The University of Hong Kong

香港大學

Final Report

Marine Engine Tests on Laboratory Setting

Submitted to: Environmental Protection Department
HKSAR Government

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Date: 20 March, 2013

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Executive Summary

Background

Marine vessels emissions have been increasing over the past decades and become the top emitter of sulphur dioxide (SO_2), respirable suspended particulates (RSP) and nitrogen oxides (NOx) emissions in Hong Kong. The Hong Kong SAR Government has studied ways to reduce the marine emissions. One approach is to improve the quality of locally supplied marine diesel to reduce emissions from local and river vessels. The Environmental Protection Department (EPD) of the HKSAR Government proposed to reduce the sulphur limit of marine light diesel from 0.5% to 0.05%, which would result in a corresponding reduction of SO_2 and RSP emissions of individual vessel by about 90% and 30% respectively. A Working Group (WG) was formed in May 2012 with members from government officials of various departments, local vessel operators' representatives and experts in academia. The 1st and 2nd WG meetings agreed to conduct engine test on two commonly in-use marine engines using the high sulphur diesel (HSD, maximum 0.5% sulphur content by mass) and low sulphur diesel (LSD, maximum 0.05% sulphur content by mass) fuel in order to confirm the compatibility and performance of the LSD in existing vessel engines.

The Department of Mechanical Engineering at the University of Hong Kong was commissioned by the EPD in July 2012 to conduct a study on "Marine Engine Tests on Laboratory Setting" as a means to address the concerns of the WG members. The study employed tailor-made laboratory setup for evaluating the performance of two marine type diesel engines under different simulated working conditions. Methodologies of the test had been presented and endorsed in the 2nd WG meeting on 5 June 2012. An interim report summarising the preliminary results obtained from testing the Gardner 6LXB engine was issued to EPD in January 2013. This Executive Summary of the final report summarizes all the results obtained from testing the two selected in-use marine type diesel engines i.e. Gardner 6LXB and Cummins NTA855(M).

Objectives and Scope of Works

(1) To conduct tests for LSD for assessing the following for the two in-use marine engines under controlled laboratory environment:

(a) the performance in terms of maximum engine power output and fuel consumption at various load conditions; and

(b) the durability in terms of fuel lubricity and engine compatibility, which are based on measured fuel lubricity, microscopic examination of fuel injectors and pump, and analysis of used engine oil.

(2) To conduct the same tests for HSD as base case for comparison with LSD.

Results

A. Gardner Engine

(1) Diesel Fuel Analysis

HSD and Euro V diesel (EVD, maximum 10 parts per million sulphur content by mass) were provided by the fuel supplier of the government. LSD for testing was produced by blending one part of HSD with 10 parts of EVD by volume. Certificates of Quality (CoQ) for HSD and EVD provided by the fuel supplier and tested by an independent laboratory confirmed diesel compliance to specifications. In particular, the net calorific value (NCV, kJ/L) of the LSD was lower than the HSD by 1.6% and 2.2% respectively for the two analysed samples obtained during the HSD and LSD Performance Tests.

(2) Performance Test

(a) Maximum engine power

The maximum output power between the LSD and HSD fuels under the following four cases: before the HSD durability (baseline 1), after the HSD durability, before the LSD durability (baseline 2), and after the LSD durability can be found in the table below:

Max. power output	Base-line 1	After 200-hr of HSD Durability	Base-line 2	After 200-hr of LSD Durability	Overall average
HSD (kW)	106.2	116.3	115.3	117.7	113.9
LSD (kW)	104.9	115.0	109.5	117.8	111.8
% change LSD Vs HSD	-1.3%	-1.1%	-5.0%	+0.1%	-1.8%

As can be seen from the above table, the percentage change in maximum power varies from +0.1% to -5% with an overall average -1.8%. This drop in maximum power matched with the decrease in NCV for the LSD Vs HSD (1.9%).

(b) Specific fuel consumption

Specific fuel consumptions (SFC) at various engine loadings were determined. Sixth different engine loading conditions were tested, respectively 100% (i.e. 89 kW), 85%, 75%, 50%, 25% loading and a load cycle from 83% to 87%. The comparison of SFC between LSD and HSD under different loading conditions is shown in the table below for the following three stages: Baseline, after 200-hr Durability Test without engine oil replacement, and after 200-hr Durability Test with engine oil replacement.

Before and after the HSD Durability Test: Engine loading condition	Baseline (1st)	After 200-hr	After 200-hr & engine oil replacement	Average
100% LSD Vs HSD	-1.3%	+0.7%	+1.4%	-0.1%
85% LSD Vs HSD	+0.1%	+0.6%	+0.9%	+0.4%
75% LSD Vs HSD	+1.2%	+0.6%	+1.1%	+1.0%
50% LSD Vs HSD	-0.3%	+1.9%	+1.2%	+0.6%
25% LSD Vs HSD	-1.0%	+2.0%	+1.2%	+0.3%
Load Cycle (83% to 87% load) LSD Vs HSD	+0.9%	+1.0%	+1.3%	+1.0%

Overall average: +0.5%

Before and after the LSD Durability Test: Engine loading condition	Baseline (2nd)	After 200-hr	After 200-hr & engine oil replacement	Average
100% LSD Vs HSD	+1.1%	+2.6%	+2.9%	+1.9%
85% LSD Vs HSD	+1.2%	+2.7%	+2.6%	+1.9%
75% LSD Vs HSD	+1.1%	+2.6%	+2.5%	+1.8%
50% LSD Vs HSD	+1.1%	+1.9%	+2.0%	+1.5%
25% LSD Vs HSD	+0.6%	+1.3%	+1.6%	+1.0%
Load Cycle (83% to 87% load) LSD Vs HSD	+0.8%	+2.7%	+3.0%	+1.8%

Overall average: +1.7%

Before (1st baseline) and after the HSD Durability Test, the average SFC for LSD varied from -0.1% to +1.0% with an overall average of +0.5% for all the loading conditions. Similarly, before (2nd baseline) and after the LSD Durability Test, the SFC for LSD varied from +1.0% to +1.9% with an overall average of +1.7% for all the loading conditions. Thus, there is a slight increase in the % increase of SFC for the LSD durability test, which is consistent with the larger reduction in NCV (2.2% compared to1.6%).

(3) Durability Test

(a) Basic operational data

Durability Test was conducted first for HSD then LSD, both maintained for running 200 hours and at 68 kW constant power output, with 33.5 and 23.0 litre engine oil re-filled to replenish consumption. The large difference of 10.5 litres in engine oil consumption between HSD and LSD may be due to the following reasons:

(i) Larger amount of engine oil leakage and poorer control of engine oil addition at the beginning of the HSD Durability Test;
(ii) Engine run-in effect that consume more HSD;
(iii) Inherent feature of using LSD. Some researchers found that LSD would produce less sulphur dioxide than HSD during the combustion, which would be transformed to sulphuric acid. This would lead to less severe pitting and improved cylinder surface finish, hence lower engine oil consumption.

(b) Fuel injector test

Fuel injectors opening pressures were tested before and after the trial for each of the test fuels and fuel atomization patterns observed to ensure proper fuel delivery before and after the HSD and LSD Durability Test. The results obtained indicated that the opening pressures of all the injectors complied with the limit stipulated in the Gardner's operation and maintenance instruction manual demonstrating that the fuel deliveries are normal during the two durability tests. Atomization patterns of injector spray for all the six injectors were also found satisfactory for both HSD and LSD.

(c) Fuel injection pump test

Fuel injection pump was tested before and after the HSD and LSD Durability Tests. The test on maximum fuel setting and fuel delivery quantities of injection pump per 200 strokes @600 rpm were measured by standard test equipment, and was manually observed and recorded. All the results were found to fall within ± 0.2 c.c., within the sensitivity range of the combined test equipment uncertainty and human error.

Both fuel injector and pump test results are consistent with the observation of injector nozzles, hollow piston valves, pump plungers and delivery valves by SEM and LPEM, and the measured results of fuel lubricity being well below 460 μm.

(d) Engine Oil Analysis

Engine oil samples were taken at 0, 100 and 200 hours of the HSD and LSD Durability Tests for chemical analyses and the results are shown below for the HSD and LSD Durability Test:

HSD Durability Test: Test Parameter	Spec.	0-hr	100-hr	200-hr	Difference (200hr -0hr)
Viscosity, cSt @ 100℃	14.1	14.0	14.2	14.7	+0.7
Total Base Number (mg KOH/g)	10.1	9.2	8.0	7.8	-1.4
Wear Elements (ppm): Ag, Mo, Ni, Sn which have less than 4 ppm are not shown					
Al	0	3	5	5	+2
Cr	0	7	18	22	+15

Cu	0	5	9	9	+4
Fe	0	18	19	19	+1
Pb	0	2	4	5	+3

LSD Durability Test: Test Parameter	Spec.	0-hr	100-hr	200-hr	Difference (200hr -0hr)
Viscosity, cSt @ 100℃	14.1	14.1	14.3	14.6	+0.5
Total Base Number (mg KOH/g)	10.1	8.8	8.3	8.7	-0.1
Wear Elements (ppm): Ag, Mo, Ni, Sn which have less than 4 ppm are not shown					
Al	0	1	3	4	+3
Cr	0	2	13	18	+16
Cu	0	1	3	5	+4
Fe	0	4	11	16	+12
Pb	0	1	2	3	+2

The following are the observations from the engine oil analysis:

(i) Viscosity

There is an increase in viscosity over the 200 hours' Durability Test and the increase is 5.0% and 3.5% for HSD and LSD respectively. This means that the viscosity increase faster for the HSD case.

(ii) TBN

There is a rather big reduction in TBN over the 200 hours' test period for the HSD (15%) but only a minor reduction of 1% for the LSD. A plausible explanation is that additive replenishment (i.e. topping off the oil) is replacing sufficient additive to offset the amount consumed by much lower quantity of sulphuric acid generated from the LSD than the HSD combustion. Nevertheless, both TBN values at 200-hr for HSD and LSD are still within normal range. According to the engine oil manufacturer, engine oil need to be changed when the TBN values drops below half of the original values. Thus, the lower TBN depletion rate for LSD should benefit the engine operation by possible reduction of engine oil changing frequency. Such benefit would become more since LSD consumes less engine oil.

(iii) Elemental analysis

There is a general increase in metal concentrations in the engine oil over the 200-hr testing due to engine wear. Incremental metal concentrations due to wear for HSD and LSD were more or less similar except higher iron for LSD.

(e) Scanning Electronic Microscope (SEM) Examination

To investigate whether there is wear and tear problem caused by fuel flow, all components of fuel injectors and pump set of the Gardner engine that may be subject to wear and tear due to fuel lubricity were purchased new and examined before and after the Durability Tests. These components include injector nozzles, hollow piston valves, pump plungers and delivery valves. The SEM photos taken showed that the shapes and sizes of the nozzles remain the same after the 200-hr Durability Tests for both HSD and LSD cases. Some deposits found inside the nozzles of both HSD and LSD was identified to be mainly carbon and oxygen, which may come from the unburnt fuel. In general, based on the SEM observations, no abnormal finding and discrepancy could be identified for both the HSD and LSD cases.

(f) Low Power Electronic Microscope (LPEM) Examination

The surface finishes of the plungers were compared under LPEM for both the HSD and LSD cases. As can be seen from the photos taken, the surface finishes of the examined component did not exhibit any significant changes before and after the Durability Test for both HSD and LSD. The LPEM investigation indicated that there are no significant differences in the tear and wear characteristics for both the HSD and LSD cases.

B. Cummins Engine

(1) Diesel Fuel Analysis

The two test fuels (HSD and LSD) examined by the independent laboratory matched with the CoQ provided by the fuel supplier. The test results indicate that the percentage difference in NCV between LSD and HSD are -1.5% and -2.2% for the two batches of samples with an average of -1.8%.

(2) Performance Test

(a) Maximum engine power

The variation in maximum engine output power between the LSD and HSD fuels are shown in the table below:

Max. power output	Base-line 1	After 200-hr of HSD Durability	Base-line 2	After 200-hr of LSD Durability	Overall average
HSD (kW)	300.7	301.2	290.2	292.6	296.4
LSD (kW)	302.7	303.0	289.9	293.2	297.5
% change LSD Vs HSD	+0.7%	+0.6%	-0.1%	+0.2%	+0.4%

Despite a small reduction in NCV of the LSD fuel, there is a small percentage increase in maximum power, which varies from +0.7% to -0.1% with an overall average of +0.4%..

(b) Specific fuel consumption

Six different engine loading conditions were tested, respectively 100% (i.e. 196 kW), 85%, 75%, 50%, 25% loading and a load cycle from 83% to 87%. The comparison of SFC between LSD and HSD under different loading conditions is shown in the table below for the following three cases: Baseline, after 200-hr Durability Test without engine oil replacement, and after 200-hr Durability Test with engine oil replacement.

Before and after the HSD Durability Test: Engine loading condition	Baseline (1st)	After 200-hr	After 200-hr & engine oil replacement	Average
100% LSD Vs HSD	+1.0%	+1.2%	+0.8%	+1.0%
85% LSD Vs HSD	+1.6%	+1.5%	+1.6%	+1.6%
75% LSD Vs HSD	+1.6%	+1.4%	+1.5%	+1.5%
50% LSD Vs HSD	+1.2%	+1.3%	+1.3%	+1.3%
25% LSD Vs HSD	+1.4%	+1.3%	+1.1%	+1.3%
Load Cycle (83-87%) LSD Vs HSD	+1.4%	+1.5%	+1.2%	+1.3%
			Overall average:	+1.3%

Before and after the LSD Durability Test: Engine loading condition	Baseline (2nd)	After 200-hr	After 200-hr & engine oil replacement	Average
100% LSD Vs HSD	+1.4	+1.7	+1.7	+1.5
85% LSD Vs HSD	+1.2	+2.0	+1.9	+1.6
75% LSD Vs HSD	+0.8	+2.1	+1.9	+1.4
50% LSD Vs HSD	+1.0	+2.1	+1.9	+1.5
25% LSD Vs HSD	+0.9	+1.6	+1.9	+1.4
Load Cycle (83% to 87%) LSD Vs HSD	+1.2	+1.4	+1.5	+1.3
				Overall average: +1.4%

All the SFC results obtained were normal and fell within the range provided in the engine manual. Same as the Gardner engine, the variation in SFC with and without engine oil replacement were very similar in magnitude indicating that the engine oil replacement did not affect SFC significantly. Before (1st baseline) and after the HSD Durability Test, the SFC for LSD over HSD varied from +1.0% to +1.6% with an overall average of +1.3% for all the loading conditions. Before (2nd baseline) and after the LSD Durability Test, the SFC for LSD over HSD varied from +1.3% to +1.6% with an overall average of +1.4% for all the loading conditions. The slight increase (+1.3% to +1.4%) in SFC for LSD over HSD is consistent with the reduced NCV (-1.8%, LSD Vs HSD) as mentioned in the Diesel Fuel Analysis.

(3) Durability Test

(a) Basic operational data

Durability Test was conducted first for HSD then LSD, both maintained for running 200 hours and at 186 kW constant power output. Different from the Gardner engine tested, the Cummins engine completed both the 200-hr HSD and LSD Durability Tests without the need of replenishing engine oil.

(b) Fuel injector test

The amount of fuel injection of all the six injectors complied with their operation limit demonstrating that the fuel deliveries were normal before and after the two Durability Tests. Atomization patterns for all the six injectors were found satisfactory for both HSD and LSD.

(c) Fuel metering pump check

Fuel injection pump was tested before and after the trial for HSD durability and LSD Durability Tests. All the results were found to fall within ± 3% considered to be within the sensitivity range of the combined test equipment uncertainty and human error. Thus, there was no significant difference before and after both the HSD and LSD Durability Tests.

Both fuel injector and pump test results were consistent with the observation of injector nozzles, metering pump plungers and fuel injector plungers by SEM and LPEM, and measured results of fuel lubricity being well below 460 μm.

(d) Engine Oil Analysis

The results of the engine oil analysis at 0, 100 and 200 hours for HSD and LSD Durability Tests are shown in the tables below:

Test Parameter (HSD Durability Test)	Spec.	0-hr	100-hr	200-hr	Change (200hr -0hr)
Viscosity, cSt @ 100℃	15.5	14.9	14.7	15.3	+0.4
Total Base Number (mg KOH/g)	10	11.2	10.7	10.4	-0.8
Wear Elements (ppm): Ag, Al, Cr, Ni, Sn which have less than 2 ppm are not shown					
Cu	0	1	3	5	+4
Fe	0	3	17	27	+24
Mo	0	35	39	38	+3
Pb	0	0	0	2	+2

Test Parameter (LSD Durability Test)	Spec.	0-hr	100-hr	200-hr	Change (200hr -0hr)

Viscosity, cSt @ 100℃	15.5	15.0	14.8	15.2	+0.2
Total Base Number (mg KOH/g)	10	11.4	11.5	11.6	+0.2
Wear Elements (ppm): Ag, Al, Cr, Ni, Sn which have less than 2 ppm are not shown					
Cu	0	0	1	2	+2
Fe	0	2	12	18	+16
Mo	0	35	38	37	+2
Pb	0	0	0	1	+1

The following are the observations from the engine oil analysis:

(i) Viscosity

There was an increase in viscosity over the 200 hours' Durability Test and the increase is +2.7% and +1.3% for HSD and LSD respectively showing that the rate of viscosity increase for LSD was lower.

(ii) TBN

There was a significant reduction in TBN over the 200 hours' test period for the HSD (7.1%) but the TBN values for LSD could be maintained (+1.8%). Nevertheless, the TBN values for HSD were still within normal range. As mentioned above, engine oil need to be changed when the TBN values drops below half of the original values. Thus, the non-depleted TBN for LSD would benefit the engine operation by possible reduction of engine oil changing frequency. As the extent of this reduction would also depend on the viscosity deterioration rate of the engine oil, it is likely that the benefit for LSD, which has a lower viscosity deterioration rate as shown in (i) above, should even be greater.

(iii) Elemental analysis

There is a general increase in metal concentrations in the engine oil over the 200-hr testing due to engine wear. The incremental metal concentrations due to wear for HSD and LSD were more or less similar except higher iron for HSD.

(e) Scanning Electronic Microscope (SEM) Examination

The SEM photos taken showed that the shapes and sizes of the nozzles remained the same after the 200-hr durability tests for both HSD and LSD cases. Some deposits were found inside the nozzles of both HSD and LSD, which was identified to be mainly carbon and oxygen, and most likely come from the unburnt fuel. In general, based on the SEM observations, no abnormal finding and discrepancy could be identified for both the HSD and LSD cases.

(f) Low Power Electronic Microscope (LPEM) Examination

The surface finishes of the metering pump plungers and fuel injector plungers were compared for both the HSD and LSD cases. The LPEM examination showed that the surface finishes of the examined component did not exhibit any significant changes before and after the Durability Test for both HSD and LSD. The LPEM investigation indicated that there are no significant differences in the wear/tear characteristics for both the HSD and LSD cases.

Conclusions

(a) The maximum power of the Gardner and Cummins engine can be maintained for LSD with respect to HSD. There was a very minor drop (from +0.1% to -5%, average -1.8%) for the Gardner but also a minor increase (-0.1% to +0.7%, average +0.4%) for the Cummins engines respectively. However, these small variations are insignificant and unnoticeable during actual operation.

(b) There was a small increase in specific fuel consumption (SFC) under constant load conditions of an average of +1.1% (from -1.3% to +2.9%) and +1.4% (from +0.8% to +2.1%) for the Gardner and Cummins engines respectively for LSD wrt HSD, which is in line with the small net reduction in calorific values of the LSD wrt HSD.

(c) The change in SFC for load variation during operation is also small between the HSD and LSD, with an average of +1.4% (from +0.8% to +3.0%) for Gardner and +1.3% (from +1.2% to +1.5%) for Cummins.

(d) Error for maximum power determination and % SFC change was estimated to be ±4.4% and ±1.7% respectively, showing high accuracy for the results obtained.

(e) From the Durability Test, there was not much difference of fuel injectors and pump wear due to fuels between HSD and LSD after the 200 hours' operation, as indicated from the fuel injector and pump performance tests, and microscopic examinations (SEM and LPEM).

(f) There were some changes in engine oil characteristics indicating benefits when the fuel was switched from HSD to LSD: slower decrease in TBN and slower increase in viscosity. However, the wear elements in the engine oil did not show significant difference between HSD and LSD.

(g) There was an indication of lower engine oil consumption for LSD during the Gardner engine testing, which however, is not obvious during the Cummins engine testing.

(h) The observations from the engine oil consumption and chemical analysis indicate some advantages of the LSD fuel over HSD, which is in line with the USEPA's claimed benefits on LSD.

1. Introduction

1.1 Background

Marine emissions have been increasing over the past decades and become the top emitter of sulphur dioxide (SO_2), respirable suspended particulates (RSP) and nitrogen oxides (NOx) emissions in Hong Kong. The Hong Kong SAR Government has studied ways to reduce the marine emissions. One approach is to improve the quality of locally supplied marine diesel to reduce emissions from ocean-going ships, river and local vessels. The Environmental Protection Department (EPD) of the HKSAR Government proposed to reduce the sulphur limit of marine light diesel from 0.5% to 0.05%, which would result in a corresponding reduction of SO_2 and RSP emissions of individual vessel by about 90% and 30% respectively. A Working Group (WG) was formed in May 2012 with members from government officials of various departments, local vessel operators' representatives and experts in academia (See Appendix I for its Terms of Reference and Membership). During the 1st and 2nd meetings, the WG members agreed to conduct engine test on two commonly in-use marine engines using the high sulphur diesel (HSD) (0.5% S max) and low sulphur diesel (LSD) (0.05% S max) fuel in order to confirm the compatibility of the LSD in existing vessel engines.

The Department of Mechanical Engineering at The University of Hong Kong was commissioned by the EPD in July 2012 to conduct a study on "Marine Engine Tests on Laboratory Setting" as a means to address the request of the WG members. The study will employ tailor-made laboratory setup for evaluating the performance of two marine type diesel engines under different simulated working conditions. Methodologies as described in the following had been presented in the 2nd WG meeting on 5 June 2012. In the 3rd WG meeting on 21 September 2012, members maintained the agreed methodology of testing durability and accepted to treat engine oil analysis as reference. Two site visits were arranged for WG members to get familiarized with the facilities and operations of the testing laboratory sites for Gardner and Cummins engines on 7 November 2012 and 23 January 2013 respectively.

An interim report[1] summarising the preliminary results obtained from testing the Gardner 6LXB engine was issued to EPD in January 2013. This final report includes all the results obtained from testing of both the Gardner 6LXB in the interim report and Cummins NTA855(M) engines. Its final version incorporates comment from WG members raised in the 4th WG meeting on 14 March 2013, i.e. including measurement ranges in the Conclusion.

1.2 Objectives

The objectives of the study are summarized as follows:

- To conduct tests for LSD (not more than 0.05% sulphur content by mass) to assess:

  (1) performance in terms of engine power output and fuel consumption for two in-use marine engines, i.e. Gardner 6LXB and Cummins NTA855(M) under controlled laboratory environment; and

  (2) durability of engines in terms of fuel lubricity and compatibility with engine; and

- To conduct the same tests for HSD, the locally supplied marine light diesel at nominal maximum sulphur content of 0.5% (5,000 ppm) by mass, as base case for comparison with LSD.

1.3 Structure of the Report

This report is organized into eight sections followed by eight Appendices including supplementary information related to the main report and sample log information.

Sections 1 and 2 give the background and scope of works of this project. Sections 3 and 4 explain the methodologies and describe the test rig components and instrumentation. Whilst many of the early sections apply both for Gardner and Cummins engines, Sections 5 and 6 provide the test results of Gardner and Cummins engine tests respectively. Section 7 analyses the uncertainties of the experiment and Section 8 concludes the results and observations of the whole test.

2. Scope of Works:

The scope of works of the present study includes the followings:

- Evaluation of performance characteristics of HSD and LSD fuels on two (2) in-service marine-type diesel engines

  Three (3) identical Performance Tests to be performed at regular interval per test fuel, namely, Baseline Test (Before Durability), After 200-hr Durability Test which consists of two tests: before and after engine oil replacement. An AC alternator was coupled onto the two marine engines for generating electricity. Output power of the engines can be altered by resistive load banks for determining the maximum power output under steady state conditions.

- Evaluation of fuel economy of HSD and LSD fuels on two (2) in-service marine-type diesel engines

  Fuel flow sensors to be installed onto the fuel line of the engine to determine the engine fuel consumption rate under various load conditions.

- Evaluation of durability study on wear/ tear effects of HSD and LSD fuels on two in-service marine-type diesel engines

  The wear/tear effects of the two engines to be evaluated and compared for HSD and LSD fuels. The engines would be running at 80 - 90% of the rated engine power for 200 hours. Microscopic examination of needle valves and nozzles of fuel injectors and moving parts of fuel pump, together with analysis of engine oil and major fuel composition would be conducted before and after the test intervals.

More details of the above scope of works can be found in Section 3 Methodology.

3. Methodology

3.1 Test Rig

- Two type of engines (i.e. Gardner and Cummins) were chosen by the WG as suitable surrogates for conservativeness to represent all in-use marine diesel engines:
  - Gardner 6LXB was selected to be representative engine of small power rating and old age (built on or before 1980), popular type as power generation and propulsion for fishing vessel;
  - Cummins NTA855A(M) was selected to be representative engine of large to medium power rating and medium age (built before 1990), normally used in tugs as propulsion and barges as goods handling.

- Each of the above test engines was coupled with an AC alternator for electricity generation.

- An AC alternator was proposed by HKU instead of dynamometer to conduct tests for practical reason as no dynamometer is readily available on loan for extended period of time. As the emission testing is not the purpose, dynamometer which allows adjusting engine speed is also not necessary. In fact, it will be easier to control a constant load using an AC alternator. The only consideration is to control the higher engine room temperature caused by the higher heat generated than actual in-use environment.

- A tailor-made test rig, consisting of a suitable mechanical coupling mechanism, was fabricated for connecting the test engines onto the AC alternator. The two test engines were reconditioned before the testing. The test rig was housed inside an acoustic enclosure to reduce its noise level and a water-cooled radiator was employed for cooling (see photos in Section 4).

- Commissioning test after engine installation was installed to ensure satisfactory running conditions for subsequent testing.

- Automatic recording instrument was used to monitor engine fuel consumption and power output during the Performance Tests. Engine operation parameters were available for tracking engine performances.

- Resistive load banks with selective step change settings were used for varying output power ratings of the engines. A customised load bank was prepared for providing +/- 2% step change at approximate 85% of the rated engine power demand.

3.2 Fuel Supply System

- The test fuels, namely HSD and Euro V diesel, were provided by EPDs fuel contractor Sinopec (Hong Kong) Petroleum Company Ltd. and temporarily stored in 200-litre drums at the test site. HSD was used without any blending while LSD was produced by blending 1 part HSD with 10 parts Euro V diesel by volume.

- Fuel supply and blending for Performance and Durability Tests were handled differently as discussed below.

- Performance Test: Fuel transfer pumps with flow meters were used for fuel blending and fuel consumption record was provided on regular basis to assure measurement accuracy. In-line fuel flow sensors in duplicate were installed at the inlet of the engine for determining the total volume of fuel delivered to the engine.

- Durability Test: The test fuels were transferred from the storage drums to a fuel tank with capacity 400 litres before delivering to the test engine.

- Fuel supplier's Certificate of Quality (CoQ) or equivalent (if available) containing physical and chemical characteristics of the transported HSD and Euro V diesel were provided by the fuel contractor, which can be used to compare with the fuel quality test results obtained by an independent qualified laboratory (i.e. SGS) appointed by EPD.

3.3 Performance Test

- Six (6) Performance Tests (3 LSD and 3 HSD) were carried out for each of the test engines. To reduce the experimental uncertainty, three Performance Tests were conducted for each engine and for each type of fuel, and the average of the three tests was compiled. The three tests are: 1) Before durability, as baseline; 2) After durability before engine oil replacement, indicating the combined effect due to engine wear and durability; 3) After durability and after engine oil replacement, indicating the effect due to durability.

- Both HSD and LSD fuels were used in each Performance Test. HSD was tested first as baseline while LSD test was conducted after the HSD test. HSD was tested first as this is the common fuel that the local trade is using for marine applications.

- Test sequence for each engine is summarised as follows:

i. Start with 15 minutes warm-up phase at various engine power outputs;

ii. Measure fuel consumption at marine medium continuous rating speed (rated engine speed) at 6 engine loadings, i.e. actual 100% (maximum) power output (which may be de-rated from the rated power output), 85%, 75%, 50% and 25% each for 15 min;

iii. Measure fuel consumption at sequential power output of 83% -> 85% -> 87% ->

85% -> 83% to mimic fluctuating load operations, with each step for 3 min;

iv. End with 15 min cool-down at idle speed;

v. Repeat the above steps ii and iii twice and adopt the average of the three measurements as the result.

- Engine oil (together with filters for engine oil, fuel and intake air) was changed at the beginning of the first Performance Test, end of durability and subsequent 2nd and 3rd Performance Tests for each engine-fuel combination. Engine oil of recommended types for the two engines suitable for use in HSD and LSD was adopted.

3.4 200-hour Durability Test

- 200-hour Durability Test was carried out after the Performance Test for each engine. The 200-hour was selected with reference to overseas experiences.

- Both HSD and LSD fuels were used and compared in each Durability Test. The test was conducted in sequence of Gardner-HSD, then Gardner-LSD, and Cummins-HSD then Cummins-LSD.

- The rated power output at marine continuous rating speed of the Gardner 6LXB engine is 94 kW and in the present study the selected running output power from the alternator was 68 kW. This selected figure was based on losses due to de-rate of aged engine (80% of the rated power) and power loss due to driveline components (about 10% of the rated engine power). The estimated engine output power is approximately 80% of the rated engine power.

- The rated power output at marine continuous rating speed of the Cummins NTA855(M) engine is 261 kW and in the present study the selected running output power from the alternator was 186 kW. This selected figure was based on losses due to de-rate of aged engine (80% of the rated power) and power loss due to driveline components (about 10% of the rated engine power). The estimated engine output power is approximately 80% of the rated engine power.

- Test sequence for each of the engines is summarised as follows:
    i. Start with 15 minute warm-up phase at idle speed;
    ii. Run at 80% of the rated power output at marine continuous rating speed (i.e. 68 kW for Gardner, and 186 kW for Cummins) continuously for 12 hours/ day;
    iii. End with 15 min cool-down phase at idle speed;
    iv. Repeat the above Steps i to iii until 200 hours of operation are accumulated;

- Scanning electronic microscope (SEM) and low power electronic microscopic (LPEM) examination for wear condition analysis of nozzles of fuel injectors and moving parts of fuel injector/ pump were carried out respectively, before and after the Durability Test for 2 engine-fuel combinations: Gardner-HSD (Cummins-HSD) then Gardner-LSD (Cummins-LSD), thus total 4 examinations for each of the test engines (see Section 3.5 for more details). Similarly, atomisation pattern and pressure leakage test of fuel injectors, and delivery quantity of fuel pump test were conducted on test bench to check compliance of manufacturer’s recommended operation limit for fuel injectors and pump before and after Durability Test.

- Engine oil samples were collected at three stages of the Durability Test. Their analysed results were used as reference for Gardner since make-up oil quantity was significant to render scientific analysis difficult. However, no make-up oil was necessary for Cummins. Details can be found in Section 3.6 below.

3.5 Fuel Diesel Analysis and Lubricity Evaluation

- Two (2) duplicate representative fuel samples (HSD & LSD) of suitable volume (~500 ml) were collected using glass bottles (which were thoroughly clean before sampling) (2 samples in total). The above sampling was carried out during the first and final Performance Tests. One set of the samples was delivered to a qualified laboratory (i.e. SGS Hong Kong Ltd.) for physical and chemical analysis including lubricity, thus assuring that they meet the expected HSD and LSD specifications as tabulated in Table 1 below. The duplicated sample served as a reserve in case there is any doubt or dispute on the test results, which may then be tested for confirmation.

Table 3.1. Test parameters of diesel fuel

Test Parameter	Test Method or Equivalent	HSD Spec.	LSD Spec.
Net Calorific Value	ASTMD240	NA	NA
Density (g/litre)	ASTMD4052	0.82-0.87	0.82-0.86
Sulphur (% wt.)	ASTMD4294	0.5% max.	0.05% max.
Cetane Index	ASTMD4737	48 min.	48 min.
Lubricity, Corrected Wear Scar Diameter (wsd1.4) at 60°C (um)	ENISO12156-1:2006 HFRR	NA	460 max.

- Microscopic examination (including both Scanning electronic microscope SEM and low power electronic microscope LPEM) and pressure bench test were conducted, which helped to identify the wear condition of the needle valves and nozzles of fuel injectors and moving parts of fuel pump before and after the Durability Test for 2 engine-fuel combinations: Gardner-HSD (or Cummins-HSD), Gardner-LSD (or Cummins-LSD). SEM can reveal the fine details of the metal surface including its composition and was used mainly on the fuel injector nozzles. A low power microscope serves to complement SEM and was used to obtain the surface roughness condition of the needle valves and pump plungers. The parts were delivered to

International Diesel Engineering Co. for bench testing for the operating pressure and re-conditioning. Surface images of the key components were recorded and compared with their brand new conditions.

3.6 Engine Oil Selection and Degrade Evaluation

- Monograde diesel engine oils Mobil Delvac 1340 (SAE Grade 40) was used for Gardner 6LXB engine, with typical properties in Table 3.2. Mobil Delvac 1330 or 1340 have been used by marine trade for Gardner 6LXB engines and the higher grade of 1340 was selected for conservative reason.

Table 3.2. Typical properties of Mobil Delvac 1340 engine oil

Test Parameter	Delvac 1340
Grade	SAE 40
Viscosity, ASTM D445	
cSt @ 40℃	146
cSt @ 100℃	14.1[#]
Viscosity Index, ASTM D2270	99
Sulfated Ash, wt%, ASTM D874	1.1
Total Base Number, ASTM D2896	10.1
Pour Point, ℃, ASTM D97	-21
Flash Point, ℃, ASTM D92	254
Density, kg/l @ 15℃, ASTM D4052	0.8875

[#] Viscosity based on product sheet is 14.6 but does not represent actual figure, which may vary with the base oil used in its manufacture. Certificate of Analysis of the product being delivered to HKU shows 14.1 instead.

- Diesel engine oils Mobil Delvac MX 15W-40 (SAE Grade 15W-40) was used for Cummins NTA855(M) engine, with typical properties in Table 3.3. Mobil Delvac MX 15W-40 has been commonly used by marine trade and is equivalent to Valvoline Premium Blue E recommended by Cummins.

Table 3.3. Typical properties of Mobil Delvac MX 15W-40 engine oil

Test Parameter	Delvac MX 15W-40
Grade	SAE 15W-40
Viscosity, ASTM D445	
cSt @ 40℃	105
cSt @ 100℃	15.5*
Viscosity Index, ASTM D2270	138
Sulfated Ash, wt%, ASTM D874	1.1
Total Base Number, ASTM D2896	10
Pour Point, ℃, ASTM D97	-33
Flash Point, ℃, ASTM D92	215
Density, kg/l @ 15℃, ASTM D4052	0.8685

* Viscosity based on product sheet is 14.2 but does not represent actual figure, which may vary with the base oil used in its manufacture. Certificate of Analysis of the product being delivered to HKU shows 15.5 instead.

- Three (3) duplicate representative engine oil samples of suitable volume (~200 ml) were collected using glass bottles (which were thoroughly clean before sampling) for two (2) combinations: Gardner-HSD (or Cummins-HSD), Gardner-LSD (or Cummins-LSD), at three stages of Durability Test (6 samples in total). One set of samples was delivered to a qualified laboratory (Signum Oil Analysis via Tat Petroleum) for physical and chemical analysis of quality as according to those parameters tabulated in Table 3.4 below. The three stages are: 1) after Performance Test but before commencement of durability ("0-hr"); 2) middle of durability ("100-hr"); and 3) completion of durability ("200-hr"). The duplicated sample serves as a reserve in case there is any doubt or dispute on the test results, which may then be tested for confirmation. Numerical comparisons and analysis of used engine oil conditions and the wear condition can be made from the results of the three groups of test parameters shown in Table 3.4. Subject to results availability, attempt will be made to quantify the cost benefits and cost implication due to different engine oil change frequency.

Table 3.4. Test parameters of engine oil

Test parameters	Test Method or Equivalent	Oil Contamination Guidelines
Viscosity@100℃ cSt	ASTM D445	+/- SAE viscosity grade or 5 cSt from the new oil
Total Base Number (TBN)	ASTM D2896	2.5 number minimum or half new oil value or equal to Total Acid Number
Spectra-Elements Analysis: ppm Al, Cr, Cu, Fe, Ni, Sn	ASTM D5185	Vary depending on wear metal and engine, refer to ExxonMobil's "Used Oil Interpretation Guidelines for Heavy Duty Diesel Engine Oils". June 2005 version.

- Certificates of Analysis or equivalent for physical and chemical characteristics of new engine oil were obtained from Tat Petroleum as reference to the quality test results provided by Signum Oil Analysis.

- Consumables (such as engine oil filters, fuel filters, air intake filters) were selected according to engine manufacturers' recommendations and if not available the commonly used one (by the trade) were adopted. New filter elements were used before the 1st and 3rd Performance Tests for both engines.

3.7 Monitoring and data collection

Data was monitored and recorded during the Performance and Durability Tests as follows:

- Performance Test

- Fuel consumption by the engine at various load demands was recorded by Oval M-III

Flow Sensors and DATAQ Counter Data Logger;

- Engine speed was determined by Deep Sea Electronics control module and magnetic pick-up sensor;
- Power output from the AC alternator/ Engine was recorded by Fluke Power Logger.

● Durability Test

- Engine speed, engine coolant temperature, engine oil pressure and alternator/ engine output power were monitored and recorded regularly in log sheet. The recorded information is used to reflect the engine running conditions to check if the engine is in good order during the Durability Tests
- Fuel pump components and fuel injector plungers were examined by low power microscope;
- Fuel nozzle surface and composition of residual (if any) were examined by Scanning Electron Microscope;
- Atomisation pattern, operating pressure and conditions of the fuel injector and fuel pump were tested by service test bench;
- Properties of HSD and LSD were analysed by qualified laboratory;
- Properties of engine oils at different stages were analysed by qualified laboratory.
- In addition, air intake and exhaust gas temperatures were recorded regularly to monitor combustion performance for Cummins engine. This is an extra item of the original methodology agreed by the WG in its 2nd meeting, requested by a WG member after the first site visit of Gardner engine testing.

4. Description of the Test Rig Components and Instrumentation

Test Engine - Gardner 6LXB (Photo 4.1)

Test period: 31-Aug-12 to 08-Nov-12

Specification

Rated power output	150 bhp @ 1,650 rpm
Marine continuous rating	127 bhp @ 1,500 rpm
Bore	120.6 mm
Stroke	152.4 mm
Capacity	10.45 litres
Aspiration	Natural
Configuration	6 cylinder in-line
Fuel consumption (Rated)	~ 25 l / hr @ 1,650 rpm
Fuel consumption (Continuous)	~ 23 l / hr @ 1,500 rpm

Photo 4.1. The Gardner 6LXB engine

Test Engine – Cummins NTA855-M (Photo 4.2)

Test period: 10-Dec-12 to 25-Jan-13

Specification

Rated power output	400 bhp @ 2,100 rpm
Marine continuous rating	350 bhp @ 1,800 rpm
Bore	140 mm
Stroke	152 mm
Capacity	14 litres
Aspiration	Turbocharged
Configuration	6 cylinder in-line
Fuel consumption (Rated)	~ 79.0 l / hr @ 2,100 rpm
Fuel consumption (Continuous)	~ 66.4 / hr @ 1,800 rpm

Photo 4.2. The Cummins engine

<u>Test Rig – Gardner engine</u>

A mild steel frame was employed for mounting the test engine and AC alternator (Photo 4.3). The frame was placed inside an acoustic enclosure (Dimension 6,100 (L) x 2,500 (W) x 2,500 (H) mm). Acoustic panels of thickness 100 mm (Sound Transmission Class not less than 40) were used to construct the acoustic enclosure to reduce the engine noise. The engine was cooled with a water pump (Photo 4.4) and the associated remote radiator (Photo 4.5). A PLC controller (Photo 4.6) was used for resistive load bank to control alternator power output.

Photo 4.3. The Gardner engine installed on the test rig

Photo 4.4. Water pump for engine cooling

Photo 4.5. Remote radiator

Photo 4.6. PLC controller for load bank

Test Rig – Cummins engine

A mild steel frame was employed for mounting the test engine and AC alternator. The frame was placed inside a 20-ft container (Photo 4.7 & 4.8). Same as Gardner engine, acoustic panels of thickness 100 mm (Sound Transmission Class not less than 40) were used to construct acoustic barriers to reduce the engine noise. The engine was cooled with a water pump and the associated remote radiator. A PLC controller (Photo 4.6) was used for resistive load bank to control alternator power output. Unique for Cummins engine, a water scrubber was used to remove air pollutants from the engine flue gas and air intake and exhaust gas temperatures were recorded regularly to monitor combustion performance. The latter was requested by a member of WG after the first site visit.

Photo 4.7. The Cummins engine installed on the test rig

Photo 4.8. The test rig was placed in a 20-feet container

Photo 4.9. The resistive load banks

Photo4.10. Remote radiator and water scrubber

AC Alternator

A Stamford D66-2158 AC alternator with capacity not less than 600A and mechanical coupler (Photo 4.11) was used. The mechanical coupler provides easy installation of the test engines and allows tolerance for alignment and vibration. The electricity output was controlled and protected by monitoring circuits (Photo 4.12).

Photo 4.11. AC alternator with mechanical coupler

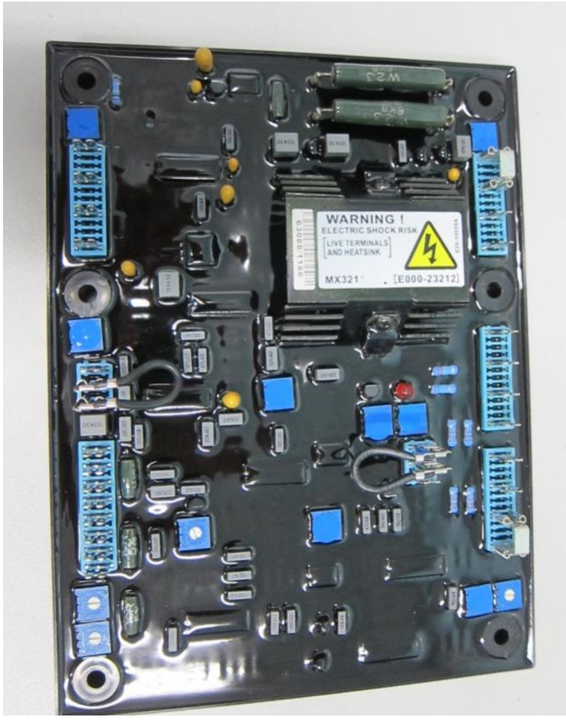


Photo 4.12. Automatic voltage regulator for alternator

Fuel Measurement

Oval M-III LSF45L0-R1 fuel flow sensor (Photo 4.13) was mounted onto the fuel line to determine the fuel flow rate while the flow record was stored in the DATAQ DI-160 counter data logger (Photo 4.13).

Photo 4.13. Fuel flow sensor with count data logger

Engine Speed Measurement

Engine speed was determined by a Deep Sea Electronic control module (Photo 4.14) with a magnetic pick-up sensor. The sensor was installed to record the number of revolution of the flywheel. The transient measurement result was displayed for accurate engine speed adjustment.

Photo 4.14. Deep Sea Electronics control module

Alternator Output Measurement

Resistive load banks (Photo 4.15) with various step load settings were used to provide output loads to the AC alternator. Customised Load Bank was used for small power adjustment. Fluke 1735 power logger (Photo 4.16) was used to record the output power, voltage and current from the AC alternator. The results could be used to estimate the output power from the test engines.

Photo 4.15. Resistive load bank

Photo 4.16. Power logger

Scanning Electron Microscope (SEM)

Hitachi S3400N VP 7060 SEM (Photo 4.17) was used to inspect fine details of the metal surface including its composition and was used mainly on the fuel injector nozzles.

Photo 4.17. SEM instrument

Low Power Electronic Microscope

An Olympus SZ (Photo 4.18) and Supereyes A005+ (Photo 19) low power microscope was used to obtain the surface roughness condition of the needle valves and pump plungers.

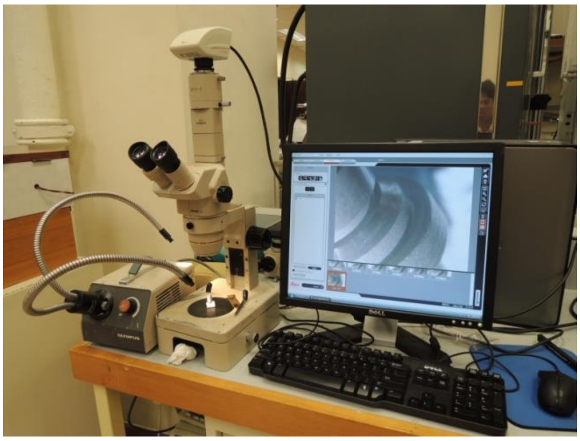


Photo 4.18. Olympus low power microscope

Photo 4.19. Supereyes low power microscope

Please refer to Appendix II for Equipment List and Appendix IV for Schematic Diagram of Instrument Setup.

5. Results and Discussions for Gardner Engine Test

5.1. Diesel Fuel Analysis

Certificates of Quality (CoQ) for HSD and Euro V diesel were obtained regularly from the fuel supplier Sinopec regularly. The properties of HSD and LSD per batch in terms of testing date are summarised in Tables 5.1 & 5.2 respectively, which matched with the specifications agreed in the 2nd WG meeting.

Table 5.1. Properties of HSD fuels

Test Parameter	Test Method or Equivalent	22-07-12	11-08-12	08-09-12
Density at 15 ˚C (kg/litre)	ASTMD4052	0.8446	0.8553	0.8540
Sulphur (% wt.)	ASTMD4294	0.370	0.416	0.419
Cetane Index	ASTMD4737	53.2	50.5	51.0
Lubricity, Corrected Wear Scar Diameter (wsd1.4) at 60°C (μm)	ENISO12156-1:2006 HFRR	N/A	N/A	N/A

Test Parameter	10-09-12
Density at 15 ˚C (kg/litre)	0.8540
Sulphur (% wt.)	0.431
Cetane Index	51.0
Lubricity, Corrected Wear Scar Diameter (wsd1.4) at 60°C (μm)	N/A

Table 5.2. Properties of Euro V diesel fuels

Test Parameter	Test Method or Equivalent	29-07-12	15-09-12	08-10-12
Density at 15 ˚C (kg/litre)	ASTMD4052	0.8241	0.8369	0.8226
Sulphur (ppm wt.)	ASTMD4294	9.0	5.2	2.5
Cetane Index	ASTMD4737	57.7	55.6	52.9
Lubricity, Corrected Wear Scar Diameter (wsd1.4) at 60°C (μm)	ENISO12156-1:2006 HFRR	<400	< 350	< 400

Test Parameter	17-10-12	30-10-12
Density at 15 °C (kg/litre)	0.8281	0.825
Sulphur (ppm wt.)	5.4	3.8
Cetane Index	56.1	54.0
Lubricity, Corrected Wear Scar Diameter (wsd1.4) at 60°C (μm)	< 350	< 400

Properties of HSD and Euro V diesel (EVD) fuels as shown in Tables 5.1 and 5.2 comply with the specifications of Sinopec and HKSAR respectively. Apart from the CoQ reports provided by the fuel supplier, physical properties of the two test fuels (HSD and LSD) were re-examined by an independent laboratory.

Test results of the two fuels obtained by SGS of the dated reports are summarised in Table 5.3 and 5.4 respectively. The results show that the LSD fuel properties comply with the proposed LSD specification for HKSAR. It can also be seen that there are only slight variation in the properties of the two fuels (HSD and LSD) for the two analyses conducted during the Performance Test. In particular, the percentage difference in NCV between LSD and HSD is -1.6% and 2.2% respectively for the two analyses.

Table 5.3. Test parameters of HSD fuel

Test Parameter	Test Method or Equivalent	Specification	27-08-12	27-11-12
Net Calorific Value (kJ/L)	ASTMD240	NA	36,197	36,315
Density (kg/litre)	ASTMD4052	0.82-0.87	0.8506	0.8565
Sulphur (% wt.)	ASTMD4294	0.5% max.	0.399	0.418
Cetane Index	ASTMD4737	48 min.	51.6	50.1
Lubricity, Corrected Wear Scar Diameter (wsd1.4) at 60°C (μm)	ENISO12156-1:2006 HFRR	NA	350	344

Table 5.4. Test parameters of LSD fuel

Test Parameter	Test Method or Equivalent	Specification	27-08-12	28-11-12
Net Calorific Value (kJ/L) (% NCV difference wrt HSD)	ASTMD240	NA	35,608 (-1.6%)	35,530 (-2.2%)
Density (kg/litre)	ASTMD4052	0.82-0.86	0.8281	0.8278
Sulphur (% wt.)	ASTMD4294	0.05% max.	0.0421	0.0411
Cetane Index	ASTMD4737	48 min.	56.8	53.5
Lubricity, Corrected Wear Scar Diameter (wsd1.4) at 60°C (μm)	ENISO12156-1:2006 HFRR	460 max.	322	358

Although only two laboratory tests on fuel properties were conducted, CoQ data obtained from the fuel supplier can justifiably represent fuel parameters relating to fuel combustion and consumption for the whole period. This is on the basis that the discrepancy between calculated and tested HSD and LSD fuels is small, as shown in Table 5.5.

Table 5.5. Discrepancy between calculated and tested HSD and LSD fuel

Test Parameters relating to fuel combustion and consumption	1st PT before HSD durability		2nd / 3rd PT after LSD durability	
	HSD	LSD	HSD	LSD
Net Calorific Value (kJ/L)	-0.4%	-0.2%	+0.1%	+0.2%
Density (kg/litre)	-0.7%	-0.3%	-0.3%	+0.0%
Cetane Index	+3.1%	+0.8%	+1.8%	+0.4%

5.2 Performance Test

(a) Maximum engine power

To determine the maximum power output of the engine, a lug down test was first conducted to obtain the engine load curve. The maximum engine power was obtained at the rated engine speed of 1650 rpm from the engine load curve. Table 5.6 shows the variation in maximum output power between the LSD and HSD fuels under the following four cases: before the HSD durability (baseline 1), after the HSD durability, before the LSD durability (baseline 2), and after the LSD durability. As can be seen, the percentage change in maximum power varies from +0.1% to -5% with an overall average -1.8%. The variations in the result may be due to the variation in the NCV for different batch of fuels provided for the testing and experimental uncertainty arose from day to day engine variations. Nevertheless, the average drop in maximum output power for LSD wrt HSD is 1.8% which matched with the decrease in NCV for the LSD wrt HSD (1.9%) as indicated in Table 5.7 below.

Table 5.6. Maximum power output test result – LSD Vs HSD

Max. power output	Baseline 1	After 200-hr (HSD Durability Test)	Baseline 2	After 200-hr (LSD Durability Test)	Overall average
HSD (kW)	106.2	116.3	115.3	117.7	113.9
LSD (kW)	104.9	115.0	109.5	117.8	111.8
% change LSD Vs HSD	-1.3%	-1.1%	-5.0%	+0.1%	-1.8%

Table 5.7. Comparison of Calorific value of HSD & LSD

	HSD	LSD	% change
Av. Calorific value (kJ/L)	36,256	35,569	-1.9%

(b) Specific fuel consumption

Specific fuel consumptions (SFC) at various engine loadings were determined, which are based on the measurement of the actual fuel consumption by the fuel sensor and the recorded energy output according to the following equation:

$$\textbf{Specific fuel consumption (litre/kWh)} = \frac{\text{fuel consumption rate (litre)}}{\text{energy output (kW/hr)}}$$

Sixth different engine loading conditions were tested, respectively 100%, 85%, 75%, 50%, 25% loading and a load cycle from 83% to 87%. Here 100% loading refers to 89 kW that was devised from the manufacturer’s rated engine power figure (i.e. 111.9 kW) minus the estimated power derate of in-service aged engine (i.e. 20% of the rated engine power).

The comparison of SFC between LSD and HSD under different loading conditions is shown in Table 5.8 for the following three cases: Baseline, after 200-hr HSD Durability Test without engine oil replacement, and after 200-hr HSD Durability Test with engine oil replacement. Table 5.9 shows the corresponding results for the 200-hr LSD durability. The original determined SFC data is enclosed in Appendix VII for reference. The data shows that SFC data obtained for both the HSD and LSD tests was rather normal and fell within the range provided in the engine manual.

It can be observed from the results that the variation in SFC with and without engine oil replacement are very similar in magnitude indicating that the engine oil replacement did not impose significant effect in SFC of the engine. As such the results with and without engine oil replacement were averaged for subsequent analysis. Table 5.8 shows that before (baseline) and after the HSD Durability Test, the average SFC for LSD varied from -0.1% to +1.0% with an overall average of +0.5% for all the loading conditions. At the same time Table 5.9 shows that before (2nd baseline) and after the LSD Durability Test, the SFC for LSD varied from +1.0% to +1.9% with an overall average of +1.7% for all the loading conditions. Comparing Table 5.8 with Table 5.9, there is a slight increase in the percentage increase of SFC for LSD is consistent with the larger reduction in NCV (2.2% compared to1.6%) for LSD as mentioned above (See Table 5.4).

Note that the above discussions of NCV and SFC refer to units based on volume since local marine trade used to adopt litre as basis for bunkering. If bunkering is by weight, the situation would be reversed. NCV (kJ/kg) of LSD would be slightly higher and SFC (g/kWh) of LSD would also be slightly less than the corresponding figures of HSD.

Table 5.8. Comparison of specific fuel consumption result before and after the HSD Durability Test – LSD Vs HSD

Engine loading condition	Baseline (1st)	After 200-hr	After 200-hr & engine oil replacement	Average
100% LSD Vs HSD	-1.3%	+0.7%	+1.4%	-0.1%
85% LSD Vs HSD	+0.1%	+0.6%	+0.9%	+0.4%
75% LSD Vs HSD	+1.2%	+0.6%	+1.1%	+1.0%
50% LSD Vs HSD	-0.3%	+1.9%	+1.2%	+0.6%
25% LSD Vs HSD	-1.0%	+2.0%	+1.2%	+0.3%
Load Cycle (83% to 87% load) LSD Vs HSD	+0.9%	+1.0%	+1.3%	+1.0%
			Overall average:	+0.5%

Table 5.9. Comparison of specific fuel consumption result before and after the LSD Durability Test – LSD Vs HSD

Engine loading condition	Baseline (2nd)	After 200-hr	After 200-hr & engine oil replacement	Average
100% LSD Vs HSD	+1.1%	+2.6%	+2.9%	+1.9%
85% LSD Vs HSD	+1.2%	+2.7%	+2.6%	+1.9%
75% LSD Vs HSD	+1.1%	+2.6%	+2.5%	+1.8%
50% LSD Vs HSD	+1.1%	+1.9%	+2.0%	+1.5%
25% LSD Vs HSD	+0.6%	+1.3%	+1.6%	+1.0%
Load Cycle (83% to 87% load) LSD Vs HSD	+0.8%	+2.7%	+3.0%	+1.8%

Overall average: +1.7%

5.3 Durability Test

(a) Basic operational data

Hourly engine operational data, including power output, coolant temperature, etc., were recorded to monitor the engine running conditions. The result showed that the test engine was running in normal conditions during the 200-hr Durability Test.

Basic operational data including engine oil consumption of the Durability Test was recorded and tabulated in Table 5.10. As mentioned in the 3rd WG meeting, large amount of engine oil was consumed during the Durability Test, particularly at the beginning of the HSD Durability Test. A difference of 10.5 litres was recorded between the HSD and LSD Durability Test. The large difference in engine oil consumption between HSD and LSD may be due to the following reasons:

(i) Larger amount of engine oil leakage and poorer control of engine oil addition at the beginning of the HSD Durability Test;

(ii) Engine run-in effect that consume more HSD;

(iii) Inherent feature of using LSD.

Regarding the above point (iii), some researchers explained that LSD would produce less sulphur dioxide than HSD during the combustion, which would transform to sulphuric acid. This would lead to less severe pitting and improved cylinder surface finish, hence lower engine oil consumption. However, we still need to ascertain this and check that such reduction was not due to the other two reasons stated above. It is therefore recommended to look more closely on the engine oil consumption of the Cummins engine in the subsequent test. Better control of engine oil addition has been conducted to avoid the above point (i) to occur. Due to different design of Cummins vs Gardner engine, the above point (ii) should no longer be applicable. The additional 10.5 litre engine oil consumption was roughly estimated to be 4.0 litre due to (i) and (ii) and 6.5 litre due to (iii) respectively.

Table 5.10. Basic information of the Durability Test

Test Parameter	HSD	LSD
Test period	2012/09/04 ~ 2012/09/24	2012/10/12 ~ 2012/11/03
Total running hours (Hour)	200	200
Constant power output maintained (kW)	68	68

Total engine oil re-filled (Litre)	33.5	23.0

i. Fuel injector test

Fuel injectors opening pressures were tested before and after the trial for each of the test fuels to check fuel injector opening pressure and fuel atomization patterns to ensure proper fuel delivery and injection during the whole Durability Test. If any injector atomization pattern were found unsatisfactory, this may indicate wear and tear of the injector nozzles, which in turn may be caused by inadequate fuel lubricity.

The fuel injector test results are tabulated in Tables 5.11 and 5.12 for HSD and LSD Durability Test respectively. The test aimed to indicate fuel injector condition in delivering and atomization of the fuel. According to Gardner's operation and maintenance instruction manual the minimum injector opening pressure should be about 1764 ~ 1778 psi. The results obtained indicated that the opening pressures of all the injector complied with this limit demonstrating that the fuel deliveries are normal during the two Durability Test. Atomization patterns injector spray conditions for all the six injectors were found satisfactory for both HSD and LSD. This is consistent with (1) the observation of pump plungers and injector nozzles by SEM and LPEM; and (2) measured results of fuel lubricity in Tables 5.3 and 5.4 being well below 460 μm.

Table 5.11. Fuel injector test (HSD Durability Test)

Injector #	Opening pressure complied with operation limit?	Nozzle atomization pattern
Injector 1	Yes	Normal
Injector 2	Yes	Normal
Injector 3	Yes	Normal
Injector 4	Yes	Normal
Injector 5	Yes	Normal

Injector 6	Yes	Normal

Table 5.12. Fuel injector test (LSD Durability Test)

Injector #	Opening pressure complied with operation limit?	Nozzle atomization pattern
Injector 1	Yes	Normal
Injector 2	Yes	Normal
Injector 3	Yes	Normal
Injector 4	Yes	Normal
Injector 5	Yes	Normal
Injector 6	Yes	Normal

ii. Fuel injection pump test

Fuel injection pump was tested before and after the trial for HSD durability and LSD Durability Tests. The testing reports were attached in Appendix VII. The test on maximum fuel setting and fuel delivery quantities of injection pump per 200 strokes @600 rpm were measured by standard test equipment, and was manually observed and recorded. All the results were found to fall within ± 0.2 c.c., considered to be within the sensitivity range of the combined test equipment uncertainty and human error. Thus, there is no significant difference before and after both the HSD and LSD Durability Tests. This is consistent with (1) the observation of pump plungers and injector nozzles by SEM and LPEM (see results in section 5.5); and (2) measured results of fuel lubricity in Tables 5.3 and 5.4 being well below 460 um.

5.4. Engine Oil Analysis

Engine oil samples were also taken at 0, 100 and 200 hours of the Durability Test for chemical analyses. "0-hr" represents condition of the engine oil in the engine before start of the Durability Test. Engine oil analysis was carried out by Signum. The results of the engine oil analysis at 0, 100 and 200 hours are shown in Tables 5.13 and 5.14 for HSD and LSD Durability Tests respectively, complete reports can be found in Appendix VII. The following points were observed from the results:

(a) Viscosity

As can be seen, there is an increase in viscosity over the 200 hours' Durability Test and the increase is 5.0% and 3.5% for HSD and LSD respectively. Increase for HSD over LSD would have been more than 1.5% if no make-up oil was introduced.

(b) TBN

There is a rather big reduction in TBN over the 200 hours' test period for the HSD (15%) but only a minor reduction of 1% for the LSD. A plausible explanation is that additive replenishment (i.e. topping off the oil) is replacing sufficient additive to offset the amount consumed by much lower quantity of sulphuric acid generated from the LSD than the HSD combustion. Nevertheless, both TBN values at 200-hr for HSD and LSD are still within normal range. According to the engine oil manufacturer, engine oil need to be changed when the TBN values drops below half of the original values. Thus, the lower TBN depletion rate for LSD may potentially benefit the engine operation by possible reduction of engine oil changing frequency. Such benefit would become even more if no make-up oil was introduced. However, whether this reduction can be achievable or not still depends on the viscosity depletion rate of the engine oil which may happen after 200-hour. One may argue that the trend of viscosity from the 200-hr had been favourable to LSD, further supporting LSD benefit. In any case, no conclusive statement can be drawn at this point.

(c) Elemental analysis

There was a general increase in metal concentrations in the engine oil over the 200-hr testing due to engine wear. As can be seen from Tables 5.13 and 5.14, incremental metal concentrations due to wear for HSD and LSD were more or less similar except higher iron for LSD. It should be noted that engine oil had been replenished continually during the Durability Test that changed continually the engine oil properties. Therefore, the behaviour of the engine oils observed can only be considered as indicative. It is also noted that there were some metals detected in the engine oil sample at 0-hr of the HSD Durability Test, which may be due to the residual metals left after the 1st engine oil replacement before the Durability Test. Although incremental values are taken for the analysis, it is still recommended to have more adequate flushing during the engine oil replenishment in the subsequent Cummins test to reduce the amount of residual metals left in the engine oil.

Table 5.13. Typical properties of Mobil Delvac 1340 engine oils (HSD Durability Test)

Test Parameter	Spec.	0-hr	100-hr	200-hr	Change (200hr -0hr)
Viscosity, cSt @ 100℃	14.1	14.0	14.2	14.7	+0.7
Total Base Number (mg KOH/g)	10.1	9.2	8.0	7.8	-1.4
Wear Elements (ppm): Ag, Mo, Ni, Sn which have less than 4 ppm are not shown					
Al	0	3	5	5	+2
Cr	0	7	18	22	+15
Cu	0	5	9	9	+4
Fe	0	18	19	19	+1
Pb	0	2	4	5	+3

Table 5.14. Typical properties of Mobil Delvac 1340 engine oils (LSD Durability Test)

Test Parameter	Spec.	0-hr	100-hr	200-hr	Change (200hr -0hr)
Viscosity, cSt @ 100℃	14.1#	14.1	14.3	14.6	+0.5
Total Base Number (mg KOH/g)	10.1	8.8	8.3	8.7	-0.1
Wear Elements (ppm): Ag, Mo, Ni, Sn which have less than 4 ppm are not shown					

Al	0	1	3	4	+3
Cr	0	2	13	18	+16
Cu	0	1	3	5	+4
Fe	0	4	11	16	+12
Pb	0	1	2	3	+2

5.5. Scanning Electronic Microscope Examination

In order to investigate whether there is wear and tear problem caused by fuel flow, all components of fuel injectors and pump set of the Gardner engine that may be subject to wear and tear due to fuel lubricity were purchased new and examined. These components include injector nozzles, hollow piston valves, pump plungers and delivery valves. They were first examined before Durability Test as baseline; and re-examined by dismantling from the engine and pump after the two Durability Tests.

Fuel injector assembly and fuel pump element section of Gardner's delivery system are shown in Figures 5.1 and 5.2 respectively.

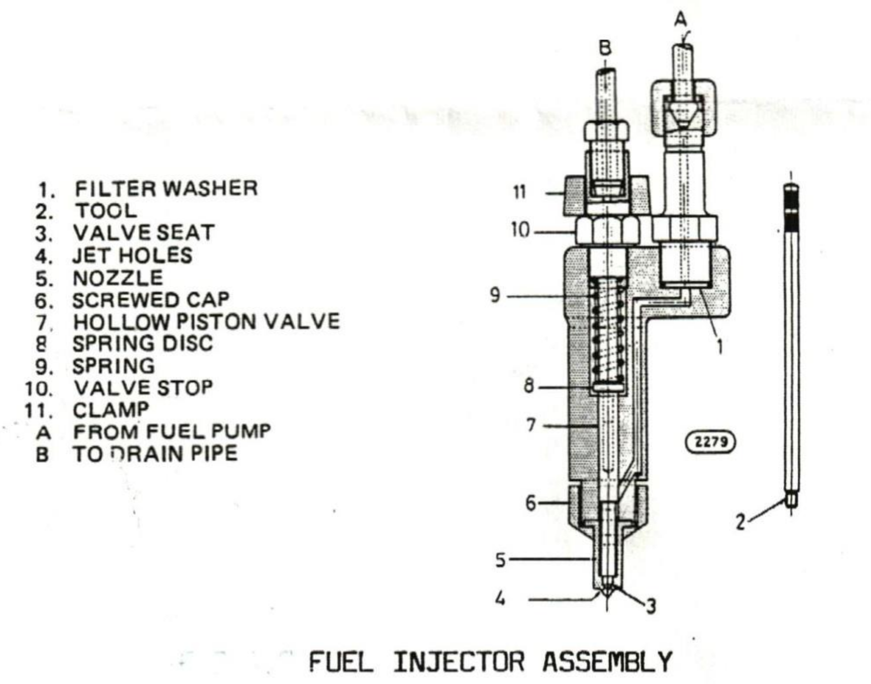


Figure 5.1. Fuel injector assembly of Gardner's delivery system.

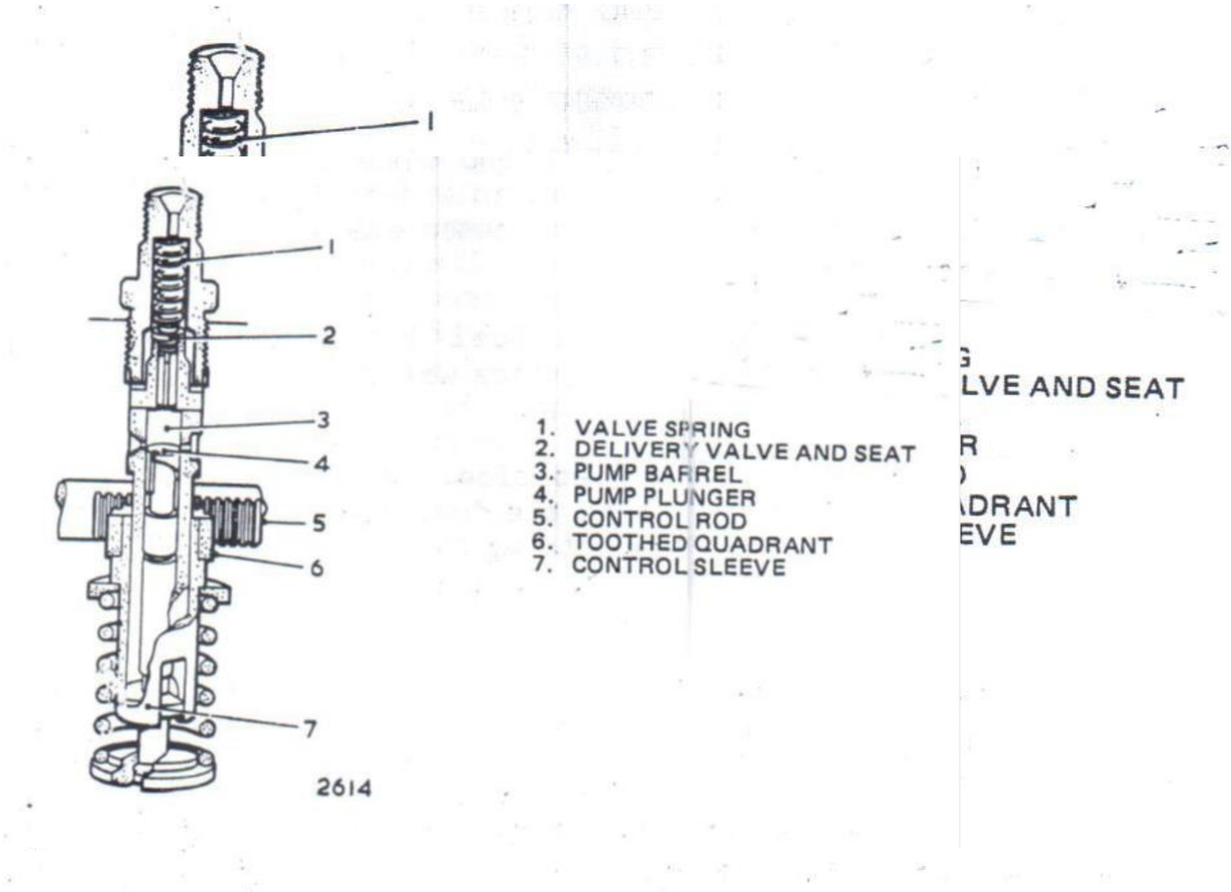


Figure 5.2. Fuel pump element section of Gardner delivery system

The injector nozzles were examined by Hitachi S3400N VP SEM instrument and some typical sample photo images of LSD are provided in Photos 5.1 to 5.5. Complete set of photos taken can be obtained from the website: www.hktscl.com.hk/Temp/Microscope.rar. As can be observed from these photos, the shapes and sizes of the nozzles remain the same after the 200-hr Durability Tests for both HSD and LSD cases. Some deposits were found inside the nozzles of both HSD and LSD, which was identified to be mainly carbon and oxygen (Photo 5.5). This may come from the unburned fuel deposited on some extruded element inside the nozzles. In general, based on the SEM observations, no abnormal finding and discrepancy could be identified for both the HSD and LSD cases.

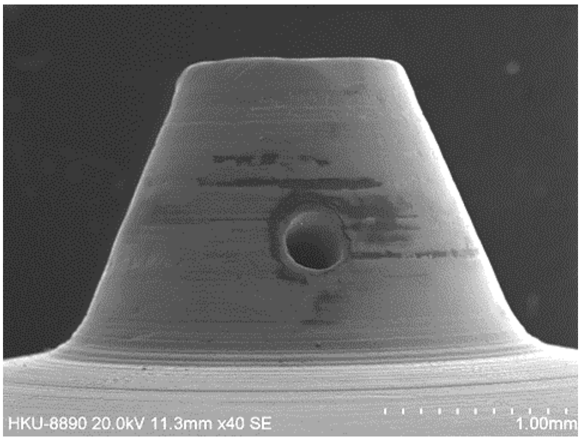


Photo 5.1. Image of nozzle injection hole (Before LSD trial)

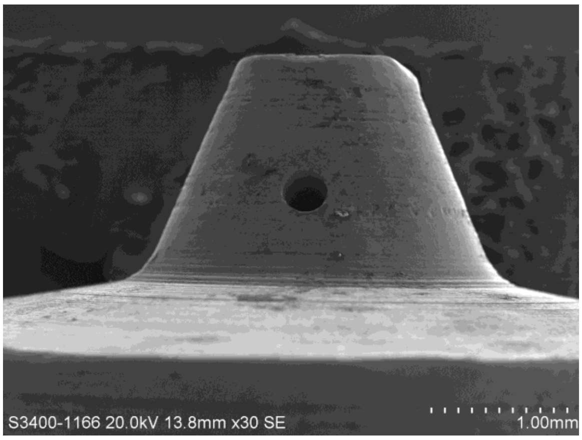


Photo 5.2. Image of nozzle injection hole (After LSD trial)

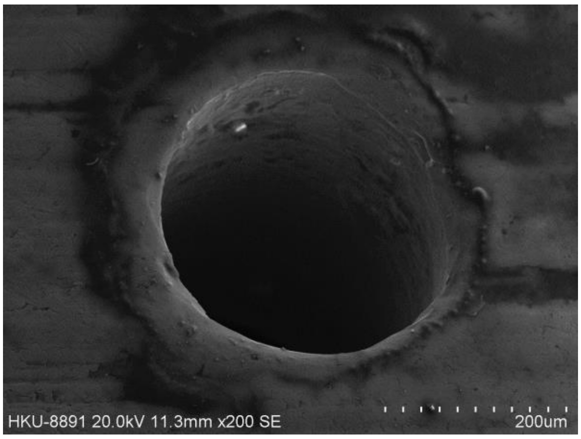


Photo 5.3. Zoom up view of the injection hole (Before LSD trial)

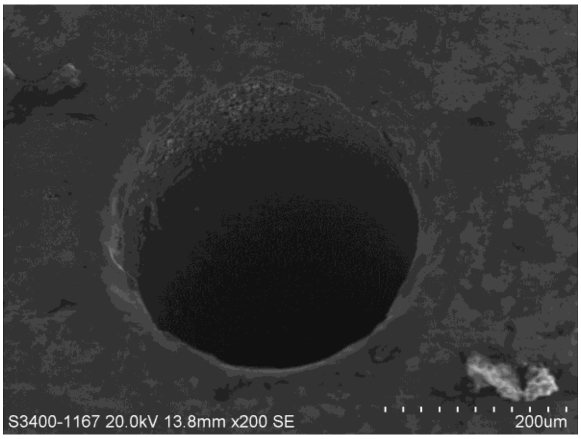
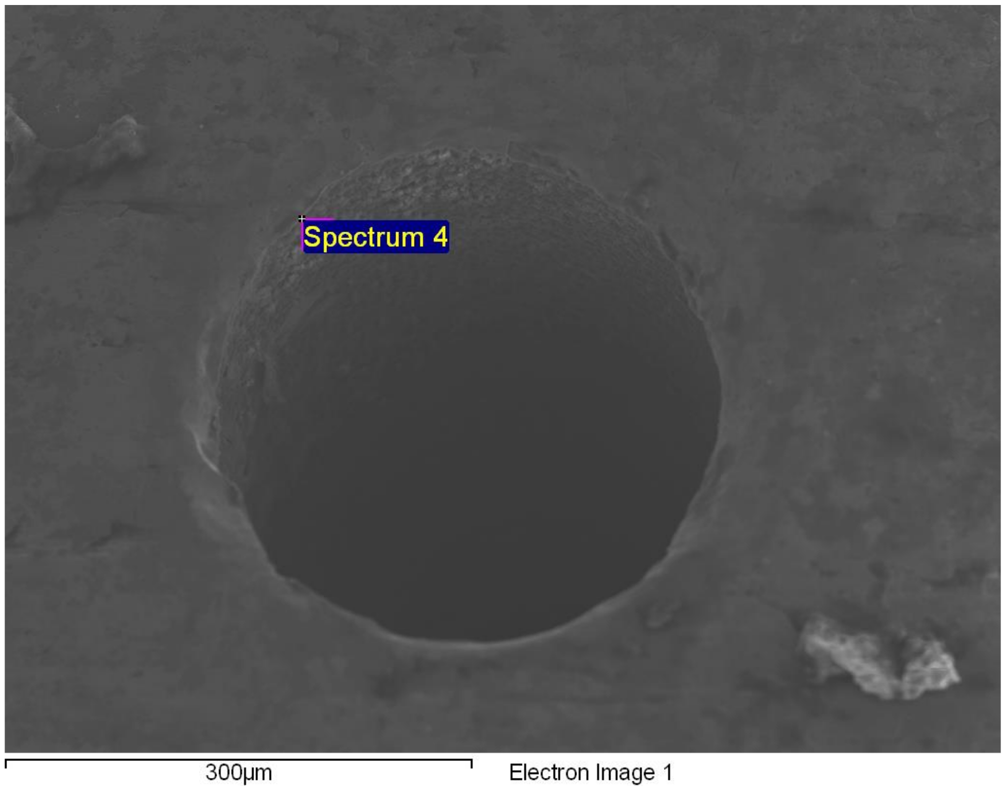


Photo 5.4. Zoom up view of the injection hole (After LSD trial)



Element	App Conc.	Intensity Corrn.	Weight%	Weight% Sigma	Atomic%
C	35.38	0.8338	44.82	1.31	59.33
O	22.32	0.6811	34.60	1.27	34.39
Na	0.47	0.6201	0.80	0.26	0.56
S	0.40	0.9292	0.46	0.12	0.23
Fe	15.27	0.8349	19.32	0.71	5.50

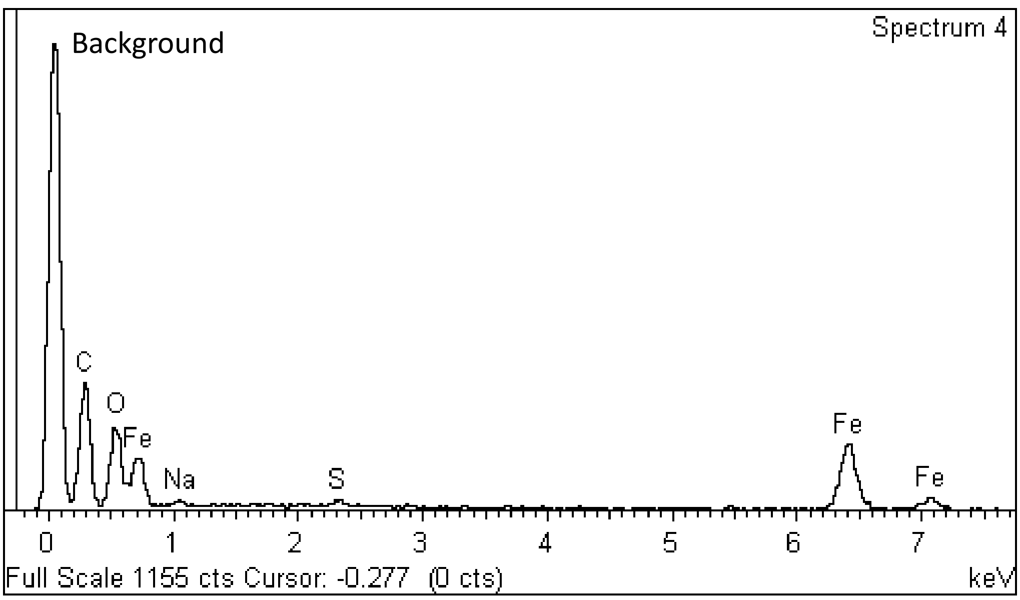


Photo 5.5. Elemental analysis of substances in an injector's nozzle hole after 200-hr Durability Test

5.6. Low Power Electronic Microscope Examination

The tear and wear characteristics of the pump plungers and fuel injector plungers were also investigated by the low power electronic microscope (LPEM). The surface finishes of the plungers were compared for both the HSD and LSD cases. Typical photos were shown in Photos 5.6 to 5.11 for the hollow piston valves of fuel injector assembly, pump plungers and fuel pump delivery of fuel pump element section of the HSD while Photos 5.12 to 5.17 show the same components for the LSD case. Complete set of photos for fuel injector assembly and fuel pump element section of Gardner delivery system can be obtained from the website: www.hktscl.com.hk/Temp/Microscope.rar. As can be seen from these photos, the surface finishes of the examined component did not exhibit any significant changes before and after the Durability Test for both HSD and LSD. The LPEM investigation indicated that there are no significant differences in the tear and wear characteristics for both the HSD and LSD cases.

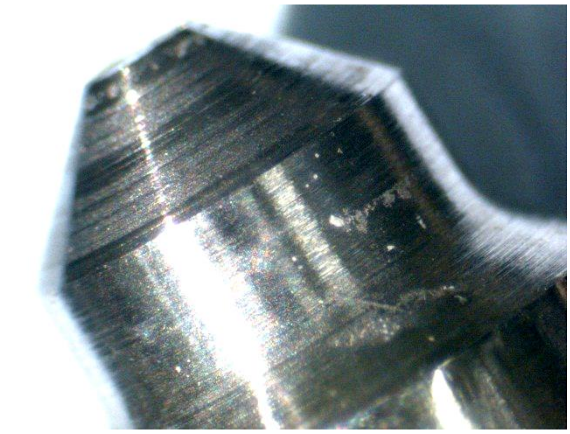


Photo 5.6. Zoom up view of the hollow piston valve (Before HSD trial)

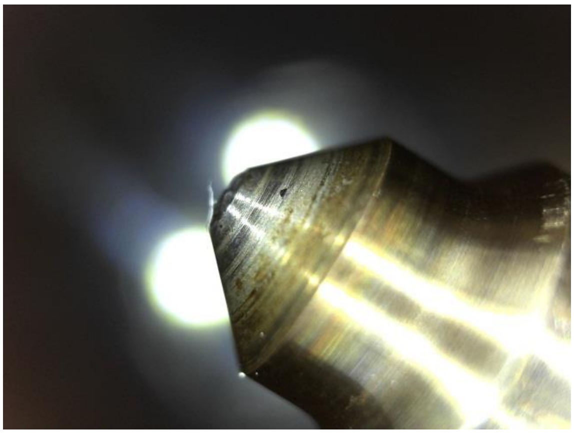


Photo 5.7. Zoom up view of the hollow piston valve (After HSD trial)

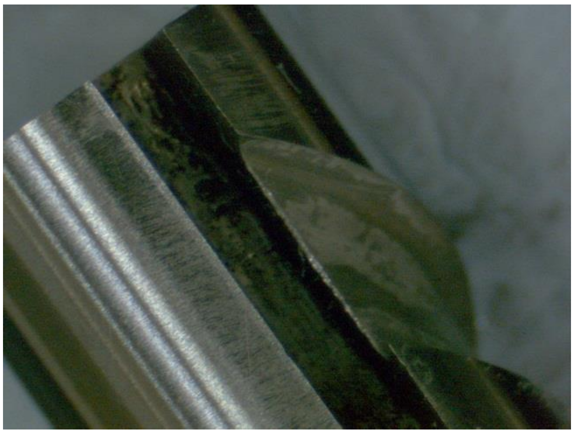


Photo 5.8. Zoom up view of the fuel pump plunger (Before HSD trial)

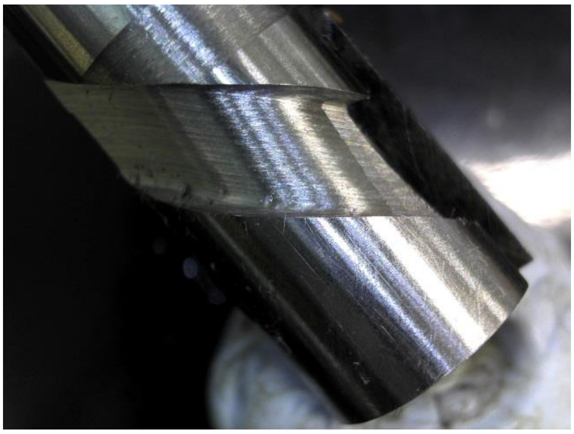


Photo 5.9. Zoom up view of the fuel pump plunger (After HSD trial)

Photo 5.10. Zoom up view of the fuel pump delivery (Before HSD trial)

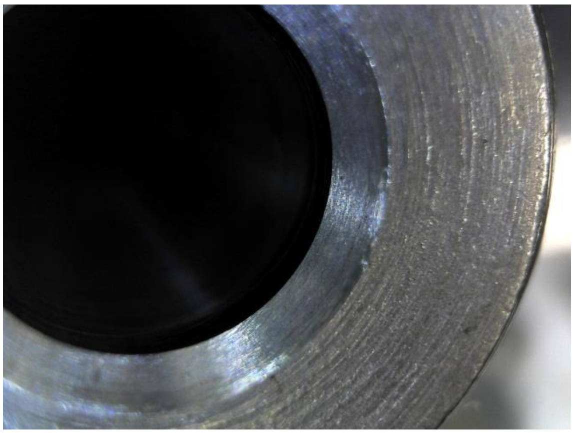


Photo 5.11. Zoom up view of the fuel pump delivery (After HSD trial)

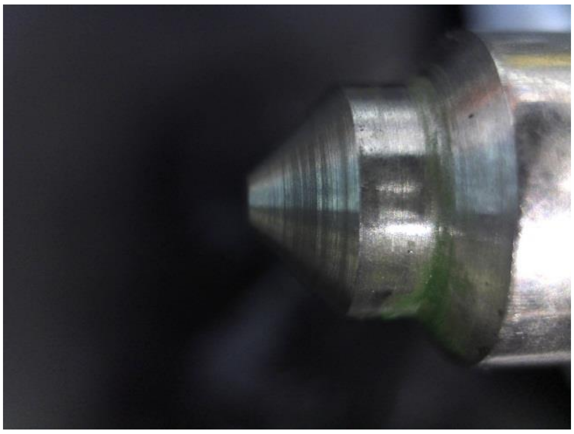


Photo 5.12. Zoom up view of the hollow piston valve (Before LSD trial)

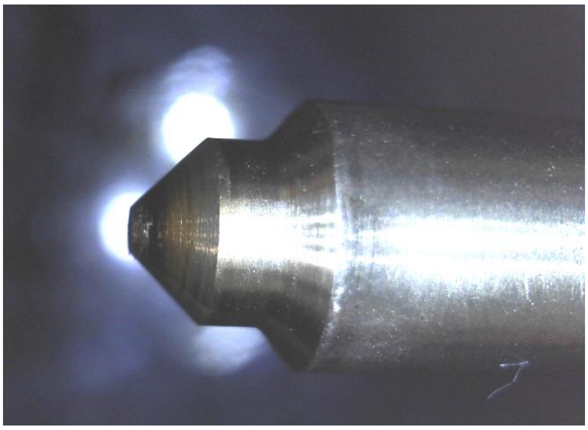


Photo 5.13. Zoom up view of the hollow piston valve (After LSD trial)

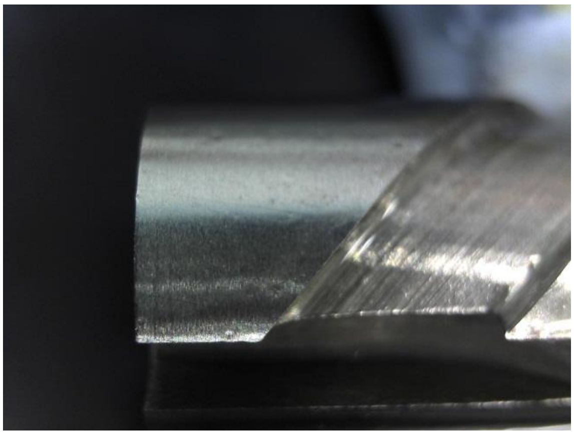


Photo 5.14. Zoom up view of the fuel pump plunger (Before LSD trial)

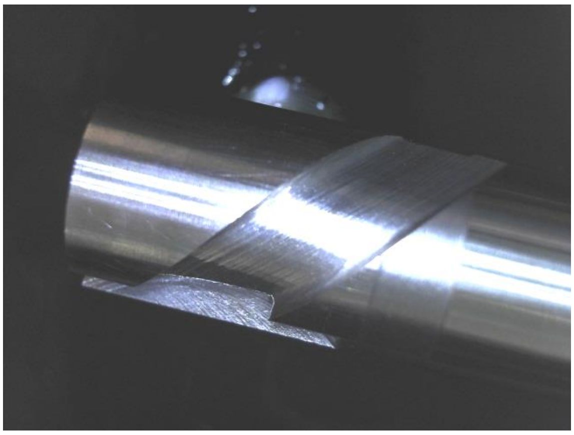


Photo 5.15. Zoom up view of the fuel pump plunger (After LSD trial)

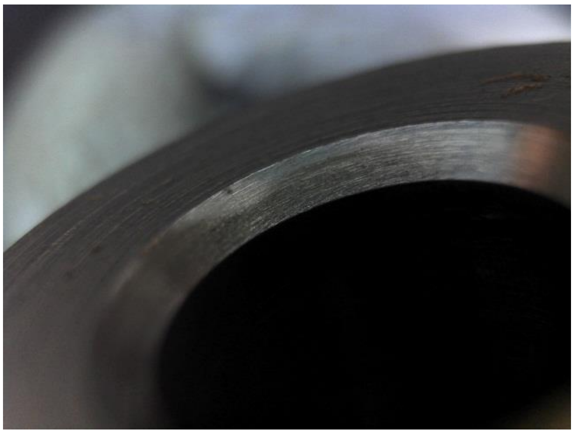


Photo 5.16. Zoom up view of the fuel pump delivery (Before LSD trial)

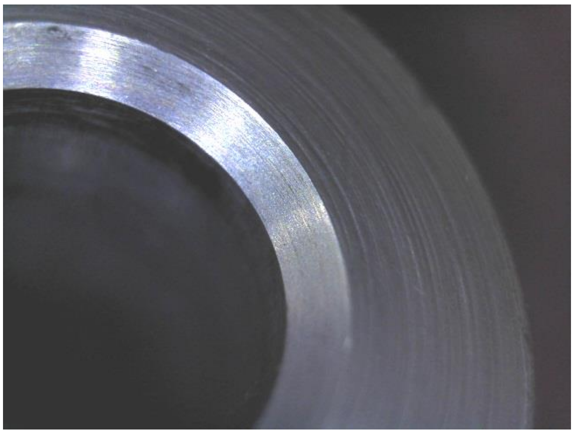


Photo 5.17. Zoom up view of the fuel pump delivery (After LSD trial)

6. Results and Discussions for Cummins Engine Test

6.1. Diesel Fuel Analysis

The properties of HSD and LSD per batch in terms of testing date are summarised in Tables 6.1 & 6.2 respectively, which showed that the amount of sulphur in HSD varied from 0.057 to 0.455%, some of which were much lower than the specifications agreed. This is due to fuel batch issue and should be considered as uncontrollable parameter. In any case, as indicated later the fuel sulphur content of HSD is always about ten times higher than that of LSD (blended by mixing HSD and Euro V diesel in volume ratio 1:10) for the Performance Test. Nevertheless, properties of HSD and Euro V diesel (EVD) fuels as shown in Tables 6.1 and 6.2 comply with the specifications of Sinopec and HKSAR respectively.

Table 6.1. Properties of HSD fuels

Test Parameter	Test Method or Equivalent	9-11-12	6-12-12	11-12-12
Density at 15 °C (kg/litre)	ASTMD4052	0.8563	0.8497	0.8515
Sulphur (% wt.)	ASTMD4294	0.455	0.298	0.196
Cetane Index	ASTMD4737	50.8	52.8	52.2
Lubricity, Corrected Wear Scar Diameter (wsd1.4) at 60°C (μm)	ENISO12156-1:2006 HFRR	N/A	N/A	N/A

Test Parameter	17-12-12	19-12-12	9-1-13
Density at 15 °C (kg/litre)	0.8477	0.8540	0.8540
Sulphur (% wt.)	0.057	0.116	0.238
Cetane Index	52.3	50.4	48.4
Lubricity, Corrected Wear Scar Diameter (wsd1.4) at 60°C (μm)	N/A	N/A	N/A

Table 6.2. Properties of Euro V diesel fuels

Test Parameter	Test Method or Equivalent	30-10-12	13-11-12	25-12-12

Density at 15 ˚C (kg/litre)	ASTMD4052	0.8250	0.8255	0.8361
Sulphur (ppm wt.)	ASTMD4294	3.8	7.5	7.7
Cetane Index	ASTMD4737	54.0	55.8	54.4
Lubricity, Corrected Wear Scar Diameter (wsd1.4) at 60°C (μm)	ENISO12156-1:2006 HFRR	<400	<350	<420

Test Parameter	31-12-12	15-1-13
Density at 15 ˚C (kg/litre)	0.8253	0.8266
Sulphur (ppm wt.)	4.2	7.5
Cetane Index	54.9	54.2
Lubricity, Corrected Wear Scar Diameter (wsd1.4) at 60°C (μm)	<420	<460

The two test fuels (HSD and LSD) were examined by an independent laboratory (SGS) and the results in Table 6.3 and 6.4 of the dated reports showed that the LSD fuel properties comply with the proposed LSD specification for HKSAR. The percentage difference in NCV between LSD and HSD are -1.5% and -2.2% for the two batches of samples with an average of -1.8%.

Table 6.3. Test parameters of HSD fuel

Test Parameter	Test Method or Equivalent	Specification	24-12-12	6-2-13
Net Calorific Value (kJ/L)	ASTMD240	NA	36,325	36,485
Density (kg/litre)	ASTMD4052	0.82-0.87	0.8543	0.8569
Sulphur (% wt.)	ASTMD4294	0.5% max.	0.455	0.170
Cetane Index	ASTMD4737	48 min.	49.7	50.5
Lubricity, Corrected Wear Scar Diameter (wsd1.4) at 60°C (μm)	ENISO12156-1:2006 HFRR	NA	369	349

Table 6.4. Test parameters of LSD fuel

Test Parameter	Test Method or Equivalent	Specification	24-12-12	6-2-13
Net Calorific Value (kJ/L) (% NCV difference wrt HSD)	ASTMD240	NA	35,790 (-1.5%)	35,685 (-2.2%)
Density (kg/litre)	ASTMD4052	0.82-0.86	0.8320	0.8274
Sulphur (% wt.)	ASTMD4294	0.05% max.	0.0434	0.0165
Cetane Index	ASTMD4737	48 min.	55.7	54.3
Lubricity, Corrected Wear Scar Diameter (wsd1.4) at 60°C (μm)	ENISO12156-1:2006 HFRR	460 max.	384	349

As discussed in 5.1 and illustrated in table 5.5, CoQ data obtained from the fuel supplier can justifiably represent fuel parameters especially for period between the above SGS tests.

6.2. Performance Test

(a) Maximum engine power

The lug down test result in Table 6.5 showed a small percentage change in maximum power, which varies from +0.7% to -0.1% with an overall average of +0.4%. The average NCV for different batch of fuels is tabulated in Table 6.6 which shows that the overall change in NCV of LSD wrt HSD is -1.8%. The result indicates a small increase in maximum power for LSD despite a small reduction in NCV of the LSD fuel.

Table 6.5. Maximum power output test result – LSD Vs HSD

Max. power output	Baseline 1	After 200-hr (HSD Durability Test)	Baseline 2	After 200-hr (HSD Durability Test)	Overall average
HSD (kW)	300.7	301.2	290.2	292.6	296.4
LSD (kW)	302.7	303.0	289.9	293.2	297.5
% change LSD Vs HSD	+0.7%	+0.6%	-0.1%	+0.2%	+0.4%

Table 6.6. Comparison of Calorific value of HSD & LSD

	HSD	LSD	% change
Av. Calorific value (kJ/L)	36,405	35,738	-1.8%

(b) Specific fuel consumption (SFC)

Sixth different engine loading conditions were tested, respectively 100%, 85%, 75%, 50%, 25% loading and a load cycle from 83% to 87%. Here 100% loading refers to 196 kW that was devised from the manufacturer's rated engine power figure (i.e. 261 kW @ 1,800 RPM) minus the estimated power de-rate of in-service aged engine (i.e. 20% of the rated engine power) and power losses from the driveline system (i.e. 10% of the engine power). The comparison of SFC between LSD and HSD under different loading conditions is shown in Table 6.7 for the following three cases: Baseline, after 200-hr HSD Durability Test without engine oil replacement, and after 200-hr HSD Durability Test with engine oil replacement. Table 6.8 shows the corresponding results for the 200-hr LSD durability. The original determined SFC data is enclosed in Appendix VII for reference. The data shows that SFC data obtained for both the HSD and LSD tests was rather normal and fell within the range provided in the engine manual.

It can be observed from the results that, similar to the case of Gardner engine, the variation in SFC with and without engine oil replacement are very similar in magnitude indicating that the engine oil replacement did not impose significant effect in SFC of the engine. As such the results with and without engine oil replacement were averaged for subsequent analysis. Table 6.7 shows that before (baseline) and after the HSD Durability Test, the average SFC for LSD varied from +1.0% to +1.6% with an overall average of +1.3% for all the loading conditions. At the same time Table 6.8 shows that before (2nd baseline) and after the LSD Durability Test, the SFC for LSD varied from +1.3% to +1.6% with an overall average of +1.4% for all the loading conditions. Comparing Table 6.7 with Table

6.8, there is a slight increase (+1.3% to 1.4%) in SFC for LSD which is consistent with the reduced NCV (-1.8%, LSD Vs HSD) as mentioned above (See Table 6.6).

Note that the above discussions of NCV and SFC refer to units based on volume since local marine trade used to adopt litre as basis for bunkering. If bunkering is by weight, the situation would be reversed. NCV (kJ/kg) of LSD would be slightly higher and SFC (g/kWh) of LSD would also be slightly less than the corresponding figures of HSD.

Table 6.7. Comparison of specific fuel consumption result before and after the HSD Durability Test – LSD Vs HSD

Engine loading condition	Baseline (1st)	After 200-hr	After 200-hr & engine oil replacement	Average
100% LSD Vs HSD	+1.0%	+1.2%	+0.8%	+1.0%
85% LSD Vs HSD	+1.6%	+1.5%	+1.6%	+1.6%
75% LSD Vs HSD	+1.6%	+1.4%	+1.5%	+1.5%
50% LSD Vs HSD	+1.2%	+1.3%	+1.3%	+1.3%
25% LSD Vs HSD	+1.4%	+1.3%	+1.1%	+1.3%
Load Cycle (83% to 87% load) LSD Vs HSD	+1.4%	+1.5%	+1.2%	+1.3%

Overall average: +1.3%

Table 6.8. Comparison of specific fuel consumption result before and after the LSD Durability Test – LSD Vs HSD

Engine loading condition	Baseline (2nd)	After 200-hr	After 200-hr & engine oil replacement	Average
100% LSD Vs HSD	+1.4	+1.7	+1.7	+1.5
85% LSD Vs HSD	+1.2	+2.0	+1.9	+1.6
75% LSD Vs HSD	+0.8	+2.1	+1.9	+1.4
50% LSD Vs HSD	+1.0	+2.1	+1.9	+1.5
25% LSD Vs HSD	+0.9	+1.6	+1.9	+1.4
Load Cycle (83% to 87% load) LSD Vs HSD	+1.2	+1.4	+1.5	+1.3

Overall average: +1.4%

6.3. Durability Test

(a) Basic operational data

Hourly engine operational data, including power output, coolant temperature, air intake temperature, exhaust gas temperature etc., were recorded to monitor the engine running conditions. The result showed that the test engine was running in normal conditions during the 200-hr Durability Test. Operational data of the Durability Test was recorded and tabulated in Table 6.9. The Cummins engine completed both the 200-hr Durability Tests without the need of replenishing engine oil. Note that this observation is not the same as the Gardner engine (see Table 5.10). Based on the engine oil meter markings, engine oil consumption was slightly larger for HSD than LSD though both cases did not require oil replenishment.

Table 6.9. Basic information of the Durability Test

Test Parameter	HSD	LSD
Test period	2012/12/12 ~ 2012/12/25	2013/01/08 ~ 2013/01/23
Total running hours (Hour)	200	200
Constant power output maintained (kW)	186	186

The Cummins engine was encountered an engine failure on 19-Jan-2013 after 163-hr of operation with LSD as the test fuel. The fuel metering pump was found inoperative and a joint inspection with all relevant parties was conducted on 21-Jan-2013. The metering pump was dismantled and found that all the 3 plungers in the metering pump were jammed by a layer of wax like substance on surface, which was suspected to be due to the fuel quality issue. The wax like substance should come from the impurities of the fuel but it could be removed easily by thinner. Visual examination on the surface of jammed plungers showed no sign of wear/ tear that would be expected if it were caused by inadequate fuel lubricity properties. After the plungers had been cleaned, the pump was re-calibrated then installed onto the Cummins engine. The on-site test confirmed that the repaired pump was working properly without any significant change in engine output power and fuel consumption. The Durability Test was resumed around 4:00 pm on 21-Jan-2013. Some similar incidents were heard from other engine operations using the fuel of the same supplier.

Since no major parts were repaired/ replaced after the inspection (except rubber seals and overhaul gasket) and the bench test results showed that the metering pump was working properly without significant performance shift after the incident and at the end of the Durability Test (after the remaining 37-hr of high power operation and 2 sets Performance Test). The SEM and LPEM examination results revealed that there was no abnormal wear/ damage/ appearance change in metal surface (see Section 6.6).

Based on the afore-mentioned findings, it can be concluded that the incident did not cause any damage to the major components in the metering pump or fuel system and the incident may be considered as an isolated case.

(b) Fuel injector test

The fuel injector test results are tabulated in Tables 6.10 and 6.11 for HSD and LSD Durability Test respectively. The test aimed to indicate fuel injector condition in delivering and atomization of the fuel. The results obtained indicated that the amount of fuel injection of all the injectors complied with their operation limit demonstrating that the fuel deliveries are normal during the two Durability Tests. Atomization patterns injector spray conditions for all the six injectors were found satisfactory for both HSD and LSD. This is consistent with (1) the observation of pump plungers and injector nozzles by SEM and LPEM; and (2) measured results of fuel lubricity in Tables 6.3 and 6.4 being well below 460 μm.

Table 6.10. Fuel injector test (HSD Durability Test)

Injector #	Opening pressure complied with operation limit?	Nozzle atomization pattern
Injector 1	Yes	Normal
Injector 2	Yes	Normal
Injector 3	Yes	Normal
Injector 4	Yes	Normal
Injector 5	Yes	Normal
Injector 6	Yes	Normal

Table 6.11. Fuel injector test (LSD Durability Test)

Injector #	Opening pressure complied with operation limit?	Nozzle atomization pattern
Injector 1	Yes	Normal
Injector 2	Yes	Normal
Injector 3	Yes	Normal
Injector 4	Yes	Normal
Injector 5	Yes	Normal
Injector 6	Yes	Normal

(c) Fuel metering pump check

Fuel injection pump was tested before and after the trial for HSD durability and LSD Durability Tests. The testing reports were attached in Appendix VII. The test on fuel delivery quantities and pressure settings were measured by a standard test equipment, and was manually observed and recorded. All the results were found to fall within ± 3% considered to be within the sensitivity range of the combined test equipment uncertainty and human error. Thus, there is no significant difference before and after both the HSD and LSD Durability Tests. This is consistent with (1) the observation of pump plungers and injector nozzles by SEM and LPEM; and (2) measured results of fuel lubricity in Tables 6.3 and 6.4 being well below 460 um.

6.4. Engine Oil Analysis

The results of the engine oil analysis at 0, 100 and 200 hours are shown in Tables 6.12 and 6.13 for HSD and LSD Durability Tests respectively, complete reports can be found in Appendix VII. The following points were observed from the results:

(a) Viscosity

As can be seen, there is an increase in viscosity over the 200 hours' Durability Test and the increase is +2.7% and +1.3% for HSD and LSD respectively. In other words, LSD rate of viscosity increase is about half that of HSD.

(b) TBN

There is a fairly reduction in TBN over the 200 hours' test period for the HSD (7.1%) but a minor increase of 1.8% for the LSD. Both TBN values at 200-hr for HSD and LSD are still within normal range. According to the engine oil manufacturer, engine oil need to be changed when the TBN values drops below half of the original values. Thus, the non-existent TBN depletion rate for LSD may potentially benefit the engine operation by possible reduction of engine oil changing frequency. However, whether this reduction can be achievable or not still depends on the viscosity depletion rate of the engine oil which may happen after 200-hour. From the observed trend of viscosity during the 200-hour, results had been favourable to LSD and further support LSD benefit. In any case, no conclusive statement can be drawn at this point of 200-hour operation.

(c) Elemental analysis

There was a general increase in metal concentrations in the engine oil over the 200-hr testing due to engine wear. As can be seen from Tables 6.12 and 6.13, incremental metal concentrations due to wear for HSD and LSD were more or less similar except higher iron for HSD. It is also noted that there were some metals detected in the engine oil sample at

0-hr of the HSD Durability Test, which may be due to the residual metals left after the 1st engine oil replacement before the Durability Test.

(d) Comparison with results for Gardner engine

When compared with Tables 5.13/ 5.14 of engine oil analysis for Gardner engine, Tables 6.12/ 6.13 for Cummins engine showed comparatively better quality even after 200 hours: less increase in viscosity, less depletion of TBN and less wear elements except iron. This can be explained by the fact that diesel of lower sulphur content produce less sulphur dioxide/ sulphuric acid as explained in section 5.3. Based on the diesel analysis in sections 5.1 and 6.1, weighted average sulphur content of HSD/ LSD over the 200 hours (when engine oil analysis were measured) were as follow:

Gardner-HSD: 0.41% (normal as the nominal sulphur limit is 0.5%)

Gardner-LSD: 0.04%

Cummins-HSD: 0.17% (exceptionally low caused by lower sulphur batches in Dec 2012)

Cummins-LSD: 0.01%

Table 6.12. Typical properties of Mobil Delvac MX 15W40 engine oils (HSD Durability Test)

Test Parameter	Spec.	0-hr	100-hr	200-hr	Change (200hr -0hr)
Viscosity, cSt @ 100℃	15.5	14.9	14.7	15.3	+0.4
Total Base Number (mg KOH/g)	10	11.2	10.7	10.4	-0.8
Wear Elements (ppm): Ag, Al, Cr, Ni, Sn which have less than 2 ppm are not shown					
Cu	0	1	3	5	+4
Fe	0	3	17	27	+24
Mo	0	35	39	38	+3
Pb	0	0	0	2	+2

Table 6.13. Typical properties of Mobil Delvac MX 15W40 engine oils (LSD Durability Test)

Test Parameter	Spec.	0-hr	100-hr	200-hr	Change (200hr -0hr)
Viscosity, cSt @ 100℃	15.5	15.0	14.8	15.2	+0.2
Total Base Number (mg KOH/g)	10	11.4	11.5	11.6	+0.2
Wear Elements (ppm): Ag, Al, Cr, Ni, Sn which have less than 2 ppm are not shown					
Cu	0	0	1	2	+2
Fe	0	2	12	18	+16
Mo	0	35	38	37	+2
Pb	0	0	0	1	+1

6.5. Scanning Electronic Microscope Examination

The components under SEM examination include fuel injector nozzles, injection plungers and metering pump plungers, which were first examined before Durability Test as baseline; and re-examined by dismantling from the engine and pump after the two Durability Tests.

Fuel injector assembly and fuel metering pump element section of the Cummins's delivery system are shown in Figures 6.1 and 6.2 respectively.

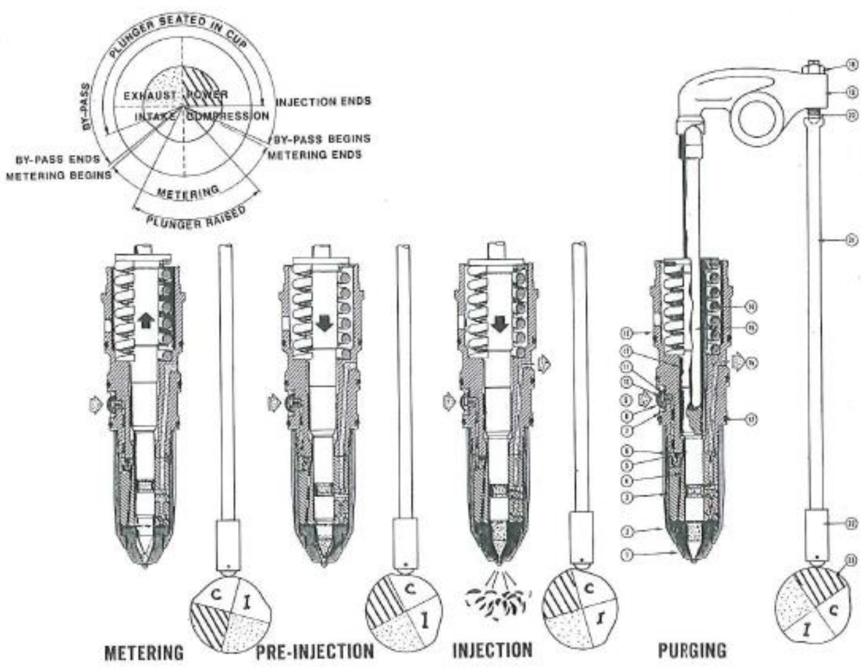


Figure 9-8
Sequence of Events in Injecting Fuel.
(Courtesy of Cummins Engine Co.)

Index:

1—Cup	9—Fuel in	17—O ring
2—Cup retainer	10—Orifice	18—Nut
3—Barrel	11—Orifice gasket	19—Rocker lever
4—Plunger	12—Coupling	20—Adjusting screw
5—Check ball	13—Adapter	21—Push rod
6—Gasket	14—Spring	22—Tappet
7—Clip	15—Link	23—Camshaft lobe
8—Screen	16—Fuel out	

Figure 6.1. Fuel injector assembly of Cummins delivery system

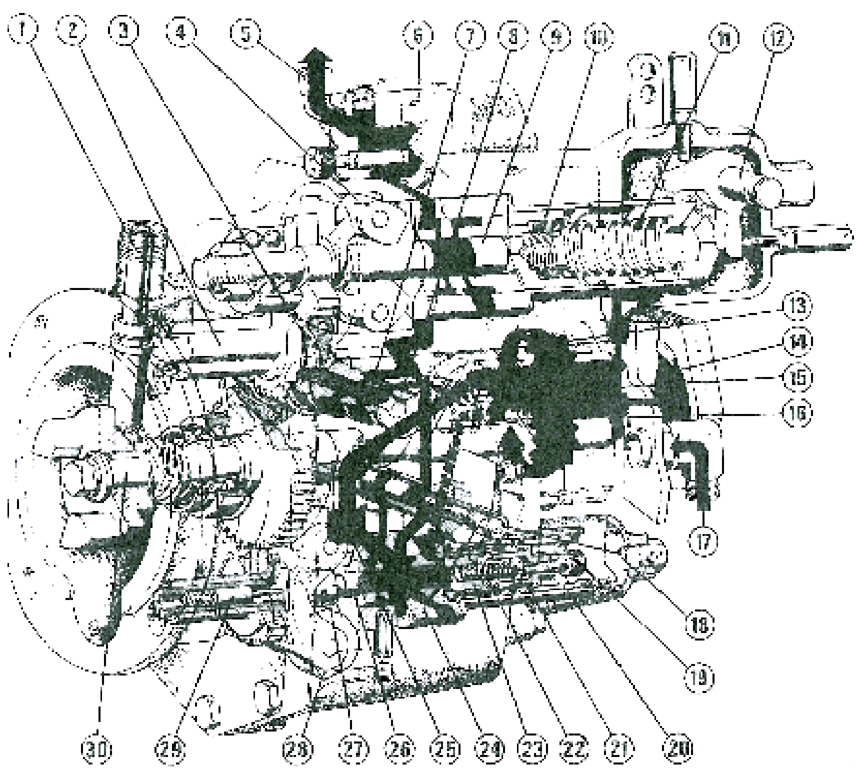


Figure 9-26
PT (Type G) Variable Speed AFC Fuel Pump and
Fuel Flow.
(Courtesy of Cummins Engine Co.)

Index:
1—Tachometer shaft
2—Idler gear and shaft
3—AFC piston
4—VS governor weights
5—Fuel to injectors
6—Shut-down valve
7—AFC control plunger
8—AFC fuel barrel
9—VS governor plunger
10—VS idle spring
11—VS high-speed spring
12—VS throttle shaft
13—Gear pump
14—Pulsation damper
15—AFC needle valve
16—Pressure regulator valve
17—Fuel from filter
18—Throttle shaft
19—Idle adjusting screw
20—Spring spacer
21—High-speed spring
22—Idle spring
23—Idle spring p unger
24—Fuel adjusting screw
25—Filter screen
26—Governor plunger
27—Torque spring
28—Governor we ghts
29—Governor assist plunger
30—Main shaft

Figure 6.2. Fuel metering pump element section of Cummins delivery system

The injector nozzles were examined by Hitachi S3400N VP SEM instrument and some typical sample photo images of HSD are provided in Photos 6.1 to 6.5. Complete set of photos taken can be obtained from the website: www.hktscl.com.hk/Temp/Microscope.rar. As can be observed from these photos, the shapes and sizes of the nozzles remain the same after the 200-hr durability tests for both HSD and LSD cases. Some deposits were found inside the nozzles of both HSD and LSD, which was identified to be mainly carbon and oxygen (Photo 6.5). This may come from the unburned fuel deposited on some extruded element inside the nozzles. In general, based on the SEM observations, no abnormal finding and discrepancy could be identified for both the HSD and LSD cases.

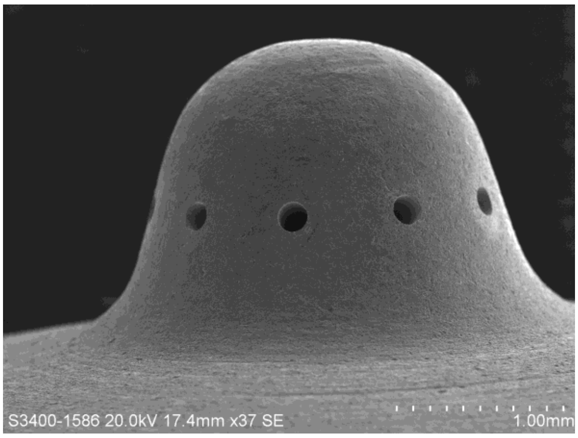


Photo 6.1. Image of nozzle injection hole (Before HSD trial)

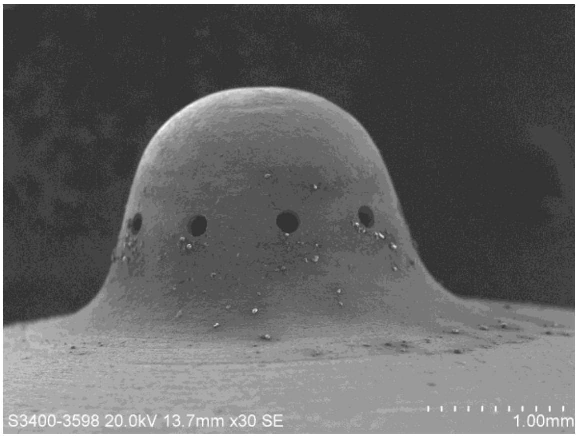


Photo 6.2. Image of nozzle injection hole (After HSD trial)

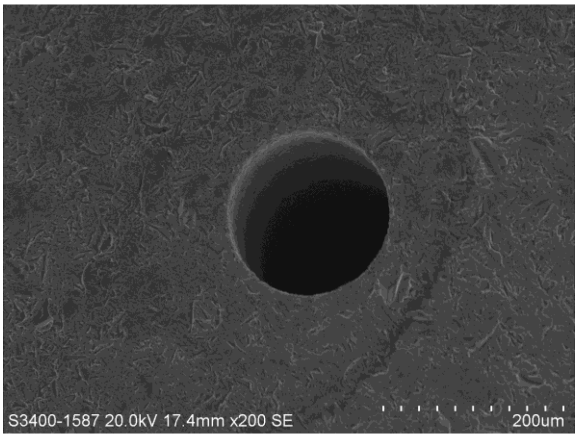


Photo 6.3. Zoom up view of the injection hole (Before HSD trial)

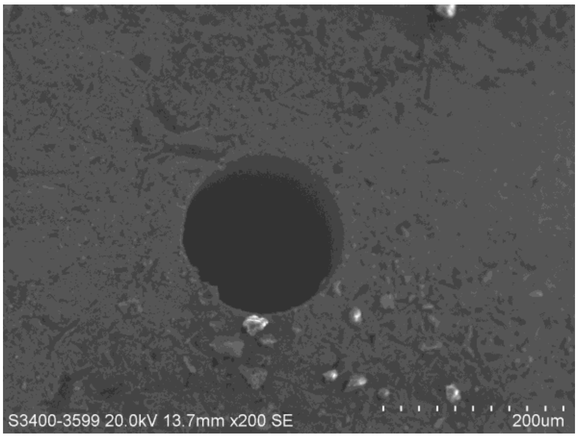
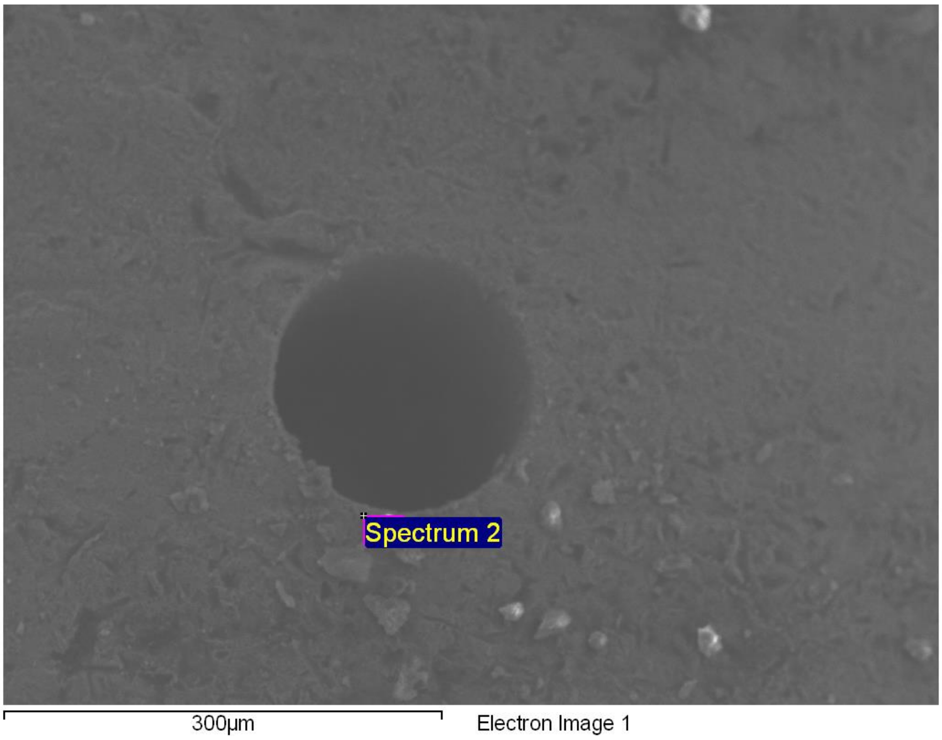


Photo 6.4. Zoom up view of the injection hole (After HSD trial)



Element	App Conc.	Intensity Corrn.	Weight%	Weight% Sigma	Atomic%
C	34.94	0.7023	41.17	1.12	58.30
O	26.73	0.7160	30.87	0.96	32.82
S	1.80	0.9248	1.61	0.14	0.85
Fe	27.05	0.8491	26.35	0.70	8.03

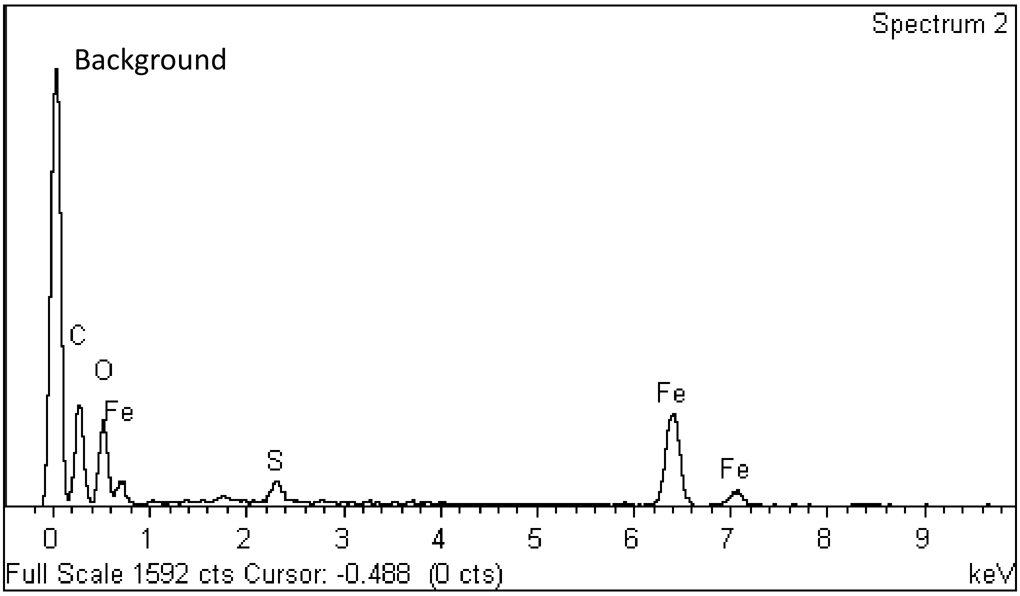


Photo 6.5. Elemental analysis of substances in an injector's nozzle hole after 200-hr HSD durability test

6.6. Low Power Electronic Microscope Examination

The surface finishes of the metering pump plungers and fuel injector plungers were compared for both the HSD and LSD cases. Typical photos were shown in Photos 6.6 to 6.11 for the fuel injector plungers and metering pump plungers of the HSD while Photos 6.12to 6.17 showing the same components for the LSD case. Complete set of photos for fuel injector assembly and fuel pump element section of Gardner delivery system can be obtained from the website: www.hktscl.com.hk/Temp/Microscope.rar. The LPEM examination showed that the surface finishes of the examined component did not exhibit any significant changes before and after the Durability Test for both HSD and LSD. The LPEM investigation indicated that there are no significant differences in the tear and wear characteristics for both the HSD and LSD cases.

Photo 6.6. Zoom up view of the fuel injector plunger (Before HSD trial)

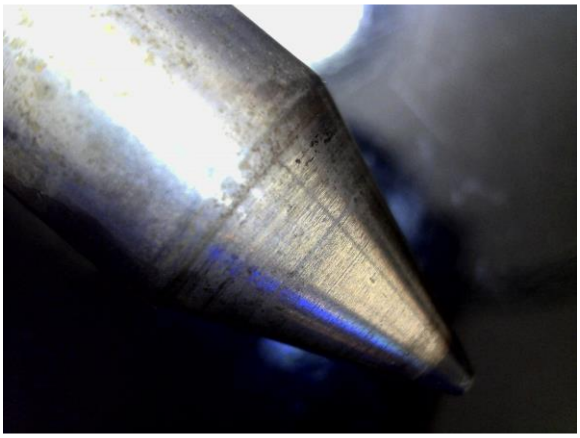


Photo 6.7. Zoom up view of the fuel Injector plunger (After HSD trial)

Photo 6.8. Zoom up view of the fuel injector plunger (Before HSD trial)

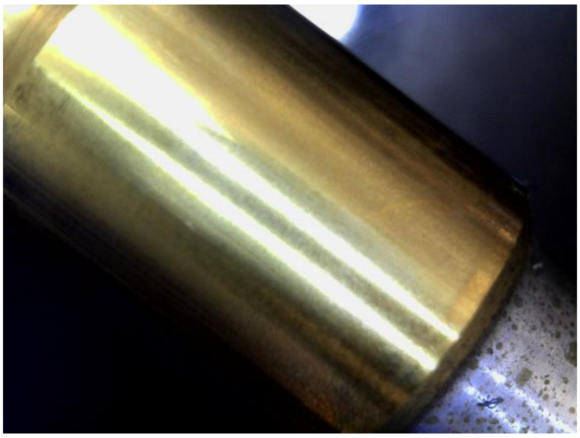


Photo 6.9. Zoom up view of the fuel injector plunger (After HSD trial)

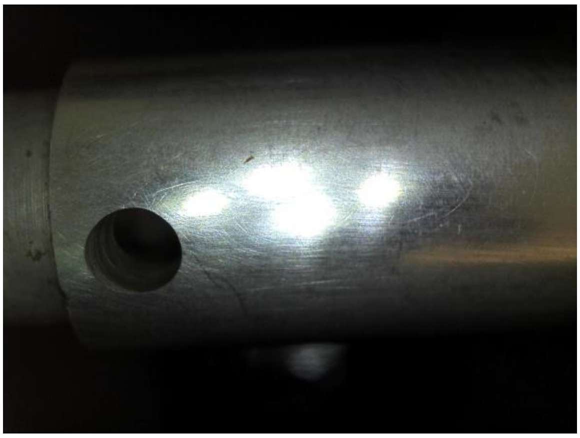


Photo 6.10. Zoom up view of the fuel metering pump plunger (Before HSD trial)

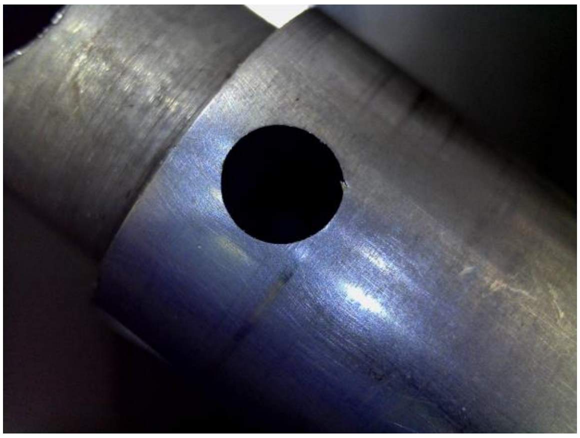


Photo 6.11. Zoom up view of the fuel metering pump plunger (After HSD trial)

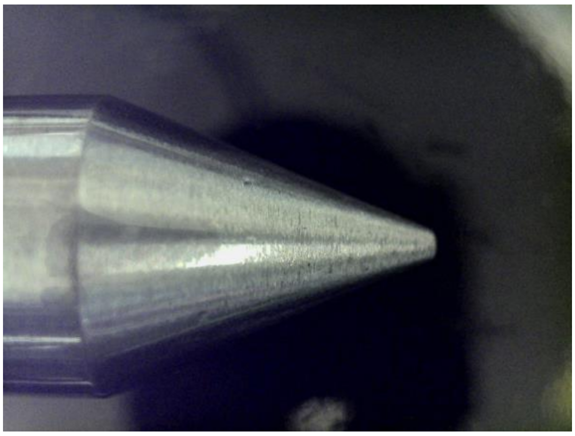


Photo 6.12. Zoom up view of the fuel injector plunger (Before LSD trial)

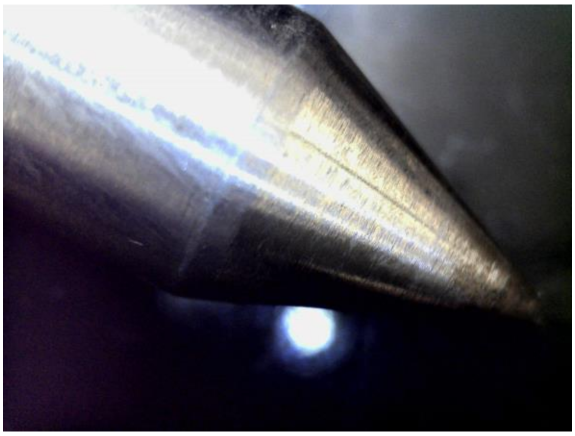


Photo 6.13. Zoom up view of the fuel injector plunger (After LSD trial)

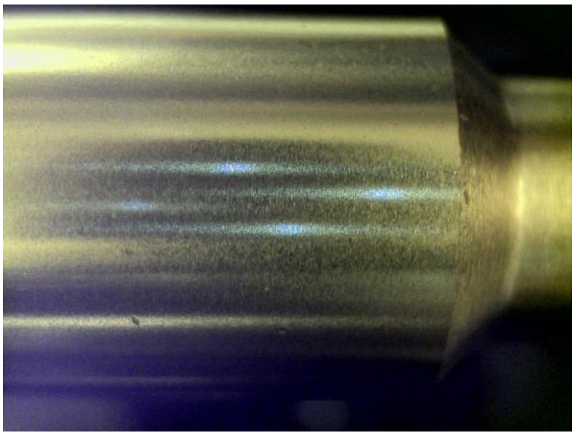


Photo 6.14. Zoom up view of the fuel injector plunger (Before LSD trial)

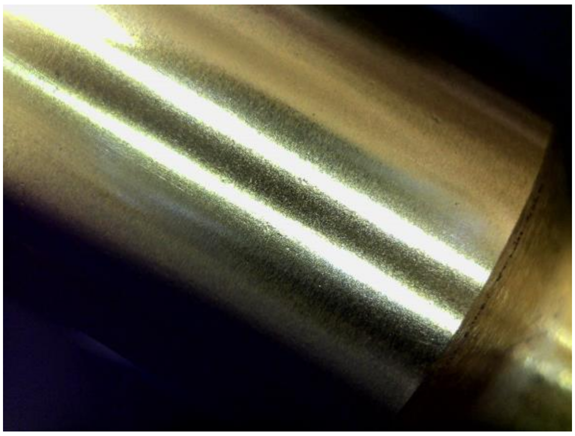


Photo 6.15. Zoom up view of the fuel injector plunger (After LSD trial)

Photo 6.16. Zoom up view of the fuel metering pump plunger (Before LSD trial)

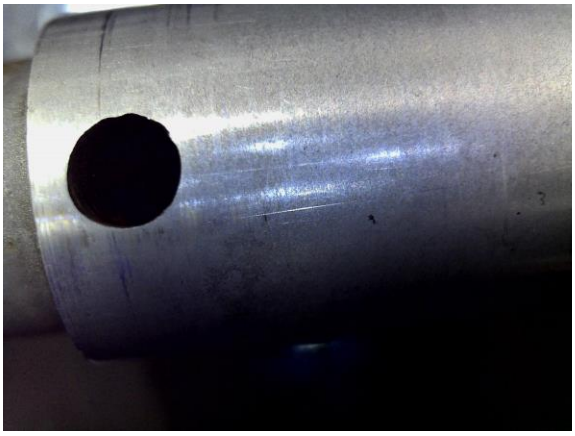


Photo 6.17. Zoom up view of the fuel metering pump plunger (After LSD trial)

7. Error Analysis

Laboratory experiments involve taking measurements of physical quantities. It is inevitable and unavoidable that measurement of physical quantity will introduce errors. The discrepancy between the measured value and the true value of the quantity may arise from different sources. No matter how careful in the measurement or accurate of the instruments, error cannot be totally eliminated but can only be reduced in magnitude through careful and well planned measurement methodology.

7.1 Types of errors

There are three types of errors during measurement: personal, systematic and random.

Personal errors arise from personal bias or carelessness in reading an instrument, in recording observations, or in calculations. There are four pieces of instruments that have been used in the present study: a current and a voltage sensor to measure the generator output current and voltage, and a fluid flow meter to measure the fuel flow rate. The current and voltage sensor output was connected to a power logger while the signal from the flow meter was connected to a notebook computer. As all the measurement outputs were digital and recorded by computer/logger, therefore no reading error or personal error will be involved in the present study.

Systematic errors are associated with particular instruments or techniques. Improperly calibrated instrument is one of the sources of this error. All the instruments used in recording the results have been calibrated but the instrument still have instrumental error which is normally indicated in the instrument’s specification.

Random errors also exist, which are resulted from unknown and unpredictable variations in the experimental situation. Unpredictable fluctuations in temperature or in-line voltage are the examples of random errors (also called accidental errors). Since the above unpredictable variations or fluctuations normally exhibit for a short period of time, these random errors can be reduced by repeating the measurement for a sufficient number of times or by improving the experimental technique. In this study, the measurements of the power and fuel flow were repeated a no. of times so as to reduce the random errors.

7.2 Uncertainty determination

The uncertainty of a measurement signifies how close it comes to the true value, i.e., how correct it is. The uncertainty of the present measurement is estimated in the following paragraphs.

The following table shows the accuracy of all the relevant equipment used in the study:

Equipment	Model	Accuracy
Power logger	Fluke power logger 1735	Intrinsic ±0.7%; Operation ±1.5%
Current sensor	Fluke power logger 1735	±2% (estimated)
Voltage sensor	Fluke power logger 1735	±2% (estimated)
Fuel flow sensor	Oval M-III LSF45L0-R1	±1%

For the determination of the specific fuel consumption SFC:

SFC = Fuel flow rate / Power

The error for determining each fuel flow rate data using the fuel flow sensor = ±1%

Repeating and averaging the measurement can improve the accuracy and the error for n repeated measurement can be determined as[2,3]:

(Error in each measurement)/ $\sqrt{n}$.

Each fuel flow rate reading is obtained from an average of 180 data, so the error for each fuel flow rate measurement = $\pm 1\%/\sqrt{n} = \pm 1\%/\sqrt{180} = \pm 0.07\%$

The error in each power measurement = error in Current sensor + error in Voltage sensor + error in power logger = 2% + 2% +0.7% +1.5% = 6.2%.

For the determination of maximum engine power, two to three instantaneous measurements were taken, taking the worst case of two measurements, the error in maximum power determination = $(\pm 6.2\%)/\sqrt{2} = 4.4\%$.

For determination of SFC at 100% power, 40 data was taken, while 20 data was taken for the variable power (87% to 83% loading) measurement. So taking the worst case of 20 data for the uncertainty estimation, the error involved in the SFC determination would be = $\pm 6.2\%/\sqrt{20} = \pm 1.39\%$ (or ±1.4%)

Since the error in a division calculation A/B = error A + error B, therefore the error in each SFC measurement = ± (0.07% + 1.39%) = ± 1.46%.

Three readings were taken to obtain the average SFC, so the error involved in the average SFC

= ± 1.46%/√3 = ±0.84%.

The change in SFC for LSD wrt HSD is calculated by the following equation:

% change in SFC = $(SFC_{LSD}-SFC_{HSD})/SFC_{HSD}$ x 100% = $[(SFC_{LSD})/SFC_{HSD} -1]$ x100%

Therefore, the error in each % change determination = ± (0.84 + 0.84%) = ± 1.7%.

8. Conclusions

(a) The maximum power of the Gardner and Cummins engine can be maintained for LSD with respect to (wrt) HSD. There was a very minor drop (from +0.1% to -5%, average -1.8%) for the Gardner but also a minor increase (-0.1% to +0.7%, average +0.4%) for the Cummins engines respectively. However, these small variations are insignificant and unnoticeable during actual operation.

(b) There was a small increase in specific fuel consumption (SFC) under constant load conditions of an average of +1.1% (from -1.3% to +2.9%) and +1.4% (from +0.8% to +2.1%) for the Gardner and Cummins engines respectively for LSD wrt HSD, which is in line with the small net reduction in calorific values of the LSD wrt HSD.

(c) The change in SFC for load variation during operation is also small between the HSD and LSD, with an average of +1.4% (from +0.8% to +3.0%) for Gardner and +1.3% (from +1.2% to +1.5%) for Cummins.

(d) Error for maximum power determination and % SFC change was estimated to be ±4.4% and ±1.7% respectively, showing high accuracy for the results obtained.

(e) From the Durability Test, there was not much difference of fuel injectors and pump wear due to fuels between HSD and LSD after the 200 hours' operation, as indicated from the fuel injector and pump performance tests, and microscopic examinations (SEM and LPEM).

(f) There were some changes in engine oil characteristics indicating benefits when the fuel was switched from HSD to LSD: slower decrease in TBN and slower increase in viscosity. However, the wear elements in the engine oil did not show significant difference between

HSD and LSD.

(g) There was an indication of lower engine oil consumption for LSD during the Gardner engine testing, which however, is not obvious during the Cummins engine testing.

(h) The observations from the engine oil consumption and chemical analysis indicate some advantages of the LSD fuel over HSD, which is in line with the USEPA's[4] claimed benefits on LSD.

References

1. Leung, D.Y.C., Cheng, S.W.K., "Marine Engine Tests on Laboratory Setting- Interim Report", the University of Hong Kong, 5 December 2012.
2. Experimental Data Analyst Documentation Ch 3 Experimental errors and error analysis. http://Reference.wolfram.com/applications/eda/ExperimentalErrorsAndErrorAnalysis.html
3. Experimental error and data analysis. The University of Tennessee at Chattanooga. http://www.utc.edu/Faculty/Harold-Climer/oldlaberr.html
4. Summary of EPA's Proposal for Nonroad Diesel Engines and Fuel, P.45 http://www.walshcarlines.com/pdf/control_of_emissions_of.d2f.pdf and EPA Document No. II-A-194, Air Docket A-2001-28.

Appendix I - Terms of Reference and Membership of the Working Group

Working Group on Upgrading the Quality of Marine Light Diesel

提升船用輕柴油質素工作小組

A. Terms of Reference **職權範圍**

The Government has proposed to upgrade the quality of locally supplied marine diesel.

The Working Group shall offer assistance to the Government in:
(a) considering the technical and other relevant issues, such as the implications for operation cost and fuel supply, concerning the initiative, and the practical measures for addressing these issues;
(b) collating the views of local vessel trades on this initiative.

政府建議提升本地供應船用輕柴油的質素。

工作小組須協助政府，職責如下：

(a) 考慮此建議的技術和其他相關事宜，例如營運成本和燃料供應，及處理這些事宜的實際方案；

(b) 收集本地船舶業界對此建議的意見。

B. Membership of Working Group **工作小組成員名單**

The Working Group consists of 6 government officials, 14 local vessel operators, 1 Technical Advisor (see table below) and some experts on need basis.

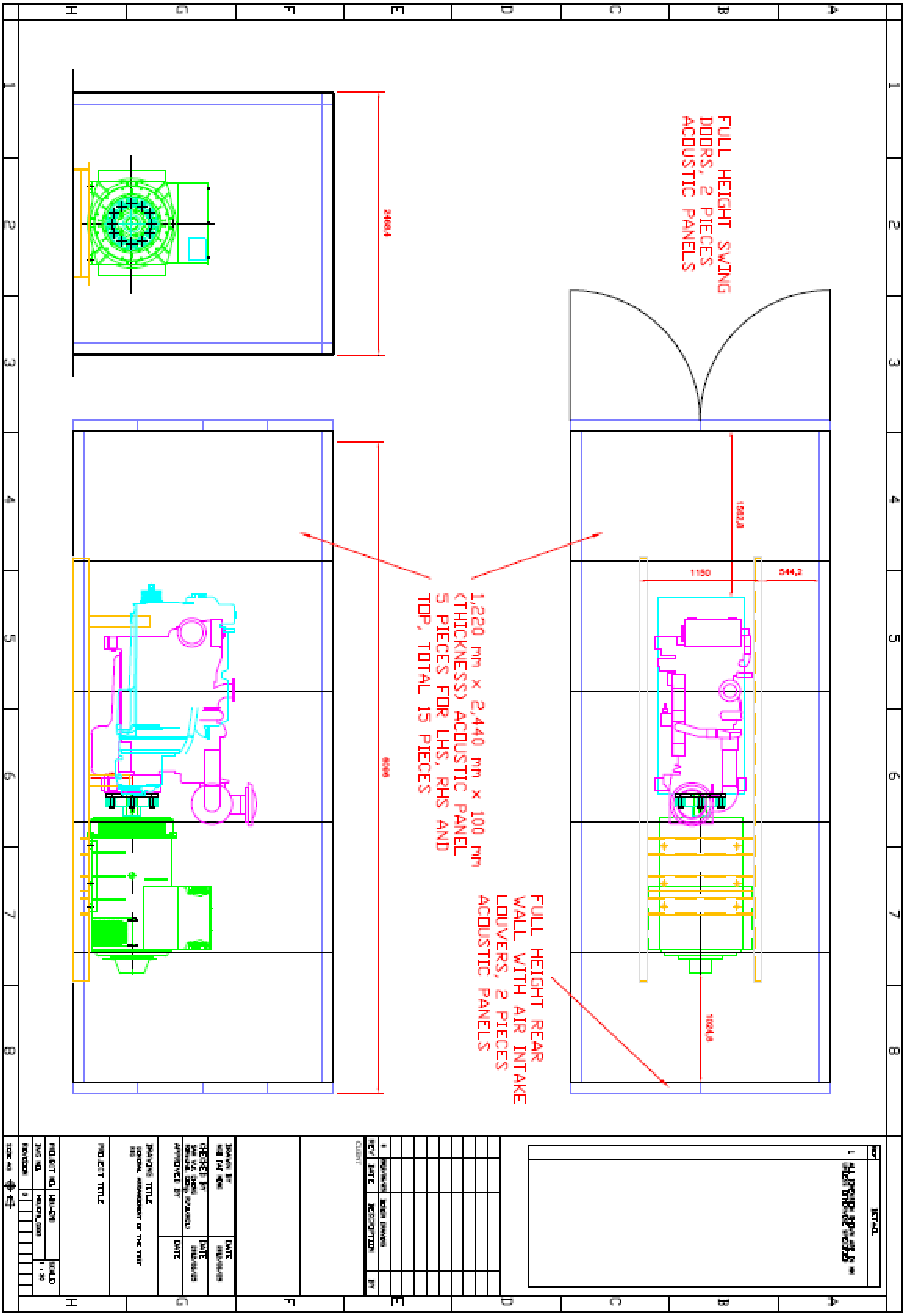
工作小組的成員包括6位政府部門代表、14位本地船舶營運者代表、1技術顧問(詳見下表)和一些按需要獲邀的專家。

政府部門代表 (共 6 人)		
部門名稱	職 位	代表姓名
環境保護署	助理署長、會議主席	莫偉全
	首席環保主任	彭錫榮
	高級環保主任	李裕韜
	環保主任、會議秘書	張金興
海事處	本地船舶安全組	王永泉/尹少康/王漢忠/鄧光輝;
運輸署	高級運輸主任	曾玉儀/吳錦嫺
本地船舶營運者代表 (共 14 人)		
船舶類型	營運者類型	代表姓名
第 I 類	渡輪 街渡 客船	梁德興、黃鋭昌、伍兆緣 李誠慶 郭志航
第 II 類	拖船 貨船	溫子傑、郭德基 黃耀勤、王妙生、郭美儀、楊積有
第 III 類	漁船	彭華根、姜紹輝、楊潤光
技術顧問 (共 1 人)		
	理工大學機械工程學系	張鎮順教授

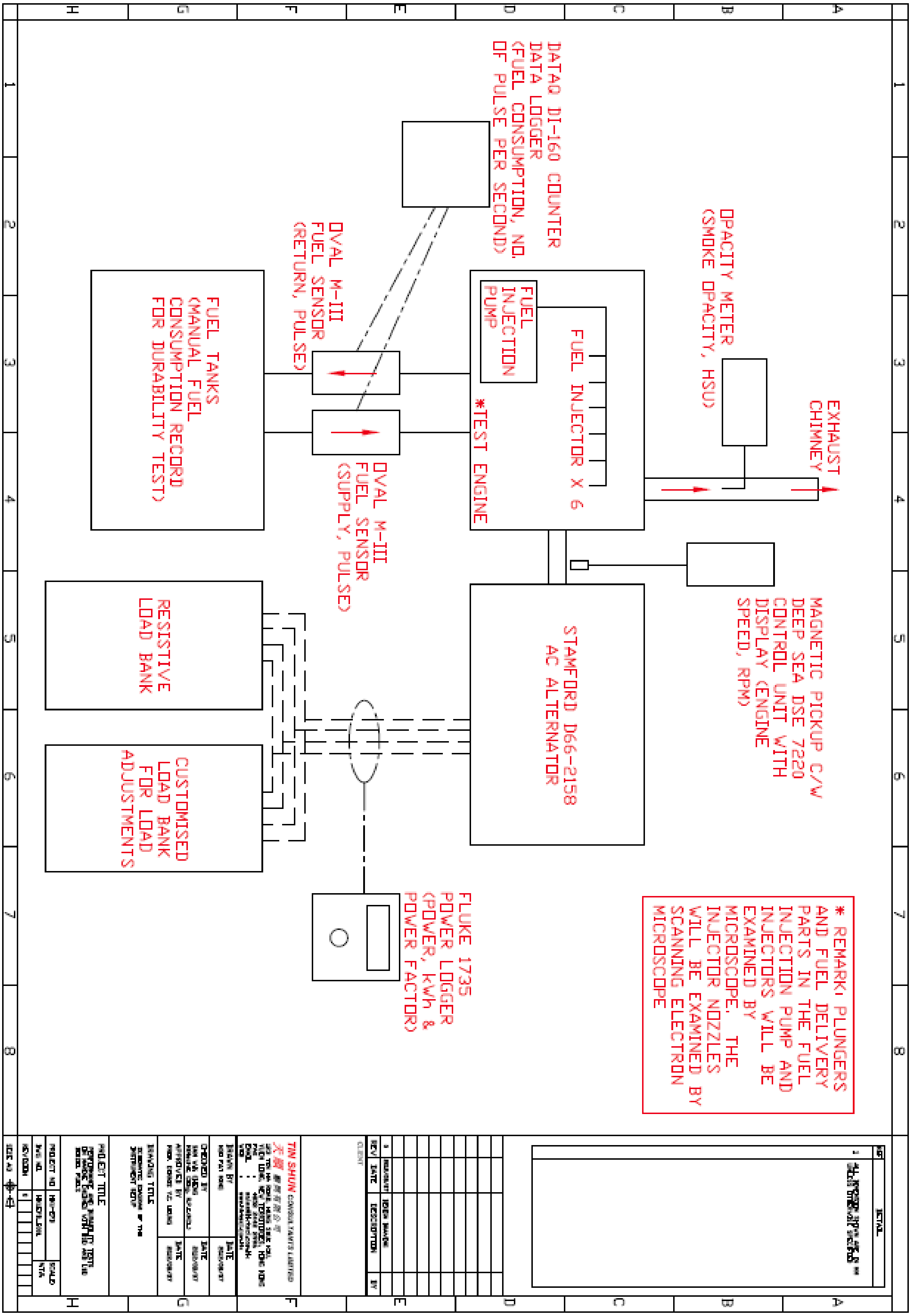
Appendix II – Equipment List

1. Stamford Double Bearing Type AC Alternator ; Model D66-2158
2. Oval M-III Flowmate Flowmeter ; Model LSF45L0-R1
3. Fluke Power Logger ; Model 1735
4. Deep Sea Electronics Control Module ; Model DSE 7220
5. DATAQ Count Data Logger ; Model DI-160
6. Graphtec midi logger ; Model GL200A
7. Hitachi Scanning Electron Microscope ; Model S3400N VP
8. Olympus Low Power Microscope ; Model SZ
9. Supereyes .Low Power Microscope ; Model A005+
10. Resistive Load Banks ; Capacity upto 600A
11. Customised Load Bank for Small Power Adjustment ; Capacity 0 ~ 6 kW or 0 ~ 9A
12. IAC 100mm (Thickness) Acoustic Panel with 48 kg/m^3Infill Fiberglass
13. Fuel injector and fuel pump test bench

Appendix III –Test Rig Arrangement



Appendix IV – Schematic Diagram of Instrument Setup



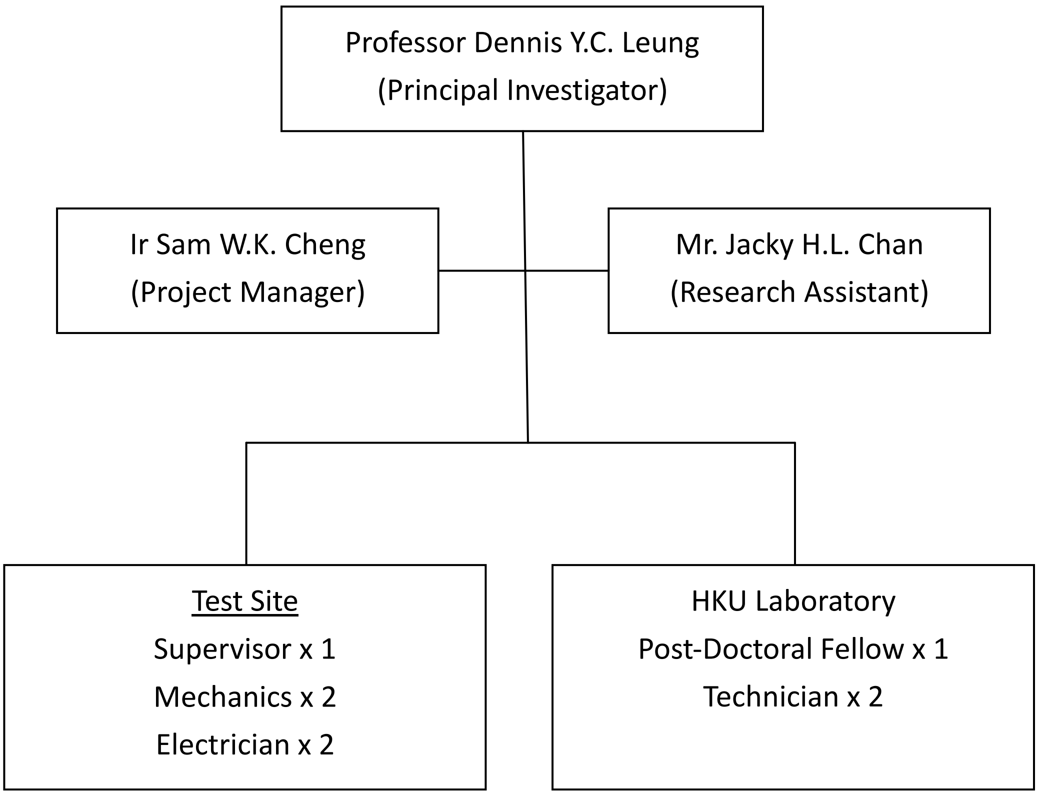
Appendix V –Work Plan and Project Schedule

Milestone Date	Description
23 July 2012	Award of tender
07 August 2012	Submission of Inception Report
09 August 2012	Collection of the overhauled Gardner engine from supplier
31 August2012	Performance test on HSD & LSD fuels (Gardner engine)
02 September 2012	200-hour Durability Test on HSD fuel (Gardner engine)
25 September 2012	Performance test on HSD & LSD fuels (Gardner engine)
27 September 2012	Performance test on HSD & LSD fuels after engine oil replacement
26 September 2012	Overhaul of fuel system (Gardner engine)
09 October 2012	Performance test on HSD & LSD fuels (Gardner engine)
12 October 2012	200-hour Durability Test on LSD fuel (Gardner engine)
06 November 2012	Performance test on HSD & LSD fuels (Gardner engine)
08 November 2012	Performance test on HSD & LSD fuels after engine oil replacement
10 November 2012	Overhaul of fuel system (Gardner engine)
10 November 2012	Return of Gardner & collection of overhauled Cummins engine from supplier
16 November 2012	Submission of Draft Interim Report
05 December 2012	Submission of Final Interim Report
10 December 2012	Performance test on HSD & LSD fuels (Cummins engine)
12 December 2012	200-hour Durability Test on HSD fuel (Cummins engine)
27 December 2012	Performance test on HSD & LSD fuels (Cummins engine)
28 December 2012	Performance test on HSD & LSD fuels after engine oil replacement
03 January 2013	Overhaul of fuel system (Cummins engine)
07 January 2013	Performance test on HSD & LSD fuel (Cummins engine)
08 January 2013	200-hour Durability Test on LSD fuel (Cummins engine)
24 January 2013	Performance test on HSD & LSD fuels (Cummins engine)
25 January 2013	Performance test on HSD& LSD fuels after engine oil replacement
28 January 2013	Overhaul of fuel system (Cummins engine)
28 January 2013	Return of Cummins engine
18 February 2013	Submission of Draft Final Report
31 March 2013	Submission of Final Report

Appendix VI – Project Team and Division of Work

Professor Dennis Y.C. Leung is the principal investigator of the project team and Ir Sam W.K. Cheng will assist him to coordinate the site works and test arrangements.

Technical staff will work at the test site on shift basis for conducting Performance and Durability Tests. SEM and detailed analysis will be assisted by researchers in laboratories at HKU.



Appendix VII – Diesel Fuel Analysis (SGS) – Gardner engine

SGS

27th August 2012
Report No. OGC/122192/HK (A)

REPORT OF ANALYSIS

THIS IS TO REPORT that we, S.G.S. Hong Kong Ltd., did at the request of Messrs. ENVIRONMENTAL PROTECTION DEPARTMENT to carry out analysis for the product sample of Diesel Oil.

We report as follows:

On 20th August 2012, we received two (2) x 500ml samples contained in glass bottles which samples were said to be product of Diesel Oil as instructed. The samples were collected from ENVIRONMENTAL PROTECTION DEPARTMENT and delivered to our SGS Laboratory for analysis.

Sample Detail

HSD
11-AUG-12

Samples analysis date: 23rd to 24th August 2012

Test	Unit	Method	Specification	Result
Lubricity at 60°C (WS1.4)	μm	ISO 12156-1:2006	Max. 460	350
Net Calorific Value	kJ/L	ASTM D240-09	-	36197
Density at 15°C	g/L	ASTM D4052-11	-	850.6
Total Sulphur Content	%(m/m)	ASTM D4294-10	-	0.399
Cetane Index (Procedure A)	Rating	ASTM D4737-10	-	51.6

The sample will be retained for 90 days at our SGS Laboratory for reference.

This test report only with responsibility for received sample.
This report reflects our findings of the submitted sample only and does not refer to any other matter.

Precision parameters apply in the determination of above test results. Also refer to ASTM D3244 IP-367 and Appendix E of IP Standard Methods for Analysis and Testing for utilization of test data of determine conformance with specifications.

This test document can not be reproduced in any way except in full context without the prior approval in writing from SGS Hong Kong Ltd. Laboratory, Hong Kong.
The above reflects our findings at time, date and place of inspection only.

Our intervention as above has been carried out to the best of our knowledge and ability and our responsibility is limited to the exercise of reasonable care.

* * * * * *

For and on behalf of
S.G.S. Hong Kong Ltd.

Authorized Signature

Appendix VII – Diesel Fuel Analysis (SGS) – Gardner engine

SGS

27th August 2012
Report No. OGC/122192/HK (B)

REPORT OF ANALYSIS

THIS IS TO REPORT that we, S.G.S. Hong Kong Ltd., did at the request of Messrs. ENVIRONMENTAL PROTECTION DEPARTMENT to carry out analysis for the product sample of Diesel Oil.

We report as follows:

On 20th August 2012, we received two (2) x 500ml samples contained in glass bottles which samples were said to be product of Diesel Oil as instructed. The samples were collected from ENVIRONMENTAL PROTECTION DEPARTMENT and delivered to our SGS Laboratory for analysis.

Sample Detail

LSD
11-AUG-12

Samples analysis date: 23rd to 24th August 2012

Test	Unit	Method	Specification	Result
Lubricity at 60°C (WS1.4)	μm	ISO 12156-1:2006	Max. 460	322
Net Calorific Value	kJ/L	ASTM D240-09	-	35608
Density at 15°C	g/L	ASTM D4052-11	-	828.1
Total Sulphur Content	%(m/m)	ASTM D4294-10	-	0.0421
Cetane Index (Procedure A)	Rating	ASTM D4737-10	-	56.8

The sample will be retained for 90 days at our SGS Laboratory for reference.

This test report only with responsibility for received sample.
This report reflects our findings of the submitted sample only and does not refer to any other matter.

Precision parameters apply in the determination of above test results. Also refer to ASTM D3244 IP-367 and Appendix E of IP Standard Methods for Analysis and Testing for utilization of test data of determine conformance with specifications.

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The above reflects our findings at time, date and place of inspection only.

Our intervention as above has been carried out to the best of our knowledge and ability and our responsibility is limited to the exercise of reasonable care.

* * * * * *

For and on behalf of
S.G.S. Hong Kong Ltd.

Authorized Signature

"This report is issued by the Company under its General Conditions for Inspection and Testing Services (copy available upon request). The issuance of this report does not exonerate buyers or sellers from exercising all their rights and discharging all their liabilities under the Contract of Sale. Stipulations to the contrary are not binding on the Company. The Company's responsibility under this report is limited to proven negligence and will in no case be more than ten times the amount of the fees or commission. Except by special arrangement, samples, if drawn, will not be retained by the Company for more than three months."

N04 (03.04) Member of the SGS Group (SGS SA)

Appendix VII – Diesel Fuel Analysis (SGS) – Gardner engine

SGS

28th November 2012
Report No. OGC/123192/HK (A)

REPORT OF ANALYSIS

THIS IS TO REPORT that we, S.G.S. Hong Kong Ltd., did at the request of Messrs. ENVIRONMENTAL PROTECTION DEPARTMENT to carry out analysis for the product sample of Diesel Oil.

We report as follows:

On 22nd November 2012, we collected one (1) x 500ml sample contained in glass bottle which sample was said to be product of Diesel Oil as instructed. The sample was collected from ENVIRONMENTAL PROTECTION DEPARTMENT and delivered to our SGS Laboratory for analysis.

Sample Detail

LSD
2012/11/20

Samples analysis date: 26th to 27th November 2012

Test	Unit	Method	Specification	Result
Net Calorific Value	kJ/L	ASTM D240-09	-	35530
Lubricity at 60°C (WS1.4)	μm	ISO 12156-1:2006	Max. 460	358
Density at 15°C	g/L	ASTM D4052-11	-	827.8
Total Sulphur Content	%(m/m)	ASTM D4294-10	-	0.0411
Cetane Index (Procedure A)	Rating	ASTM D4737-10	-	53.5

The sample will be retained for 90 days at our SGS Laboratory for reference.

This test report only with responsibility for received sample.
This report reflects our findings of the submitted sample only and does not refer to any other matter.

Precision parameters apply in the determination of above test results. Also refer to ASTM D3244 IP-367 and Appendix E of IP Standard Methods for Analysis and Testing for utilization of test data of determine conformance with specifications.

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The above reflects our findings at time, date and place of inspection only.

Our intervention as above has been carried out to the best of our knowledge and ability and our responsibility is limited to the exercise of reasonable care.

* * * * * *

For and on behalf of
S.G.S. Hong Kong Ltd.

Authorized Signature

Appendix VII – Diesel Fuel Analysis (SGS) – Gardner engine

SGS

27th November 2012
Report No. OGC/123192/HK (B)

REPORT OF ANALYSIS

THIS IS TO REPORT that we, S.G.S. Hong Kong Ltd., did at the request of Messrs. ENVIRONMENTAL PROTECTION DEPARTMENT to carry out analysis for the product sample of Diesel Oil.

We report as follows:

On 22nd November 2012, we collected one (1) x 500ml sample contained in glass bottle which sample was said to be product of Diesel Oil as instructed. The sample was collected from ENVIRONMENTAL PROTECTION DEPARTMENT and delivered to our SGS Laboratory for analysis.

Sample Detail

HSD
2012/11/20

Samples analysis date: 26th to 27th November 2012

Test	Unit	Method	Specification	Result
Net Calorific Value	kJ/L	ASTM D240-09	-	36315
Lubricity at 60°C (WS1.4)	μm	ISO 12156-1:2006	Max. 460	344
Density at 15°C	g/L	ASTM D4052-11	-	856.5
Total Sulphur Content	%(m/m)	ASTM D4294-10	-	0.418
Cetane Index (Procedure A)	Rating	ASTM D4737-10	-	50.1

The sample will be retained for 90 days at our SGS Laboratory for reference.

This test report only with responsibility for received sample.
This report reflects our findings of the submitted sample only and does not refer to any other matter.

Precision parameters apply in the determination of above test results. Also refer to ASTM D3244 IP-367 and Appendix E of IP Standard Methods for Analysis and Testing for utilization of test data of determine conformance with specifications.

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The above reflects our findings at time, date and place of inspection only.

Our intervention as above has been carried out to the best of our knowledge and ability and our responsibility is limited to the exercise of reasonable care.

* * * * * *

For and on behalf of
S.G.S. Hong Kong Ltd.

Authorized Signature*

Appendix VII – Diesel Fuel Analysis (SGS) – Cummins engine

SGS

24th December 2012
Report No. OGC/123426/HK (A)

REPORT OF ANALYSIS

THIS IS TO REPORT that we, S.G.S. Hong Kong Ltd., did at the request of Messrs. ENVIRONMENTAL PROTECTION DEPARTMENT to carry out analysis for the product sample of Diesel Oil.

We report as follows:

On 13th December 2012, we collected one (1) x 500ml sample contained in glass bottle which sample was said to be product of Diesel Oil as instructed. The sample was collected from ENVIRONMENTAL PROTECTION DEPARTMENT and delivered to our SGS Laboratory for analysis.

Sample Detail

HSD
2012/12/07

Samples analysis date: 19th to 21st December 2012

Test	Unit	Method	Result
Net Calorific Value	kJ/L	ASTM D240-09	36325
Lubricity at 60°C (WS1.4)	μm	ISO 12156-1:2006	369
Density at 15°C	g/L	ASTM D4052-11	854.3
Total Sulphur Content	%(m/m)	ASTM D4294-10	0.455
Cetane Index (Procedure A)	Rating	ASTM D4737-10	49.7

The sample will be retained for 90 days at our SGS Laboratory for reference.

This test report only with responsibility for received sample.
This report reflects our findings of the submitted sample only and does not refer to any other matter.

Precision parameters apply in the determination of above test results. Also refer to ASTM D3244 IP-367 and Appendix E of IP Standard Methods for Analysis and Testing for utilization of test data of determine conformance with specifications.

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The above reflects our findings at time, date and place of inspection only.

Our intervention as above has been carried out to the best of our knowledge and ability and our responsibility is limited to the exercise of reasonable care.

* * * * * *

For ~~and on behalf~~ of
S.G.S. Hong Kong Ltd.

Authorized Signature

Appendix VII – Diesel Fuel Analysis (SGS) – Cummins engine

SGS

24th December 2012
Report No. OGC/123426/HK (B)

REPORT OF ANALYSIS

THIS IS TO REPORT that we, S.G.S. Hong Kong Ltd., did at the request of Messrs. ENVIRONMENTAL PROTECTION DEPARTMENT to carry out analysis for the product sample of Diesel Oil.

We report as follows:

On 13th December 2012, we collected one (1) x 500ml sample contained in glass bottle which sample was said to be product of Diesel Oil as instructed. The sample was collected from ENVIRONMENTAL PROTECTION DEPARTMENT and delivered to our SGS Laboratory for analysis.

Sample Detail

LSD
2012/12/07

Samples analysis date: 19th to 21st December 2012

Test	Unit	Method	Result
Net Calorific Value	kJ/L	ASTM D240-09	35790
Lubricity at 60°C (WS1.4)	μm	ISO 12156-1:2006	384
Density at 15°C	g/L	ASTM D4052-11	832.0
Total Sulphur Content	%(m/m)	ASTM D4294-10	0.0434
Cetane Index (Procedure A)	Rating	ASTM D4737-10	55.7

The sample will be retained for 90 days at our SGS Laboratory for reference.

This test report only with responsibility for received sample.
This report reflects our findings of the submitted sample only and does not refer to any other matter.

Precision parameters apply in the determination of above test results. Also refer to ASTM D3244 IP-367 and Appendix E of IP Standard Methods for Analysis and Testing for utilization of test data of determine conformance with specifications.

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The above reflects our findings at time, date and place of inspection only.

Our intervention as above has been carried out to the best of our knowledge and ability and our responsibility is limited to the exercise of reasonable care.

* * * * * *

For and on behalf of
S.G.S. Hong Kong Ltd.

Authorized Signature

Appendix VII – Diesel Fuel Analysis (SGS) – Cummins engine

SGS

6th February 2013
Report No. OGC/130323/HK (A)

REPORT OF ANALYSIS

THIS IS TO REPORT that we, S.G.S. Hong Kong Ltd., did at the request of Messrs. ENVIRONMENTAL PROTECTION DEPARTMENT to carry out analysis for the product sample of Diesel Oil.

We report as follows:

On 31st January 2013, we collected one (1) x 500ml sample contained in glass bottle which sample was said to be product of Diesel Oil. The sample was collected from ENVIRONMENTAL PROTECTION DEPARTMENT and delivered to our SGS Laboratory for analysis.

Sample Detail

HSD 2013/01/22
Performance

Samples analysis date: 4th to 5th February 2013

Test	Unit	Method	Result
Net Calorific Value	kJ/L	ASTM D240-09	36485
Lubricity at 60°C (WS1.4)	μm	ISO 12156-1:2006	349
Density at 15°C	g/L	ASTM D4052-11	856.9
Total Sulfur Content	%(m/m)	ASTM D4294-10	0.170
Cetane Index (Procedure A)	Rating	ASTM D4737-10	50.5

The sample will be retained for 90 days at our SGS Laboratory for reference.

This test report only with responsibility for received sample.
This report reflects our findings of the submitted sample only and does not refer to any other matter.

Precision parameters apply in the determination of above test results. Also refer to ASTM D3244 IP-367 and Appendix E of IP Standard Methods for Analysis and Testing for utilization of test data of determine conformance with specifications.

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The above reflects our findings at time, date and place of inspection only.

Our intervention as above has been carried out to the best of our knowledge and ability and our responsibility is limited to the exercise of reasonable care.

* * * * * *

For ~~and on~~ behalf of
S.G.S. Hong Kong Ltd.

Authorized Signature

Appendix VII – Diesel Fuel Analysis (SGS) – Cummins engine

SGS

6th February 2013
Report No. OGC/130323/HK (B)

REPORT OF ANALYSIS

THIS IS TO REPORT that we, S.G.S. Hong Kong Ltd., did at the request of Messrs. ENVIRONMENTAL PROTECTION DEPARTMENT to carry out analysis for the product sample of Diesel Oil.

We report as follows:

On 31st January 2013, we collected one (1) x 500ml sample contained in glass bottle which sample was said to be product of Diesel Oil. The sample was collected from ENVIRONMENTAL PROTECTION DEPARTMENT and delivered to our SGS Laboratory for analysis.

Sample Detail

LSD 2013/01/22
Performance

Samples analysis date: 4th to 5th February 2013

Test	Unit	Method	Result
Net Calorific Value	kJ/L	ASTM D240-09	35685
Lubricity at 60°C (WS1.4)	μm	ISO 12156-1:2006	349
Density at 15°C	g/L	ASTM D4052-11	827.4
Total Sulfur Content	%(m/m)	ASTM D4294-10	0.0165
Cetane Index (Procedure A)	Rating	ASTM D4737-10	54.3

The sample will be retained for 90 days at our SGS Laboratory for reference.

This test report only with responsibility for received sample.
This report reflects our findings of the submitted sample only and does not refer to any other matter.

Precision parameters apply in the determination of above test results. Also refer to ASTM D3244 IP-367 and Appendix E of IP Standard Methods for Analysis and Testing for utilization of test data of determine conformance with specifications.

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The above reflects our findings at time, date and place of inspection only.

Our intervention as above has been carried out to the best of our knowledge and ability and our responsibility is limited to the exercise of reasonable care.

* * * * * *

For and on behalf of
S.G.S. Hong Kong Ltd.

Authorized Signature

Appendix VII – Reports on Performance of Fuel Pump and Fuel Injectors: Gardner-HSD (International Diesel Engineering Co.)

International Diesel Engineering Co.
先 進 公 司

G/F., 9 Ping Lan Street, Aplichau,
Aberdeen, Hong Kong.
Telephone: (852) 2555 3839
Facsimile: (852) 2870 0539

ADS ASSOCIATION OF DIESEL SPECIALISTS MEMBER

Specialist Service For:
Diesel Fuel Injection Systems
Automobile Electrics
Electrical / Mechanical
Equipment Installation

DELPHI
(AUTHORIZED SERVICES AGENT)
(特約維修服務中心)

REPORT

友聯發動機設備有限公司

Date: 27-8-2012

Make of pump: Gardner 6LXB
Serial No : Nil
Pump Type : BPF3B75CS6704
Engine No. : 235352

This is to certify that One Off Gardner 6LXB Fuel Pump & Six pcs Fuel Injectors. have been brought to us for overhauling and calibration, after complete overhauling and calibration they are tested in accordance with factory specification as follows and certified in good operating condition, with results within normal range.

		1	2	3	4	5	6	7	8
RPM 600	9MM	5.5cc	5.6cc	5.5cc	5.5cc	5.5cc	5.6cc	cc	cc
Control Rod Openings	12MM	12.0cc	12.0cc	12.0cc	12.0cc	12.0cc	12.0cc	cc	cc
Per 200 Strokes	18MM	27.1cc	27.2cc	27.1cc	27.1cc	27.2cc	27.2cc	cc	cc

		1	2	3	4	5	6	7	8
RPM 200	9MM	2.5cc	2.6cc	2.6cc	2.5cc	2.5cc	2.6cc	cc	cc
Control Rod Openings	12MM	9.5cc	9.5cc	9.5cc	9.5cc	9.5cc	9.5cc	cc	cc
Per 200 Strokes	18MM	24.2cc	24.2cc	24.1cc	24.2cc	24.1cc	24.2cc	cc	cc

Governor Cutting In Speed 950 RPM

Per 200 Strokes Max Fuel Setting 850 RPM 23.0 cc

Idling Speed 300 RPM 2.0 cc

Gardner Injector are set and

	1	2	3	4	5	6
opening pressure of Ib/IN²	2000	1998	1999	2000	1999	2000

All injectors showed satisfactory atomisation pattern, with spray angle within normal range, no fuel blockage nor leakage.

For and on behalf of
INTERNATIONAL DIESEL ENGINEERING CO.

Fok Kam Hung
Services Manager

Appendix VII – Reports on Performance of Fuel Pump and Fuel Injectors: Gardner-HSD (International Diesel Engineering Co.)

International Diesel Engineering Co.
先 進 公 司

G/F., 9 Ping Lan Street, Aplichau,
Aberdeen, Hong Kong.
Telephone: (852) 2555 3839
Facsimile: (852) 2870 0539

ASSOCIATION OF DIESEL SPECIALISTS MEMBER

Specialist Service For:
Diesel Fuel Injection Systems
Automobile Electrics
Electrical / Mechanical
Equipment Installation

DELPHI
(AUTHORIZED SERVICES AGENT)
(特約維修服務中心)

REPORT

友聯發動機設備有限公司

Date: 4-10-2012

Make of pump: Gardner 6LXB
Serial No : Nil
Pump Type : BPF3B75CS6704
Engine No. : 235352

This is to certify that One Off Gardner 6LXB Fuel Pump & Six pcs Fuel Injectors. have been brought to us for overhauling and calibration. All figures shown from this report were after testing for 200 hours. They were tested in accordance with factory specification as follows and certified in good operating condition, with results within normal range.

		1	2	3	4	5	6	7	8
RPM 600	9MM	5.5cc	5.6cc	5.5cc	5.5cc	5.5cc	5.6cc	cc	cc
Control Rod Openings	12MM	12.0cc	12.0cc	12.0cc	12.0cc	12.0cc	12.0cc	cc	cc
Per 200 Strokes	18MM	27.1cc	27.2cc	27.1cc	27.1cc	27.2cc	27.2cc	cc	cc

		1	2	3	4	5	6	7	8
RPM 200	9MM	2.5cc	2.6cc	2.6cc	2.5cc	2.5cc	2.6cc	cc	cc
Control Rod Openings	12MM	9.5cc	9.5cc	9.5cc	9.5cc	9.5cc	9.5cc	cc	cc
Per 200 Strokes	18MM	24.2cc	24.2cc	24.1cc	24.2cc	24.1cc	24.2cc	cc	cc

Governor Cutting In Speed 950 RPM

Per 200 Strokes Max Fuel Setting 850 RPM 23.0 cc

Idling Speed 300 RPM 2.0 cc

Gardner Injector are set and

	1	2	3	4	5	6
opening pressure of Ib/IN^2	1950	1940	1950	1960	1950	1940

All injectors showed satisfactory atomisation pattern, with spray angle within normal range, no fuel blockage nor leakage.

For and on behalf of
INTERNATIONAL DIESEL ENGINEERING CO.

Fok Kam Hung
Services Manager

Appendix VII – Reports on Performance of Fuel Pump and Fuel Injectors: Gardner-LSD (International Diesel Engineering Co.)

International Diesel Engineering Co.

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G/F., 9 Ping Lan Street, Aplichau,
Aberdeen, Hong Kong.
Telephone: (852) 2555 3839
Facsimile: (852) 2870 0539

ADS ASSOCIATION OF DIESEL SPECIALISTS MEMBER

Specialist Service For:
Diesel Fuel Injection Systems
Automobile Electrics
Electrical / Mechanical
Equipment Installation

DELPHI (AUTHORIZED SERVICES AGENT)
(特約維修服務中心)

REPORT

友聯發動機設備有限公司

Date: 5-10-2012

Make of pump: Gardner 6LXB
Serial No : Nil
Pump Type : BPF3B75CS6704
Engine No. : 235352

This is to certify that One Off Gardner 6LXB Fuel Pump & Six pcs Fuel Injectors. have been brought to us for overhauling and calibration, after complete overhauling and calibration they are tested in accordance with factory specification as follows and certified in good operating condition, with results within normal range.

		1	2	3	4	5	6	7	8
RPM 600	9MM	5.6cc	5.5cc	5.5cc	5.6cc	5.5cc	5.4cc	cc	cc
Control Rod Openings	12MM	12.0cc	12.0cc	12.0cc	12.0cc	12.0cc	12.0cc	cc	cc
Per 200 Strokes	18MM	27.2cc	27.1cc	27.2cc	27.2cc	27.1cc	27.1cc	cc	cc
RPM 200	9MM	2.6cc	2.5cc	2.5cc	2.6cc	2.5cc	2.5cc	cc	cc
Control Rod Openings	12MM	9.5cc	9.5cc	9.5cc	9.5cc	9.5cc	9.5cc	cc	cc
Per 200 Strokes	18MM	24.1cc	24.1cc	24.0cc	24.1cc	24.1cc	24.0cc	cc	cc

Governor Cutting In Speed 950 RPM

Per 200 Strokes Max Fuel Setting 850 RPM 23.0 cc

Idling Speed 300 RPM 2.0 cc

Gardner Injector are set and

	1	2	3	4	5	6
opening pressure of Ib/IN²	1999	2000	2000	1999	1998	1999

All injectors showed satisfactory atomisation pattern, with spray angle within normal range, no fuel blockage nor leakage.

For and on behalf of
INTERNATIONAL DIESEL ENGINEERING CO.

Fok Kam Hung
Services Manager

Appendix VII – Reports on Performance of Fuel Pump and Fuel Injectors: Gardner-LSD (International Diesel Engineering Co.)

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G/F., 9 Ping Lan Street, Aplichau,
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ASSOCIATION OF DIESEL SPECIALISTS MEMBER

Specialist Service For:
Diesel Fuel Injection Systems
Automobile Electrics
Electrical / Mechanical
Equipment Installation

DELPHI
(AUTHORIZED SERVICES AGENT)
(特約維修服務中心)

REPORT

友聯發動機設備有限公司

Date: 12-11-2012

Make of pump: Gardner 6LXB
Serial No : Nil
Pump Type : BPF3B75CS6704
Engine No. : 235352

This is to certify that One Off Gardner 6LXB Fuel Pump & Six pcs Fuel Injectors have been brought to us for overhauling and calibration. All figures shown from this report were after testing for 200 hours. They were tested in accordance with factory specification as follows and certified in good operating condition, with results within normal range.

		1	2	3	4	5	6	7	8
RPM 600	9MM	5.4cc	5.6cc	5.4cc	5.5cc	5.5cc	5.6cc	cc	cc
Control Rod Openings	12MM	11.8cc	12.0cc	11.8cc	12.0cc	12.0cc	12.0cc	cc	cc
Per 200 Strokes	18MM	27.0cc	27.2cc	27.0cc	27.1cc	27.2cc	27.2cc	cc	cc

		1	2	3	4	5	6	7	8
RPM 200	9MM	2.4cc	2.6cc	2.5cc	2.5cc	2.5cc	2.6cc	cc	cc
Control Rod Openings	12MM	9.4cc	9.5cc	9.4cc	9.5cc	9.5cc	9.5cc	cc	cc
Per 200 Strokes	18MM	24.1cc	24.2cc	24.0cc	24.2cc	24.1cc	24.2cc	cc	cc

Governor Cutting In Speed 950 RPM

Per 200 Strokes Max Fuel Setting 850 RPM 23.0 cc

Idling Speed 300 RPM 2.0 cc

Gardner Injector are set and

	1	2	3	4	5	6
opening pressure of Ib/IN²	1950	1900	1900	1900	1820	1890

All injectors showed satisfactory atomisation pattern, with spray angle within normal range, no fuel blockage nor leakage.

For and on behalf of
INTERNATIONAL DIESEL ENGINEERING CO.

Fok Kam Hung
Services Manager

Appendix VII – Reports on Performance of Fuel Pump and Fuel Injectors: Cummins-HSD (International Diesel Engineering Co.)

International Diesel Engineering Co.
先 進 公 司
G/F., 9 Ping Lan Street, Aplichau,
Aberdeen, Hong Kong.
Telephone: (852) 2555 3839
Facsimile: (852) 2870 0539

ADS ASSOCIATION OF DIESEL SPECIALISTS MEMBER

Specialist Service For:
Diesel Fuel Injection Systems
Automobile Electrics
Electrical / Mechanical
Equipment Installation

DELPHI
(AUTHORIZED SERVICES AGENT)
(特約維修服務中心)

REPORT

友聯發動機設備有限公司

Date:3-12-2012

Make of pump: Cummins NTA-855-M
Serial No : Nil
Pump Type : Nil
Engine No. : 30339985

This is to certify that One Off Cummins Diesel Fuel Pump & Six pcs Fuel Injectors. have been brought to us for overhauling and calibration, after complete overhauling and calibration they are tested in accordance with factory specification as follows and certified in good operating condition, within normal range.

(A). Calibration Fuel Pump Values :

200 c.c.	@ 600 R.P.M.	(Idle Speed)
169 P.S.I.	@2100 R.P.M.	(482 Flow Reading)
112 P.S.I.	@1500 R.P.M.	(392 Flow Reading)

Engine cut off speed : 2450 R.P.M.

(B). Calibration Fuel Injector Values :

(1)	191.5	c.c.	(7)		c.c.
(2)	191.0	c.c.	(8)		c.c.
(3)	191.3	c.c.	(9)		c.c.
(4)	191.7	c.c.	(10)		c.c.
(5)	192.1	c.c.	(11)		c.c.
(6)	192.9	c.c.	(12)		c.c.

For and on behalf of
INTERNATIONAL DIESEL ENGINEERING CO.

Fok Kam Hung
Services Manager

Appendix VII – Reports on Performance of Fuel Pump and Fuel Injectors: Cummins-HSD (International Diesel Engineering Co.)

International Diesel Engineering Co.
先 進 公 司

G/F., 9 Ping Lan Street, Aplichau,
Aberdeen, Hong Kong.
Telephone: (852) 2555 3839
Facsimile: (852) 2870 0539

ASSOCIATION OF DIESEL SPECIALISTS MEMBER

Specialist Service For:
Diesel Fuel Injection Systems
Automobile Electrics
Electrical / Mechanical
Equipment Installation

DELPHI
(AUTHORIZED SERVICES AGENT)
(特約維修服務中心)

REPORT

友聯發動機設備有限公司

Date: 2-1-2013

Make of pump: Cummins NTA-855-M
Serial No : Nil
Pump Type : Nil
Engine No. : 30339985

This is to certify that One Off Cummins Diesel Fuel Pump & Six pcs Fuel Injectors. have been brought to us for overhauling and calibration, All Figures show from this report were after testing for 200 hours. They were test in accordance with factory specification as follows and certified in good operating condition, with results within normal range.

(A). Calibration Fuel Pump Values :

200 c.c.	@ 600 R.P.M.	(Idle Speed)
169 P.S.I.	@2100 R.P.M.	(472 Flow Reading)
117 P.S.I.	@1500 R.P.M.	(386 Flow Reading)

Engine cut off speed : 2450 R.P.M.

(B). Calibration Fuel Injector Values :

(1)	191.1	c.c.	(7)		c.c.
(2)	191.4	c.c.	(8)		c.c.
(3)	191.2	c.c.	(9)		c.c.
(4)	191.8	c.c.	(10)		c.c.
(5)	192.5	c.c.	(11)		c.c.
(6)	192.1	c.c.	(12)		c.c.

For and on behalf of
INTERNATIONAL DIESEL ENGINEERING CO.

Fok Kam Hung
Services Manager

Appendix VII – Reports on Performance of Fuel Pump and Fuel Injectors: Cummins-LSD (International Diesel Engineering Co.)

International Diesel Engineering Co.
先 進 公 司

G/F., 9 Ping Lan Street, Aplichau, Aberdeen, Hong Kong.
Telephone: (852) 2555 3839
Facsimile: (852) 2870 0539

ADS ASSOCIATION OF DIESEL SPECIALISTS MEMBER

Specialist Service For:
Diesel Fuel Injection Systems
Automobile Electrics
Electrical / Mechanical
Equipment Installation

DELPHI
(AUTHORIZED SERVICES AGENT)
(特約維修服務中心)

REPORT

友聯發動機設備有限公司

Date: 5-1-2013

Make of pump: Cummins NTA-855-M
Serial No : Nil
Pump Type : Nil
Engine No. : 30339985

This is to certify that One Off Cummins Diesel Fuel Pump & Six pcs Fuel Injectors. have been brought to us for overhauling and calibration, after complete overhauling and calibration they are tested in accordance with factory specification as follows and certified in good operating condition, within normal range.

(A). Calibration Fuel Pump Values :

200 c.c.	@ 600 R.P.M.	(Idle Speed)
169 P.S.I.	@2100 R.P.M.	(482 Flow Reading)
113 P.S.I.	@1500 R.P.M.	(388 Flow Reading)

Engine cut off speed : 2450 R.P.M.

(B). Calibration Fuel Injector Values :

(1)	191.9	c.c.	(7)		c.c.
(2)	191.8	c.c.	(8)		c.c.
(3)	191.7	c.c.	(9)		c.c.
(4)	191.5	c.c.	(10)		c.c.
(5)	191.5	c.c.	(11)		c.c.
(6)	192.8	c.c.	(12)		c.c.

For and on behalf of
INTERNATIONAL DIESEL ENGINEERING CO.

Fok Kam Hung
Services Manager

Appendix VII – Reports on Performance of Fuel Pump and Fuel Injectors: Cummins-LSD (International Diesel Engineering Co.)

International Diesel Engineering Co.
先 進 公 司

G/F., 9 Ping Lan Street, Aplichau,
Aberdeen, Hong Kong.
Telephone: (852) 2555 3839
Facsimile: (852) 2870 0539

ASSOCIATION OF DIESEL SPECIALISTS MEMBER

Specialist Service For
Diesel Fuel Injection Systems
Automobile Electrics
Electrical / Mechanical
Equipment Installation

DELPHI
AUTHORIZED SERVICES AGENT
(特約維修服務中心)

REPORT

友聯發動機設備有限公司

Date: 28-1-2013

Make of pump: Cummins NTA-855-M
Serial No : Nil
Pump Type : Nil
Engine No. : 30339985

This is to certify that One Off Cummins Diesel Fuel Pump & Six pcs Fuel Injectors. have been brought to us for overhauling and calibration. All figures shown from this report were after testing for 200 hours. They were tested in accordance with factory specification as follows and certified in good operating condition, with results within normal range.

(A). Calibration Fuel Pump Values :

200 c.c.	@ 600 R.P.M	(Idle Speed)
169 P.S.I.	@2100 R.P.M.	(477 Flow Reading)
117 P.S.I.	@1500 R.P.M.	(383 Flow Reading)

Engine cut off speed : 2450 R.P.M.

(B). Calibration Fuel Injector Values :

(1)	186.0	c.c.	(7)		c.c.
(2)	187.8	c.c.	(8)		c.c.
(3)	188.5	c.c.	(9)		c.c.
(4)	187.2	c.c.	(10)		c.c.
(5)	188.2	c.c.	(11)		c.c.
(6)	187.5	c.c.	(12)		c.c.

For and on behalf of
INTERNATIONAL DIESEL ENGINEERING CO.

Fok Kam Hung
Services Manager

Appendix VII – Engine Oil Analysis Reports (HSD Durability Test) – Gardner engine

SIGNUM OIL ANALYSIS

G-H

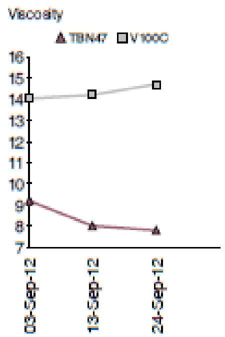
Alert

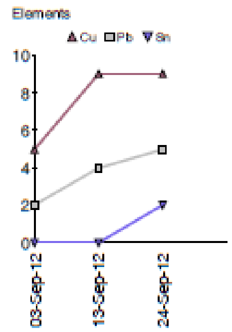
Account Number :	239528	Description :	HKU, 235352
Account Name :	Environmental Protection Department	Component :	Engine
	TAT PETROLEUM (HONGKONG) PTE LTD	Manufacturer :	Gardner
		Model :	6LXB
Date :	03-Oct-2012	Registered Lubricant :	MOBIL DELVAC 1340
Signum Number :	40211702		

Comments: The Chromium level in this sample exceeds the normal range of similar equipment.

Sample Data

Sample ID	**2275832047**	2262637021	2262637020
Date Sampled	**24-Sep-2012**	13-Sep-2012	03-Sep-2012
Date Reported	**03-Oct-2012**	21-Sep-2012	22-Sep-2012
Brand	**MOBIL**	MOBIL	MOBIL
Lubricant Tested	**DELV 1340**	DELV 1340	DELV 1340
Equip.	1		
Oil Hours	**200**	100	0
Res v. Temp			
Make-Up			
Oil Changed			
Filter Changed			





Sample Data

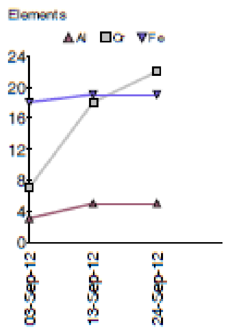
Sample ID	**2275832047**	2262637021	2262637020
Date Sampled	**24-Sep-2012**	13-Sep-2012	03-Sep-2012

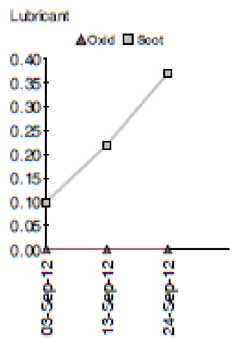
Wear Elements - ppm (mg/kg)

Ag (Silver)	0	0	0
Al (Aluminum)	5	5	3
Cr (Chromium)	*22	*18	7
Cu (Copper)	9	9	5
Fe (Iron)	19	19	18
Mo (Molybdenum)	0	0	0
Ni (Nickel)	1	1	0
Pb (Lead)	5	4	2
Sn (Tin)	2	0	0

Lubricant Data

Contamination	**Normal**	Normal	Normal
Equipment Rating	***Alert**	*Alert	Normal
Oil Rating	**Normal**	Normal	Normal
Visc @ 100C (cst)	**14.7**	14.2	14.0
SAE Viscosity	**40**	40	40
Coolant Indicator	**NotDetected**	NotDetected	NotDetected
Oxidation (Abs/cm)	**0**	0	0
PQ Index	**2**	8	13
Soot (Wt%)	**0.37**	0.22	0.10
TBN (mg KOH/g)	**7.8**	8.0	9.2
Water (Vol%)	**NotDetected**	NotDetected	NotDetected





Contaminant Elements - ppm (mg/kg)

B (Boron)	1	1	1
K (Potassium)	0	0	0
Na (Sodium)	2	2	1
Si (Silicon)	11	12	12
V (Vanadium)	0	0	0

Additive Elements - ppm (mg/kg)

Ba (Barium)	0	0	0
Ca (Calcium)	56	56	83
Mg (Magnesium)	1951	1831	1913
P (Phosphorus)	905	949	1039
Zn (Zinc)	1027	982	1082

Normal | + Caution | * Alert

Mobil

Appendix VII – Engine Oil Analysis Reports (LSD Durability Test) – Gardner engine

SIGNUM OIL ANALYSIS

G-L-0-HR

Alert

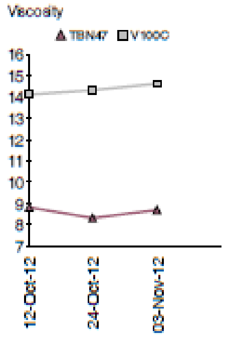
Account Number :	239528
Account Name :	Environmental Protection Department
	TAT PETROLEUM (HONGKONG) PTE LTD
Date :	15-Nov-2012
Signum Number :	40231676

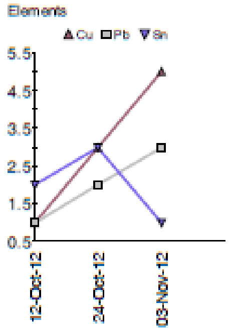
Description :	HKU, 235352
Component :	Engine
Manufacturer :	Gardner
Model :	6LXB
Registered Lubricant :	MOBIL DELVAC 1340

Comments:The Chromium level in this sample exceeds the normal range of similar equipment.

Sample Data

Sample ID	**2317496072**	2317496062	2317496059
Date Sampled	**03-Nov-2012**	24-Oct-2012	12-Oct-2012
Date Reported	**15-Nov-2012**	15-Nov-2012	15-Nov-2012
Brand	**MOBIL**	MOBIL	MOBIL
Lubricant Tested	**DELV 1340**	DELV 1340	DELV 1340
Equip.		100	
Oil Hours	**200**		0
Resv. Temp			
Make-Up			
Oil Changed			
Filter Changed			





Sample Data

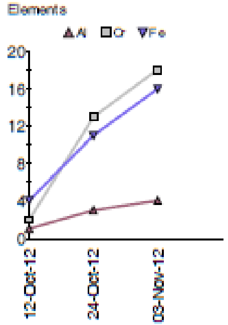
Sample ID	**2317496072**	2317496062	2317496059
Date Sampled	**03-Nov-2012**	24-Oct-2012	12-Oct-2012

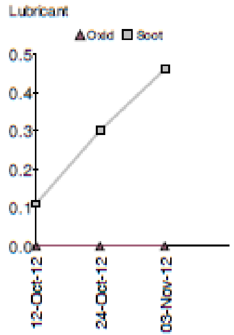
Wear Elements - ppm (mg/kg)

Ag (Silver)	**0**	0	0
Al (Aluminum)	**4**	3	1
Cr (Chromium)	***18**	*13	2
Cu (Copper)	**5**	3	1
Fe (Iron)	**16**	11	4
Mo (Molybdenum)	**0**	0	0
Ni (Nickel)	**1**	0	0
Pb (Lead)	**3**	2	1
Sn (Tin)	**1**	3	2

Lubricant Data

Contamination	**Normal**	Normal	Normal
Equipment Rating	***Alert**	*Alert	Normal
Oil Rating	**Normal**	Normal	Normal
Visc @ 100C (cst)	**14.6**	14.3	14.1
SAE Viscosity	**40**	40	40
Coolant Indicator	**NotDetected**	NotDetected	NotDetected
Oxidation (Ab/cm)	**0**	0	0
PQ Index	**5**	3	0
Soot (Wt%)	**0.46**	0.30	0.11
TBN (mg KOH/g)	**8.7**	8.3	8.8
Water (Vol%)	**NotDetected**	NotDetected	NotDetected





Contaminant Elements - ppm (mg/kg)

B (Boron)	**1**	1	1
K (Potassium)	**1**	1	0
Na (Sodium)	**1**	2	0
Si (Silicon)	**10**	9	6
V (Vanadium)	**0**	0	0

Additive Elements - ppm (mg/kg)

Ba (Barium)	**0**	0	0
Ca (Calcium)	**38**	28	23
Mg (Magnesium)	**2238**	2181	1967
P (Phosphorus)	**1020**	1010	983
Zn (Zinc)	**1151**	1135	1082

Normal | + Caution | * Alert

Results and comments of this analysis are advisory only; the validity of the data may be impaired by a non-representative sample or incorrect data. This analysis is provided for the confidential information of the party submitting it. Any use by any other person is prohibited. Marketing Affiliate - ExxonMobil Lubricants & Specialties.

Mobil

Appendix VII – Engine Oil Analysis Reports (HSD Durability Test) – Cummins engine

SIGNUM OIL ANALYSIS

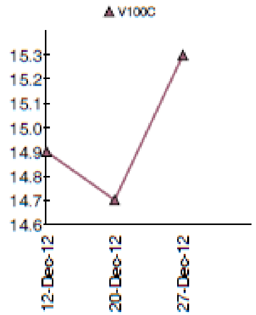
C-H-0-HR — **Normal**

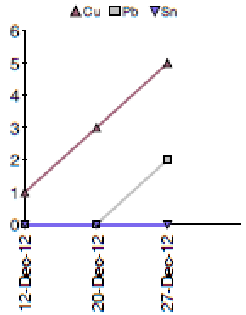
Account Number :	239528	Description :	HKU, 30339985
Account Name :	Environmental Protection Department	Component :	Engine
	TAT PETROLEUM (HONGKONG) PTE LTD	Manufacturer :	Cummins
		Model :	NTA855-M
Date :	07-Jan-2013	Registered Lubricant :	MOBIL DELVAC MX 15W40
Signum Number :	40251398		

Comments:No action is required on oil or engine. - Results are within acceptable ranges. - Examine progressive changes and monitor results for changing trends. - Sample at next scheduled interval.

Sample Data

Sample ID	**2366486013**	2366576022	2366576038
Date Sampled	**27-Dec-2012**	20-Dec-2012	12-Dec-2012
Date Reported	**03-Jan-2013**	03-Jan-2013	03-Jan-2013
Brand	**MOBIL**	MOBIL	MOBIL
Lubricant Tested	**DELMX15W40**	DELMX15W40	DELMX15W40
Equip.			
Oil Hours	**200**	100	0
Resv. Temp			
Make-Up			
Oil Changed			
Filter Changed			





Sample Data

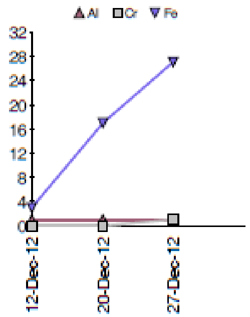
Sample ID	**2366486013**	2366576022	2366576038
Date Sampled	**27-Dec-2012**	20-Dec-2012	12-Dec-2012

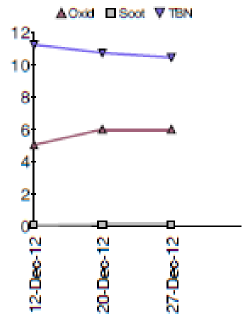
Wear Elements - ppm (mg/kg)

Ag (Silver)	**0**	0	0
Al (Aluminum)	**1**	1	1
Cr (Chromium)	**1**	0	0
Cu (Copper)	**5**	3	1
Fe (Iron)	**27**	17	3
Mo (Molybdenum)	**38**	39	35
Ni (Nickel)	**0**	0	0
Pb (Lead)	**2**	0	0
Sn (Tin)	**0**	0	0

Lubricant Data

Contamination	**Normal**	Normal	Normal
Equipment Rating	**Normal**	Normal	Normal
Oil Rating	**Normal**	Normal	Normal
Visc@100C (cst)	**15.3**	14.7	14.9
SAE Viscosity	**40**	40	40
Coolant Indicator	**NotDetected**	NotDetected	NotDetected
Oxidation (Ab/cm)	**6**	6	5
PQ Index	**0**	1	0
Soot (Wt%)	**0.13**	0.13	0.08
TBN (mg KOH/g)	**10.4**	10.7	11.2
Water (Vol%)	**NotDetected**	NotDetected	NotDetected





Contaminant Elements - ppm (mg/kg)

B (Boron)	**27**	35	45
K (Potassium)	**0**	0	0
Na (Sodium)	**0**	0	0
Si (Silicon)	**3**	2	3
V (Vanadium)	**0**	0	0

Additive Elements - ppm (mg/kg)

Ba (Barium)	**0**	0	0
Ca (Calcium)	**2257**	2245	1969
Mg (Magnesium)	**430**	448	400
P (Phosphorus)	**1096**	1147	1042
Zn (Zinc)	**1224**	1219	1122

Normal | + Caution | * Alert

Mobil

Appendix VII – Engine Oil Analysis Reports (LSD Durability Test) – Cummins engine

SIGNUM OIL ANALYSIS

C-L — **Normal**

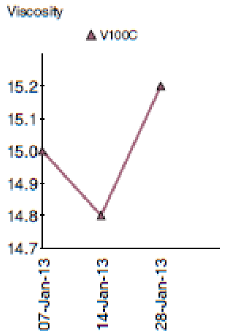
Account Number :	239528
Account Name :	Environmental Protection Department
	TAT PETROLEUM (HONGKONG) PTE LTD
Date :	04-Feb-2013
Signum Number :	40261268

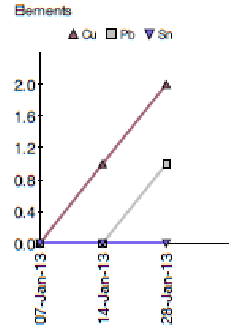
Description :	HKU, 30339985
Component :	Engine
Manufacturer :	Cummins
Model :	NTA855-M
Registered Lubricant :	MOBIL DELVAC MX 15W40

Comments: No action is required on oil or engine. - Results are within acceptable ranges. - Examine progressive changes and monitor results for changing trends. - Sample at next scheduled interval.

Sample Data

Sample ID	**3028223044**	3028440005	3028223057
Date Sampled	**28-Jan-2013**	14-Jan-2013	07-Jan-2013
Date Reported	**30-Jan-2013**	30-Jan-2013	30-Jan-2013
Brand	**MOBIL**	MOBIL	MOBIL
Lubricant Tested	**DELMX15W40**	DELMX15W40	DELMX15W40
Equip.			
Oil Hours	**200**	100	
Resv. Temp			
Make-Up			
Oil Changed			
Filter Changed			





Sample Data

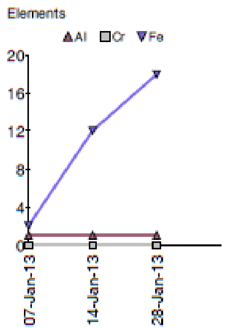
Sample ID	**3028223044**	3028440005	3028223057
Date Sampled	**28-Jan-2013**	14-Jan-2013	07-Jan-2013

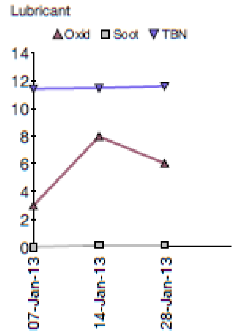
Wear Elements - ppm (mg/kg)

Ag (Silver)	**0**	0	0
Al (Aluminum)	**1**	1	1
Cr (Chromium)	**0**	0	0
Cu (Copper)	**2**	1	0
Fe (Iron)	**18**	12	2
Mo (Molybdenum)	**37**	38	35
Ni (Nickel)	**0**	0	0
Pb (Lead)	**1**	0	0
Sn (Tin)	**0**	0	0

Lubricant Data

Contamination	**Normal**	Normal	Normal
Equipment Rating	**Normal**	Normal	Normal
Oil Rating	**Normal**	Normal	Normal
Visc @ 100C (cst)	**15.2**	14.8	15.0
SAE Viscosity	**40**	40	40
Coolant Indicator	**NotDetected**	NotDetected	NotDetected
Oxidation (Ab/cm)	**6**	8	3
PQ Index	**1**	0	0
Soot (Wt%)	**0.12**	0.13	0.00
TBN (mg KOH/g)	**11.6**	11.5	11.4
Water (Vol%)	**NotDetected**	NotDetected	NotDetected





Contaminant Elements - ppm (mg/kg)

B (Boron)	**35**	41	48
K (Potassium)	**2**	2	1
Na (Sodium)	**0**	0	0
Si (Silicon)	**2**	2	2
V (Vanadium)	**0**	0	0

Additive Elements - ppm (mg/kg)

Ba (Barium)	**0**	0	0
Ca (Calcium)	**2209**	2380	2072
Mg (Magnesium)	**425**	436	414
P (Phosphorus)	**1040**	1101	1061
Zn (Zinc)	**1196**	1241	1188

Normal | + Caution | * Alert

Mobil

Appendix VII – Specific Fuel Consumption Data (Gardner Performance Tests of HSD Durability Test)

HSD 200-hr Durability Test Specific fuel consumption (l/kWh)	HSD Baseline	LSD Baseline	% variation LSD Vs HSD
Load - 100%	0.265	0.262	-1.3%
Load - 85%	0.262	0.262	0.1%
Load - 75%	0.266	0.269	1.2%
Load - 50%	0.299	0.298	-0.3%
Load - 25%	0.420	0.415	-1.0%
Load - 83%	0.263	0.267	1.6%
Load - 85%	0.263	0.267	1.3%
Load - 87%	0.263	0.263	-0.1%
Load - 85%	0.263	0.265	0.7%
Load - 83%	0.263	0.265	0.9%
Overall result for load variations 83% ~ 85% ~ 87%	0.263	0.266	0.9%

HSD 200-hr Durability Test Specific fuel consumption (l/kWh)	HSD After 200-hr	LSD After 200-hr	% variation LSD Vs HSD
Load - 100%	0.290	0.292	0.7%
Load - 85%	0.291	0.293	0.6%
Load - 75%	0.295	0.297	0.6%
Load - 50%	0.327	0.333	1.9%
Load - 25%	0.461	0.471	2.0%
Load - 83%	0.290	0.290	0.0%
Load - 85%	0.290	0.292	0.8%
Load - 87%	0.289	0.295	2.2%
Load - 85%	0.290	0.293	1.1%
Load - 83%	0.289	0.292	0.9%
Overall result for load variations 83% ~ 85% ~ 87%	0.289	0.292	1.0%

Appendix VII – Specific Fuel Consumption Data (Gardner Performance Tests of HSD Durability Test)

HSD 200-hr Durability Test Specific fuel consumption (l/kWh)	HSD After 200-hr and engine oil replacement	LSD After 200-hr and engine oil replacement	% variation LSD Vs HSD
Load - 100%	0.289	0.293	1.4%
Load - 85%	0.289	0.292	0.9%
Load - 75%	0.293	0.296	1.1%
Load - 50%	0.328	0.332	1.2%
Load - 25%	0.464	0.469	1.2%
Load - 83%	0.290	0.293	1.1%
Load - 85%	0.289	0.292	1.0%
Load - 87%	0.288	0.292	1.6%
Load - 85%	0.287	0.292	2.0%
Load - 83%	0.289	0.292	1.1%
Overall result for load variations 83% ~ 85% ~ 87%	0.289	0.292	1.3%

Appendix VII – Specific Fuel Consumption Data (Gardner Performance Tests of LSD Durability Test)

LSD 200-hr Durability Test Specific fuel consumption (l/kWh)	HSD Baseline	LSD Baseline	% variation LSD Vs HSD
Load - 100%	0.301	0.304	1.1%
Load - 85%	0.297	0.301	1.2%
Load - 75%	0.301	0.304	1.1%
Load - 50%	0.337	0.340	1.1%
Load - 25%	0.478	0.481	0.6%
Load - 83%	0.298	0.302	1.2%
Load - 85%	0.300	0.302	0.7%
Load - 87%	0.298	0.301	0.8%
Load - 85%	0.299	0.300	0.4%
Load - 83%	0.298	0.301	1.0%
Overall result for load variations 83% ~ 85% ~ 87%	0.299	0.301	0.8%

LSD 200-hr Durability Test Specific fuel consumption (l/kWh)	HSD After 200-hr	LSD After 200-hr	% variation LSD Vs HSD
Load - 100%	0.294	0.302	2.6%
Load - 85%	0.292	0.300	2.7%
Load - 75%	0.295	0.303	2.6%
Load - 50%	0.333	0.339	1.9%
Load - 25%	0.475	0.481	1.3%
Load - 83%	0.294	0.303	2.9%
Load - 85%	0.293	0.301	2.8%
Load - 87%	0.292	0.302	3.2%
Load - 85%	0.292	0.300	2.5%
Load - 83%	0.294	0.300	2.2%
Overall result for load variations 83% ~ 85% ~ 87%	0.293	0.301	2.7%

Appendix VII – Specific Fuel Consumption Data (Gardner Performance Tests of LSD Durability Test)

LSD 200-hr Durability Test Specific fuel consumption (l/kWh)	HSD After 200-hr and engine oil replacement	LSD After 200-hr and engine oil replacement	% variation LSD Vs HSD
Load - 100%	0.294	0.302	2.9%
Load - 85%	0.291	0.299	2.6%
Load - 75%	0.295	0.303	2.5%
Load - 50%	0.332	0.339	2.0%
Load - 25%	0.474	0.482	1.6%
Load - 83%	0.294	0.302	2.7%
Load - 85%	0.291	0.300	2.9%
Load - 87%	0.291	0.301	3.5%
Load - 85%	0.292	0.301	3.3%
Load - 83%	0.292	0.300	2.7%
Overall result for load variations 83% ~ 85% ~ 87%	0.292	0.301	3.0%

Appendix VII – Specific Fuel Consumption Data (Cummins Performance Tests of HSD Durability Test)

HSD 200-hr Durability Test Specific fuel consumption (l/kWh)	HSD Baseline	LSD Baseline	% variation LSD Vs HSD
Load - 100%	0.283	0.285	1.0%
Load - 85%	0.286	0.290	1.6%
Load - 75%	0.295	0.300	1.6%
Load - 50%	0.331	0.335	1.2%
Load - 25%	0.451	0.457	1.4%
Load - 83%	0.290	0.294	1.6%
Load - 85%	0.287	0.291	1.3%
Load - 87%	0.286	0.288	0.9%
Load - 85%	0.287	0.291	1.4%
Load - 83%	0.289	0.293	1.5%
Overall result for load variations 83% ~ 85% ~ 87%	0.288	0.291	1.4%

HSD 200-hr Durability Test Specific fuel consumption (l/kWh)	HSD After 200-hr	LSD After 200-hr	% variation LSD Vs HSD
Load - 100%	0.282	0.286	1.2%
Load - 85%	0.292	0.296	1.5%
Load - 75%	0.301	0.305	1.4%
Load - 50%	0.338	0.342	1.3%
Load - 25%	0.462	0.468	1.3%
Load - 83%	0.294	0.300	2.0%
Load - 85%	0.294	0.297	1.1%
Load - 87%	0.291	0.294	0.9%
Load - 85%	0.292	0.296	1.6%
Load - 83%	0.293	0.299	1.9%
Overall result for load variations 83% ~ 85% ~ 87%	0.293	0.297	1.5%

Appendix VII – Specific Fuel Consumption Data (Cummins Performance Tests of HSD Durability Test)

HSD 200-hr Durability Test Specific fuel consumption (l/kWh)	HSD After 200-hr and engine oil replacement	LSD After 200-hr and engine oil replacement	% variation LSD Vs HSD
Load - 100%	0.285	0.287	0.8%
Load - 85%	0.292	0.297	1.6%
Load - 75%	0.301	0.306	1.5%
Load - 50%	0.339	0.343	1.3%
Load - 25%	0.463	0.468	1.1%
Load - 83%	0.292	0.299	2.4%
Load - 85%	0.296	0.297	0.3%
Load - 87%	0.291	0.295	1.3%
Load - 85%	0.293	0.296	1.2%
Load - 83%	0.294	0.297	0.7%
Overall result for load variations 83% ~ 85% ~ 87%	0.293	0.297	1.2%

Appendix VII – Specific Fuel Consumption Data (Cummins Performance Tests of LSD Durability Test)

LSD 200-hr Durability Test Specific fuel consumption (l/kWh)	HSD Baseline	LSD Baseline	% variation LSD Vs HSD
Load - 100%	0.283	0.287	1.4%
Load - 85%	0.292	0.296	1.2%
Load - 75%	0.302	0.305	0.8%
Load - 50%	0.340	0.343	1.0%
Load - 25%	0.464	0.468	0.9%
Load - 83%	0.294	0.300	2.0%
Load - 85%	0.293	0.295	0.9%
Load - 87%	0.290	0.293	1.1%
Load - 85%	0.292	0.295	1.2%
Load - 83%	0.295	0.297	0.9%
Overall result for load variations 83% ~ 85% ~ 87%	0.293	0.296	1.2%

LSD 200-hr Durability Test Specific fuel consumption (l/kWh)	HSD After 200-hr	LSD After 200-hr	% variation LSD Vs HSD
Load - 100%	0.284	0.289	1.7%
Load - 85%	0.293	0.298	2.0%
Load - 75%	0.302	0.308	2.1%
Load - 50%	0.339	0.346	2.1%
Load - 25%	0.465	0.473	1.6%
Load - 83%	0.298	0.299	0.3%
Load - 85%	0.295	0.300	1.8%
Load - 87%	0.293	0.298	1.4%
Load - 85%	0.295	0.299	1.5%
Load - 83%	0.295	0.301	2.1%
Overall result for load variations 83% ~ 85% ~ 87%	0.295	0.299	1.4%

Appendix VII – Specific Fuel Consumption Data (Cummins Performance Tests of LSD Durability Test)

LSD 200-hr Durability Test Specific fuel consumption (l/kWh)	HSD After 200-hr and engine oil replacement	LSD After 200-hr and engine oil replacement	% variation LSD Vs HSD
Load - 100%	0.284	0.289	1.7%
Load - 85%	0.293	0.299	1.9%
Load - 75%	0.302	0.307	1.9%
Load - 50%	0.339	0.345	1.9%
Load - 25%	0.465	0.474	1.9%
Load - 83%	0.298	0.301	1.1%
Load - 85%	0.296	0.300	1.4%
Load - 87%	0.293	0.298	1.5%
Load - 85%	0.293	0.299	1.8%
Load - 83%	0.295	0.300	1.8%
Overall result for load variations 83% ~ 85% ~ 87%	0.295	0.299	1.5%

Appendix VIII – Sample Log

The University of Hong Kong
Department of Mechanical Engineering

Marine Engine Tests on Laboratory Setting

Performance Test

Engine Make: Gardner | Model: 6LXB
Engine rated output: 111.85 kW @ 1,650 rpm | Test cell temperature: 32 °C
Alternator output voltage: 380 V | Maximum output current: 133 A
Frequency: 55 Hz | Fuel Type: HSD / ~~LSD~~

Maximum power at 1,650 RPM: 118 kW / 118 kW / 118 kW

Time	Load	Alternator output power	Voltage	Cell temperature / Humidity	Fuel consumption	Engine speed
	%	kW	AC-V	°C / %	L / hr	RPM
Trail 1						
15 min.	100	87	219 / 380	32°C / 40%	26.0	1,656
15 min.	85	75	219 / 380	34°C / 36%	22.3	1,650
15 min.	75	66	219 / 380	35°C / 33%	20.1	1,650
15 min.	50	44	219 / 380	36°C / 31%	15.1	1,653
15 min.	25	21	219 / 380	35°C / 31%	10.4	1,650
3 min.	83	73	219 / 380	35°C / 31%	21.9	1,656
3 min.	85	75	219 / 380	36°C / 31%	22.4	1,653
3 min.	87	77	219 / 380	36°C / 31%	23.0	1,650
3 min.	85	75	219 / 380	36°C / 32%	22.5	1,656
3 min.	83	73	219 / 380	36°C / 30%	21.9	1,650
Trail 2						
15 min.	100	88	219 / 380	34°C / 33%	26.3	1,656
15 min.	85	75	219 / 380	37°C / 29%	22.4	1,650
15 min.	75	67	219 / 380	38°C / 27%	20.2	1,653
15 min.	50	44	219 / 380	38°C / 27%	15.1	1,650
15 min.	25	21	219 / 380	37°C / 27%	10.4	1,653
3 min.	83	73	219 / 380	37°C / 27%	22.1	1,653
3 min.	85	75	219 / 380	37°C / 27%	22.5	1,653
3 min.	87	77	219 / 380	37°C / 27%	23.0	1,656
3 min.	85	75	219 / 380	38°C / 26%	22.4	1,653
3 min.	83	73	219 / 380	38°C / 26%	21.9	1,656

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Appendix VIII – Sample Log

The University of Hong Kong
Department of Mechanical Engineering

Marine Engine Tests on Laboratory Setting

Time	Load	Alternator output power	Voltage	Cell temperature / Humidity	Fuel consumption	Engine speed
	%	kW	AC-V	°C / %	L / hr	RPM
Trail 3						
15 min.	100	87	219 / 380	37°C / 28%	26.4	1,653
15 min.	85	75	219 / 380	38°C / 27%	22.5	1,653
15 min.	75	67	219 / 380	39°C / 26%	20.2	1,653
15 min.	50	44	219 / 380	39°C / 26%	15.1	1,653
15 min.	25	21	219 / 380	38°C / 26%	10.5	1,653
3 min.	83	73	219 / 380	38°C / 26%	22.1	1,653
3 min.	85	75	219 / 380	38°C / 26%	22.5	1,650
3 min.	87	77	219 / 380	38°C / 26%	23.1	1,653
3 min.	85	75	219 / 380	38°C / 26%	22.5	1,656
3 min.	83	73	219 / 380	38°C / 26%	21.9	1,653

Remarks: Power logger data collected? (Y / ~~N~~)

Fuel consumption data downloaded? (Y / ~~N~~)

Test by: ______________

Date: 2012-11-07

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Appendix VIII – Sample Log

The University of Hong Kong
Department of Mechanical Engineering

Marine Engine Tests on Laboratory Setting

Durability Test – Log Sheet

Engine Make: Gardner   Model: 6LXB

Engine rated output: 68 kW @ 1,500 rpm   Fuel Type: HSD / ~~LSD~~

Date	Time	Alternator output power (kW)	Voltage (V)	Test cell temperature (°C)	Coolant temperature (°C)	Engine oil pressure (bar)	Engine Speed (RPM)
15/09/12	8:30	0	219 / 380	29	43	3.72	1506
	9:00	68	219 / 380	32	61	3.37	1506
	10:00	67	219 / 380	38	62	3.16	1506
	11:00	68	219 / 380	39	63	3.16	1506
	12:00	67	219 / 380	41	62	3.16	1509
	13:00	67	219 / 380	43	63	3.16	1500
	14:00	67	219 / 380	43	62	3.16	1503
	15:00	67	219 / 380	44	62	3.16	1509
	16:00	67	219 / 380	43	61	3.16	1509
	17:00	67	219 / 380	43	61	3.16	1509
	18:00	68	219 / 380	42	61	3.16	1503
	19:00	67	219 / 380	42	62	3.10	1503
	19:45	Stop					

Remarks: Engine oil re-filled: 1.5Litres

Accumulated running hour: 11.25 Hours   Total fuel consumed: ~ 227 Litres

Recorded by: HKU   Date: 2012/09/15

Appendix VIII – Sample Log

The University of Hong Kong
Department of Mechanical Engineering

Marine Engine Tests on Laboratory Setting

Durability Test – Log Sheet

Engine Make: Gardner   Model: 6LXB

Engine rated output: 68 kW @ 1,500 rpm   Fuel Type: ~~HSD~~ / LSD

Date	Time	Alternator output power (kW)	Voltage (V)	Test cell temperature (°C)	Coolant temperature (°C)	Engine oil pressure (bar)	Engine Speed (RPM)
16/10/12	8:30	4	219 / 380	29	35	5.23	1518
	9:00	68	219 / 380	32	62	3.37	1503
	10:00	68	219 / 380	37	63	3.30	1503
	11:00	68	219 / 380	39	63	3.16	1503
	12:00	68	219 / 380	40	62	3.16	1503
	13:00	68	219 / 380	40	63	3.16	1503
	14:00	68	219 / 381	41	63	3.16	1500
	15:00	68	220 / 381	42	63	3.16	1503
	16:00	68	220 / 381	42	62	3.16	1503
	17:00	68	220 / 381	42	62	3.16	1503
	18:00	68	220 / 381	40	61	3.16	1503
	19:00	68	219 / 381	38	62	3.16	1509
	19:30	Stop					

Remarks: Engine oil re-filled: 0 Litres

Accumulated running hour: 11.0 Hours   Total fuel consumed: ~ 220 Litres

Recorded by: HKU   Date: 2012/10/12

Appendix VIII – Sample Log

EPD Marine Engine Tests on Laboratory Setting

Contract No.: 69-EPD-12-01657

Fuel Consumption Log Sheet

Date	Time	Amount (Litre)		Remarks
(DD-MM-YY)		HSD	EURO V	
02-08-12	10:30		+200	Received by EPD
02-08-12	11:00	+1,400		Received by EPD
11-08-12	10:30	-1.2	-1	Fuel sampling for lab. analysis
22-08-12	15:30	-20		Engine commissioning
29-08-12	18:00	-28.8		Engine commissioning
31-08-12	19:00	-135.1		Gardner performance test
01-09-12	18:00	-14.9	-149	Gardner performance test
05-09-12	16:00	+1,000		Received by HKU
11-09-12	12:00	+1,200		Received by HKU
18-09-12	14:00	+1,000		Received by HKU
21-09-12	10:00		+1,000	Received by HKU
03-09-12 ~ 23-09-12	17:00	-3,902		Gardner 200-hr durability test
26-09-12 ~ 29-09-12	17:30	-348	-250	Gardner performance test
04-10-12	12:00	+1,000		Received by HKU
06-10-12 ~ 08-10-12	17:00	-50	-200	Engine commissioning
09-10-12 ~ 11-10-12	17:00	-180	-165	Gardner performance test
12-10-12	10:00		+1,000	Received by HKU
12-10-12 ~14-10-12	18:00	-40	-400	Gardner 200-hr durability test

Remarks / Incident happened