Timed Load?	Recording	Snapshot/Timed	Snapshot/Timed	Snapshot/Timed
	Units			
Engine Load	**kW**	400	400	
kWhr Generated	**kWhr**	209731	210119	
Time kWhr recorded	**HHMM**	1553	1654	
Accum Fuel Metered	**litres**	412374	412487	
Average Fuel Flow	**l/min**	2,1	2,0	
Time Fuel Meter Recorded	**HHMM**	1554	1655	
Engine Speed	**rpm**	998	998	
Engine Hours	**hrs**	18132,0	18133,1	
Charging Air Pressure	**bar**	0,85 B	0,75B	
Fuel Pressure	**bar**	6,3 B	6,3B	
Turbocharger Speed	**rpm**	8000	8000	
Temp Air Filter Inlet Casing	**°C**	36	35	
Temp Post-Compressor Chamber	**°C**	97	85	
Temp Intercool Water Outlet	**°C**	37	37	
Temp Fuel Inlet to Inj Gallery	**°C**	65	67	
Temp Water Inlet to Engine	**°C**	67	68	
Temp Water Outlet from Engine	**°C**	73	73	
Temp Exhaust Cyl 1	**°C**	337	326	
2	**°C**	339	325	
3	**°C**	344	329	
4	**°C**	323	310	
5	**°C**	340	330	
6	**°C**	343	337	
Temp Exhaust Turbo Out	**°C**	339	334	
Time Recording Finished	**HHMM**	1556	1657	
Comments:				
		Start	Stop.	

Appendix B Calibration of the Kilowatt-hour Meter

A (new) kilowatt-hour meter was installed at the beginning of the trial to measure the electrical energy produced by the generator. Results from the first tests indicated that the meter was reading around 20% higher than expected based on the generator power output indicated by the control room's analogue power meter. The control room power meter appeared to be the more correct as the engine was not capable of operating at the higher power indicated by the kilowatt-hour meter.

The vessel's Chief Electrician was questioned on the installation and calibration of the kilowatt-hour meter. He reported that the meter had been fitted correctly and that there were no means for adjusting the calibration of the meter. It was therefore expected that the meter would stay in the same state of calibration. At that time, no practical option was devised to calibrate the meter either. There seemed to be no alternative but to accept this situation.

Nonetheless, the kilowatt-hour meter did reset itself at least twice during the trial: once near to the end of the M80 trial (on 1 April 2015), after which time the meter indicated kilowatt-hour data that was more-or-less consistent with the control room's power meter; and once near the end of the trial (on 27 May 2015), after which the meter still indicated kilowatt-hour data that was more-or-less consistent with the control room's power meter.

The control room's power meter was used to set and maintain the power of the generator, and its value was recorded for all engine performance tests. This data allowed calibration of the kilowatt-hour meter against the control room's power meter, providing a correction factor for the kilowatt-hour meter's three states of calibration. This allowed the kilowatt-hour data to be recovered which was vital to the trial as, once corrected, this provided a far more accurate assessment of energy output from the engine than could be derived from the control room's analogue meter reading.

Figure 6 provides comparisons of the power output as indicated by (uncorrected) kilowatt-hour data and as indicated by the control room's power meter. Three sets of data are shown, two of which are almost overlapping. The R^2 values for these sets were no less than 0.996 indicating a very high correlation between the kilowatt-hour and control room meter indications in the three calibration modes, providing confidence in using this method to calibrate the kilowatt-hour meter.

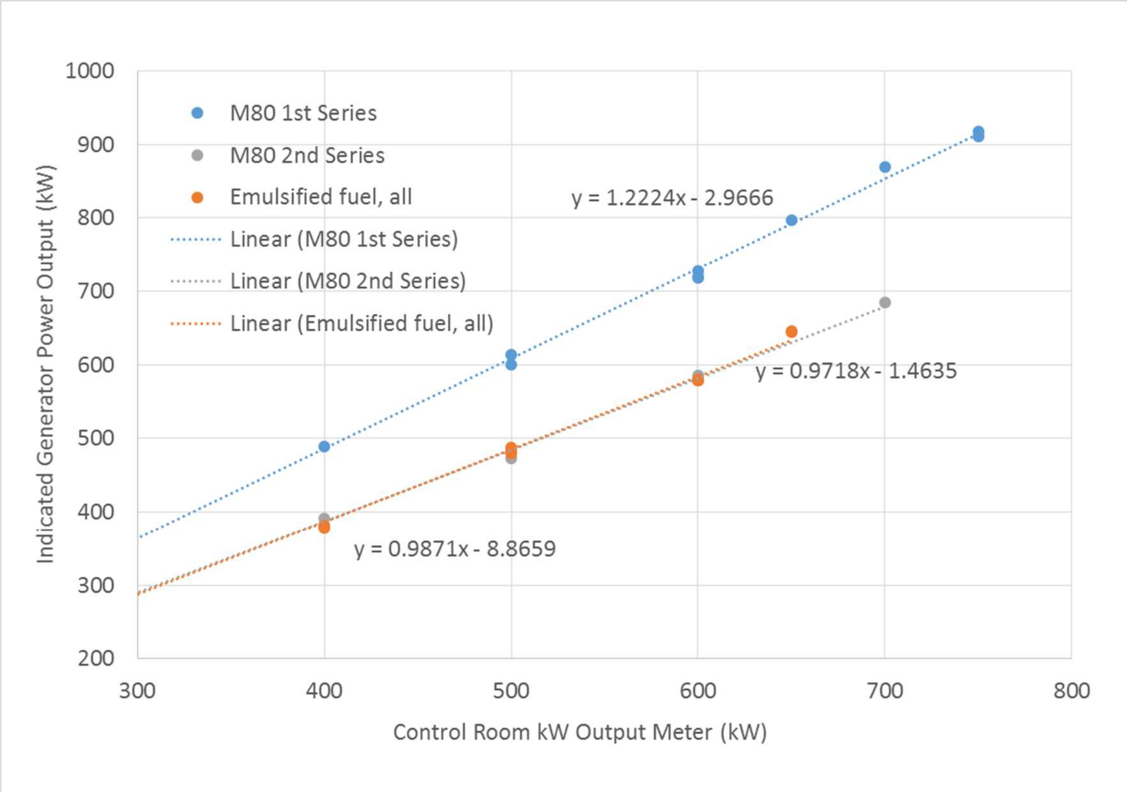

Figure 6: Comparison of Kilowatt-Hour Meter-Indicated Power Output and Control Room Indicated Power Output Illustrating the Different Calibration Modes of the Kilowatt-Hour Meter.

Appendix C: Calibration Check of the Fuel Flow Meters

C.1 Emulsifying Unit Fuel Meter

A calibration check was carried out on the fuel flow meter, metering fuel supplied by the emulsifying unit, on 9 April 2015. This check was conducted by John Fraser (Maintenance Engineer, Arahura) with Leigh Ramsey (BFSNZ) observing. The check comprised:

1. Shutting the water and emulsifier supply valves (so that only M80 was pumped).
2. Using the emulsifying unit to pump M80 through the fuel meter.
3. Diverting the fuel meter's output flow into a bucket.
4. Pumping an indicated 10.0 litres of M80 through the pump.
5. Measuring the amount of M80 delivered using a measuring jug.

The results of three tests so carried out were 10.09 litres, 10.10 litres and 10.10 litres. These results were within the accuracy of the calibration method and equipment used and therefore the calibration of the fuel flow meter was accepted.

C.2 Engine Fuel Metering

A calibration check was carried out on the generator's fuel metering. This check was also conducted by John Fraser, with Leigh Ramsey observing. The check comprised:

1. Shutting the engine's fuel outlet valve so only fuel passing by the fuel inlet meter would be registered.
2. Tapping into and pulling a fuel flow from the fuel rail at a rate of around 10 litres/min (as measured by a 10 litre container calibrated for this purpose).
3. Running several tests where the meter-indicated fuel delivery reading was compared with 10 litres of fuel delivery into the calibrated container (which gave meter-indicated results within 1% of the calibrated container results, which is within the accuracy of the method used).
4. Untapping the fuel rail, opening the engine's fuel outlet, and observing the fuel delivered after 2 minutes of fuel delivery to the engine with the engine stopped. This gave a nil fuel flow result which indicated that both meters were metering the same amount of fuel.

This indicated that the calibration of the fuel meters was within the accuracy of the calibration method and equipment used and therefore the calibration of the engine's fuel flow meter was accepted.

Appendix D: Calibration of the Emulsification Unit

The calibration of the emulsification unit was carried out on 12 March 2015, as part of the commissioning of the emulsification unit, and this calibration was checked on 9th April 2015 and 4th May 2015. John Fraser and Leigh Ramsey carried out this work. I was in attendance for the commissioning calibration of the emulsifying unit.

The commissioning calibration of the emulsification unit comprised:

1. Setting the fuel flow from the emulsification unit to around 10.0 litres per minute by adjusting a throttle valve on the outlet of the emulsification unit (with flowrate indicated by volume of fuel metered by the VAF fuel flowmeter measuring on the outlet side of the emulsification unit, over 60 seconds).
2. Fitting measuring cylinders to the delivery side of both the water and emulsifier pumps and using the valving to fill and isolate these so that the flow of each pump could be measured.
3. Varying the delivery adjustment on each of the water and the emulsifier pumps until the required flowrates were achieved (as indicated by volume pumped over 60 seconds).
4. Rechecking the total fuel flowrate and repeat steps 1 through 3 if it was not 10.0 litres per minute.
5. Locking all adjustments.
6. Removing the calibration tubes and restoring the various valve positions so that water and emulsifier were supplied from nearby drums.

Checking the calibration comprised of:

1. Checking the fuel flowrate from the emulsifying unit.
2. Setting up the measuring cylinders on the inlet to the water and emulsifier pumps as described above.
3. Checking the flowrates of the water and emulsifier pumps.
4. Returning the emulsifying unit to normal operation.

Table 2 provides the results of my checking the calibration setting arrived at by BFSNZ, a check carried out on 12 March 2015 around one hour after BFSNZ had carried out their commissioning calibration work. This calculates the emulsified fuel to have a blend ratio of 8.3% water and 0.6% emulsifier, compared with BFSNZ’s target of 8.0% and 0.6%, respectively. The unit was left at this calibration.

Parameter	Raw Data	Calculated result	Gross Result as Percentage
Total fuel flow	48.0 litres in 300 seconds.	9.6 litres/min	91.0%
Of which: water flowrate	820ml, 800ml and 800ml in 60 seconds (three tests).	0.8 litres/min	8.3%
And: Emulsifier flowrate	60ml and 60ml in 60 seconds (two tests).	0.06 litres/min	0.6%
Total "fuel" component		9.0 litres/min	91.7%

Table 2: Results of Andrew Campbell Checking the Calibration of the Emulsifying Unit After Commissioning Calibration Carried Out by BFSNZ

In an email dated 1 June 2015, Interislander (John Fraser) reports that the calibration check carried out on 9 April 2015 found "the flow of the M80 had reduced slightly in comparison to the other components" and reports that the flowrate was adjusted (to the target value). John Fraser recalls that the as-found flowrate of the emulsifying unit was 9.6 litre/min, which was adjusted to 10.0 litres/min. This would return a water content of 8.0% rather than the 8.3% water content calculated above.

The calibration check on 4 May 2015 found the calibration at the target values (i.e., 10.0 litres/min) and no adjustments were made.

BFS reports that the emulsifier is a hydrocarbon (and the results from XRF testing and others supports this). The emulsifier component has therefore been added to the M80 component to give the total "fuel" component of the emulsified fuel.

Appendix E: Determination of Water Content of the Emulsified Fuel

The determination of water content of the emulsified fuel proved more difficult than expected. After trialling different test methods, the problem turned out to be one of sample integrity – it appeared that the emulsion was separating to some degree whenever it was left to settle, and the result of water testing then became dependent upon the history of the sample. This is despite the fact that laboratory samples were often bottled and sent out on the same day (sometimes within the hour) as the larger sample was taken. The solution found was to sample directly into the sample bottles that were sent to the test laboratories and for the test procedure to include a period of vigorous shaking before a test sample was drawn from these sample bottles.

This solution was not reached before the following had been tried:

1. Use of a different test laboratory (as it was known that they had a slightly different test arrangement, within the allowances of ASTM 95).
2. Use of water determination by Karl Fischer (D6304), made practical by dilution of the emulsified fuel sample with toluene (it was believed that Karl Fischer would more effectively account for any emulsified water in the sample).
3. Testing the residue from water determination by Dean and Stark by Karl Fischer.
4. Determination of heating value and comparing the result with that of an M80 sample taken from after the centrifuge.

Table 3 lists the results from the tests carried out. The notable findings from this set of tests are:

1. The M80 samples exhibited (characteristically) relatively stable results.
2. Determination of water content by heating value was found to be unreliable. The reason for this has yet to be determined.
3. The use of the unmodified Dean and Stark method (ASTM 95) was found to be quite adequate for determination of water content of the emulsion, as inferred by the very low results for water content of the residue as determined by Karl Fischer[17].
4. Some separation of the emulsified fuel was occurring within 8 hours of standing (i.e., for there to be such a difference in the water content between the sample that was shipped and the larger sample).
5. Using the developed method, the water content of the emulsified fuel as determined by ASTM 95 was to the order of 7.6-8.0% (for fuel samples taken on 8 May 2015), which aligns well with the 8.0% result as determined by the results from the calibration checks on the emulsifying unit carried out on 4 May 2015.

[17] Karl Fischer results indicated between 100ppm and 200ppm water in the residue, showing that the vast majority of the water was accounted for in the Dean and Stark test.

From this analysis and consideration of the emulsification unit's calibration adjustment made on 9 April 2015 (see Appendix D), the following values have been used to adjust for the water content of the emulsified fuel in engine performance calculations:

8.3% for tests carried out from 12 March to 9 April 2015
8.0% for tests carried out after 9 April 2015.

Sample	Test Laboratory	Test	GCV	Water	Indicated Water Content
12 March 2015	Laboratory samples taken from 1 litre sample after 8hr standing.				
EFO day tank outlet flange	IPL	ASTM 95		1.6%	1.6%
M80 at centrifuge	IPL	ASTM 95		<0.05%	<0.05%
19 March 2015	Laboratory samples taken from glass jar samples after 24hr standing.				
EFO day tank bottom	CRL	ASTM 95		4.8%	4.8%
EFO day tank outlet flange	CRL	ISO 1928	41.95 MJ/kg		3.7%
M80 at centrifuge			43.76 MJ/kg		Reference
EFO day tank outlet flange	CRL	ASTM 95		80%	80%
24 March 2015	Laboratory sample taken from glass jar sample after 8hr standing.				
EFO in recirculation line	IPL	Modified D6304		4.3%	4.3%
2 April 2015	Transfer to courier sample bottle after shaking main sample.				
EFO in recirculation line	CRL	ISO 1928	41.15 MJ/kg		6.0%
M80 at centrifuge	CRL	ISO 1928	43.76 MJ/kg		Reference
EFO in recirculation line	IPL	D95 plus D6304		7.1%	7.1%
8 May 2015	Direct into courier sample bottle.				
EFO at engine	CRL	ISO 1928	39.48 MJ/kg		9.4%
EFO at unit	CRL	ISO 1928	38.81 MJ/kg		11.0%
M80 at centrifuge	CRL	ISO 1928	43.56 MJ/kg		Reference
EFO at engine	CRL	ASTM 95		8.0%	8.0%
EFO at engine	IPL	ASTM 95 plus D6304		7.6%	7.6%
M80 at centrifuge	IPL	ASTM 95 plus D6304		<0.05%	<0.05%

Table 3: Results from Attempts to Determine the Water Content of the Emulsified Fuel

E.1 Additional Notes on the Water Content of the Emulsified Fuel

Sampling:

The reason for sampling at the engine was to take into account any water fall-out that may be occurring in the fuel system, before the fuel arrived at the engine – it was the specification of the fuel at the engine that was important. Emulsified fuel samples were also taken at the outlet of the emulsifying unit. Samples of M80 were taken from the outlet of centrifuge #3. For all samples, between 100ml and 200ml was first drawn from the sampling port to clear the port of any old fuel before a sample was taken.

Water Removal From Bottom of Day Tank:

Water was found at the day-tank sampling cock early in the trial on emulsified fuel. John Fraser (Maintenance Engineer, Interislander) reported that 2-4 litres of water was routinely (every 24 hours) drained from this port but that on one occasion there was considerably more water found (the water content determination test relating to this is shown by the grey-lighted line in Table 3). This additional water was attributed to deck washing plus a poorly sealing sounding plug. The contents of the day-tank were sent for reprocessing by centrifuge and the sounding plug sealed.

Water does not accumulate in any of the other fuel tanks on the vessel which suggests that the free water is a function of the use of emulsified fuel, which in turn suggests that the emulsion is breaking down. From this and from the experience of preparing emulsified fuel samples for water testing, the question arises whether sufficient emulsifying agent has been added, or whether this amount of fall-out is normal.

Based on John Fraser's observations, the amount of water falling out of the emulsion would be no more than to the order of 200 litres (50 days of trial x 4 litres a day) which is very small compared with the almost 80,000 litres of emulsified fuel produced.

There do not appear to be any other locations where the water in the emulsified fuel could fall out and stay hidden, causing the emulsified fuel to possess a higher energy content than expected.

Appendix F: Results from M80 Timed Testing

Fuel	M80 Series 1	M80 Series 1	M80 Series 1	M80 Series 1	M80 Series 1	M80 Series 1	M80 Series 1	M80 Series 1	M80 Series 1	M80 Series 1	M80 Series 1	M80 Series 1	M80 Series 1		M80 Series 2	M80 Series 2	M80 Series 2	M80 Series 2	M80 Series 2	M80 Series 2
Date	11/02/15	25/02/15	25/02/15	3/03/15	1/03/15	9/03/15	9/03/15	10/03/15	10/03/15	11/03/15	11/03/15	12/03/15	13/03/15		28/05/15	28/05/15	28/05/15	28/05/15	28/05/15	29/05/15
Time (HH:MM)	16:00	11:00	15:30	15:50	0:00	15:35	10:52	15:45	10:58	11:05	15:44	15:40	11:10		11:09	12:40	13:13	14:41	16:02	16:00
kW nom	600-700	750	750	500	580-600	600	600	700	600	400	400	650	500		400	500	600	700	600	500
kWhr 1 (kW)	422709	494372	497535	535767	0	606175	603050	620455	617407	631984	634637	648633	658100		38	1248	855	1695	2503	14388
kWhr 2 (kW)	423549	495351	498461	536268	0	606667	603850	621107	618125	632359	635126	649430	658590		364	1696	1395	2231	3049	14877
Time 1 (HH:MM)	16:00	11:01	15:33	15:51	0:00	15:50	10:55	15:49	10:59	11:08	15:47	15:44	11:13		11:09	15:52	13:12	14:41	16:02	16:13
Time 2 (HH:MM)	16:56	12:05	16:34	16:40	0:00	16:31	12:01	16:34	11:59	12:07	16:47	16:44	12:02		11:59	16:48	14:08	15:28	16:58	17:15
Fuel 1 (litres cum)	283524	301158	301818	309886	0	324833	324172	327868	327223	330318	330883	333856	335861		448228	353623	448445	448661	448867	451938
Fuel 2 (litres cum)	283686	301357	302008	309993	0	324936	324339	328002	327373	330421	330988	334020	335965		448314	353750	448583	448796	449008	452065
Fuel Avg 1 (litres/min)	2.7	3.3	2.9	1.8	0	2.7	2.7	3.1	2.8	1.9	1.9	2.9	2		2.1	2.4	2.3	2.8	2.4	1.7
Fuel Avg 2 (litres/min)	2.8	3.7	3	2.1	0	2.7	2.7	3.2	2.7	1.9	1.9	2.9	2		1.6	2	2.2	2.8	2.3	2
Calcs	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0
d kWhr (kWhr)	840	979	926	501	765.5172	492	800	652	718	375	489	797	490		326	448	540	536	546	489
d Time (min)	56	64	61	49	58	41	66	45	60	59	60	60	49		50	56	56	47	56	62
d fuel (litres)	162	199	190	107	144	103	167	134	150	103	105	164	104		86	127	138	135	141	127
kW avg (kW)	900	917.8125	910.819672	613.46939	740	720	727.27273	869.33333	718	381.35593	489	797	600		391.2	480	578.5714	684.2553	585	473.22581
adj kWav (kW)	739	754	748	505	608	592	598	714	590	315	403	655	494		404	495	597	706	603	488
adj fuel (litres/hour)	174	187	187	131	149	151	152	179	150	105	105	164	127		103	136	148	172	151	123
SFC (litres/kWhr)	0.235	0.247	0.250	0.260	0.245	0.255	0.254	0.250	0.254	0.000	0.261	0.250	0.258		0.255	0.275	0.248	0.244	0.250	0.252
nominal power (kW)	650	750	750	500	590	600	600	700	600	400	400	650	500		400	500	600	700	600	500
kW avg (kW)	900	917.8125	910.819672	613.46939	740	720	727.27273	869.33333	718	381.35593	489	797	600		391.2	480	578.5714	684.2553	585	473.22581
Cal Ind kW	736	754	748	505	608	592	598	714	590	315	403	655	494		405	495	595	702	602	488
Engine hours (HH)	17193	17309.1	17313.6	17377.2	#REF!	17497.3	17492.4	17521.3	17576.5	17540.6	17545.3	17569.2	17584.7		18419.2	184219	18420.4	18421.9	18423.2	18447.4
Turbo speed (rpm)	9200	10000	10000	8500	0	9400	9000	9600	9400	7800	8000	9400	8800		8000	9800	9000	9800	9400	8400
Temp Air Filter Inlet Casing (o	41	43	44	41	0	43	41	43	43	43	42	43	43		36	37	34	37	39	38
Temp Post-Compressor Cham	137	149	163	107	0	139	134	147	148	108	109	145	121		92	131	114	131	130	109
Temp Intercool Water Outlet (	43	44	46	41	0	44	42	44	44	41	38	43	42		38	44	40	44	49	39
Temp Fuel Inlet to Inj Gallery (	81	79	80	78	0	78	78	78	79	79	77	81	79		79	79	79	79	79	72
Temp Water Inlet to Engine (o	69	69	68	70	0	69	68	68	69	69	67	69	69		69	68	68	68	68	68
Temp Water Outlet from Engi	75	76	76	73	0	74	74	74	76	74	73	75	75		74	74	72	74	74	74
Temp Exhaust Cyl 1 (o	383	419	424	354	0	393	373	412	403	342	336	396	365		334	397	369	397	381	356
Cyl 2 (oC)	386	424	431	352	0	394	374	411	403	341	332	395	366		330	396	365	396	379	352
Cyl 3 (oC)	384	420	425	357	0	396	378	416	407	347	339	397	369		343	406	373	406	386	362
Cyl 4 (oC)	377	421	420	347	0	388	381	412	400	334	326	388	363		329	398	368	398	386	356
Cyl 5 (oC)	387	433	435	360	0	397	392	421	412	354	343	403	377		332	395	359	395	372	352
Cyl 6 (oC)	400	437	438	363	0	410	402	432	420	358	345	412	383		345	412	376	412	391	373
Exhaust After Turbocharger (o	370	398	412	341	0	388	377	402	391	353	347	390	368		338	373	354	373	360	354

Appendix G: Results from Emulsified Fuel Timed Testing

Fuel	EMUL Ser 1	EMUL Ser 1	EMUL Ser 1	EMUL Ser 1	EMUL Ser 1	EMUL Ser 1	EMUL Ser 1	EMUL Ser 1	EMUL Ser 2	EMUL Ser 2	EMUL Ser 2	EMUL Ser 2	EMUL Ser 2	EMUL Ser 2	EMUL Ser 2	EMUL Ser 2	EMUL Ser 2	EMUL Ser 2
Date	23/03/15	23/03/15	0/01/00	9/04/15	15/04/15	17/04/15	17/04/15	22/04/15	28/04/15	29/04/14	29/04/15	30/04/15	30/04/15	1/05/15	4/05/15	4/05/15	4/05/15	5/05/15
Time (HH:MM)	11:16	15:42	0:00	15:50	12:30	12:10	17:50	11:11	11:00	10:31	15:44	10:45	15:50	11:02	15:40	8:01	13:15	10:10
kW nom	300	300	0	400	600	500	600	650	500	650	600	500	400	400	300	300	300	750
kWhr 1 (kW)	694818	695255	0	75136	106470	128872	131602	182248	184922	195467	198049	207307	209731	218849	220312	238856	241640	251415
kWhr 2 (kW)	695041	695554	0	75501	106952	129315	132308	182840	185464	196155	198734	207714	210119	219216	220658	239439	241970	252500
Time 1 (HH:MM)	11:21	15:46	0:00	15:57	12:34	12:17	17:56	11:11	11:07	10:31	15:44	10:49	15:53	11:04	15:49	8:11	13:20	10:17
Time 2 (HH:MM)	11:59	16:37	0:00	16:55	13:24	13:12	19:09	12:06	11:58	11:35	16:55	11:39	16:54	12:02	17:02	10:11	14:30	11:45
Fuel 1 (litres cum)	343623	343712	30471	374240	383091	389455	390230	404675	405438	408386	409110	411717	412374	414951	415293	420541	421039	423805
Fuel 2 (litres cum)	343666	343769	80333	374346	383224	389581	390427	404840	405585	408573	409299	411830	412487	415059	415398	420709	421133	424102
Fuel Avg 1 (litres/min)	1.7	1.7	0	1.9	2.7	2.4	2.7	2.8	2.8	2.7	2.5	2.4	2.1	2.2	1.4	1.4	1.4	3.4
Fuel Avg 2 (litres/min)	1.6	1.7	0	1.8	2.7	2.4	2.5	2.9	2.9	2.9	2.4	2.3	2	2.2	1.4	1.4	1.5	2.9
Calcs	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
d kWhr (kWhr)	223	299	0	365	482	443	706	592	542	688	685	407	388	367	346	583	330	1085
d Time (min)	38	51	0	58	50	55	73	55	51	64	71	50	61	58	73	120	70	88
d fuel (litres)	43	57	0	106	133	126	197	165	147	187	189	113	113	108	105	168	94	297
kW avg (kW)	352.105263	351.764706	0	377.58621	578.4	483.27273	580.27397	645.81818	637.64706	645	578.87324	488.4	381.63934	379.65517	284.38356	291.5	282.8571	739.77273
adj kWav (kW)	291	291	0	392	595	499	597	663	655	662	595	504	396	394	297	304	296	758
adj fuel (litres/hour)	68	67	0	101	147	126	149	166	159	161	147	125	102	103	79	77	74	186
SFC (litres/kWhr)	0.233	0.231	0.000	0.257	0.247	0.254	0.250	0.250	0.243	0.243	0.247	0.248	0.258	0.261	0.267	0.254	0.251	0.246
nominal power (kW)	300	300	0	400	600	500	600	650	500	650	600	500	400	400	300	300	300	750
kW avg (kW)	352.105263	351.764706	0	377.58621	578.4	483.27273	580.27397	645.81818	637.64706	645	578.87324	488.4	381.63934	379.65517	284.38356	291.5	282.8571	739.77273
Cal Ind kW	291	291	0	392	595	499	597	663	655	662	595	504	396	394	297	304	296	758
Engine hours (HH)	17646.8	17648	0	17841.3	17908	17955.7	17961.4	18064.6	18081	18102.7	18107.9	18127	0	18157.2	18154.9	18196.6	18201.8	18222.7
Turbo speed (rpm)	7000	6800	0	7400	9200	8600	9000	9800	9400	9400	9000	8600	0	7600	6600	6800	6800	10200
Temp Air Filter Inlet Casing (oC	37	394	0	36	39	40	39	37	31	36	38	36	0	37	38	36	37	41
Temp Post-Compressor Cham	82	76	0	96	129	118	127	133	113	128	117	101	0	97	84	81	81	144
Temp Intercool Water Outlet (	37	37	0	37	43	41	41	42	39	40	39	39	0	38	38	37	38	44
Temp Fuel Inlet to Inj Gallery (	78	74	0	66	66	66	65	64	63	64	65	65	0	65	65	66	66	66
Temp Water Inlet to Engine (o	66	64	0	67	70	69	68	69	67	69	68	68	0	68	67	69	69	68
Temp Water Outlet from Engi	79	77	0	73	76	74	74	75	74	75	74	74	0	74	73	74	73	75
Temp Exhaust Cyl 1 (o	315	308	0	331	394	370	388	471	369	378	376	354	0	333	316	320	319	412
Cyl 2 (oC)	317	313	0	324	390	365	384	412	377	379	377	357	0	337	316	317	315	402
Cyl 3 (oC)	327	321	0	343	396	377	389	426	373	380	380	362	0	343	321	327	326	416
Cyl 4 (oC)	303	290	0	310	377	352	370	404	355	363	361	339	0	318	291	292	291	392
Cyl 5 (oC)	317	306	0	334	389	368	382	420	361	377	374	358	0	335	307	311	312	411
Cyl 6 (oC)	329	311	0	344	404	381	392	433	377	389	391	366	0	344	318	325	321	428
Exhaust After Turbocharger (o	310	302	0	335	375	362	374	407	345	354	352	345	0	340	326	328	328	384