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Fuelling of an Automotive Engine on DIMETHYL ETHER (DME)

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A research report submitted to the Faculty of Engineering and the Built Environment, University of the Witwatersrand, in partial fulfilment of the requirements for the degree of Master of Science in Engineering.

Johannesburg, 2008

Acknowledgments

I would like to dedicate this to my wife Natalie, my parents, my brother and my sister, “Thank you guys for all your encouragement and overwhelming support.”

To my fellow post graduate colleges, workshop staff, and all supporting lecturers who contributed to the success of this project, “Thank you”

Lastly, I would like to send out the biggest thank you to my supervisor Dr. D. Cipolat for all his time and effort invested in me, especially in believing in me and helping me with the development of the new rig, “Thank you for all your time and effort Dr. Cipolat”.

Declaration

I declare that this research report is my own, unaided work. It is being submitted for the degree of Master of Science in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.

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KENAN GRÖSS

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Abstract

This research is based on development of a small compact Low Pressure Dimethyl Ether (DME) fuelling system with the scope of one day being retrofitted to a diesel Light Duty Vehicle (LDV). The development of the Low Pressure DME fuelling system is discussed along with the engine injector characteristics, the energy release, and the NO_x emissions. The recorded data was compared to a previous DME fuelling system and conventional diesel results. The report discusses in detail the complete design phase of the Low Pressure DME system, with emphasis on the delivery pressure and portability of the system. The testing phase was run using a 1330cc PH2 Lister Petter diesel engine, with the Low Pressure DME fuelling system connected to the inlet of the original diesel injector fuel pumps. Three individual tests were run, ranging from 1100 rpm to 1800 rpm, at loads of 25Nm, 35Nm and 45Nm. Engine performance and emission data were recorded for each case, with emphasis placed on the fuel injector line pressure. The results obtained indicated that the bulk modulus of the fuel played an important role when it came to fuel injector performance. Injector timing was also identified as having a significant effect. The energy released, while running on the Low Pressure DME fuelling system, clearly indicated that the maximum peak occurred well after top dead centre, this in turn influenced the cylinder pressure which ultimately reduced the usable power. From the NO_x emissions it was seen that running the engine on DME, the concentration levels started off high for low engine speeds and rapidly tapered down as the speed increased. The Low Pressure DME fuelling system produced the lowest NO_x concentration levels for high engine speeds and especially high engine loads. As a whole the Low Pressure DME fuelling system produced satisfactory results and showed definite potential for future development.

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Nomenclature

Symbol	Description	Unit
ABDC	After bottom dead centre	[°crank angle]
ATDC	After top dead centre	[°crank angle]
BP	Brake power	[W]
BBDC	Before bottom dead centre	[°crank angle]
BTDC	Before top dead centre	[°crank angle]
$C_{16}H_{34}$	Molecular formula for diesel	[]
CH_3OCH_3	Molecular formula for DME	[]
CO	Carbon monoxide	[ppm]
CO_2	Carbon dioxide	[ppm]
DME	Dimethyl Ether	[]
F	Brake load	[N]
H	Hydrogen ion	[]
HC	Hydrocarbon	[]
HP	High Pressure	[]
H_2O	Water	[]
IP	Indicated power	[W]
LP	Low Pressure	[]
m	Mass	[kg]
N_2	Nitrogen	[]
N'_2	Apparent Nitrogen	[]
NO	Nitric Oxide	[]
NO_x	Nitrogen Oxides	[ppm]
OH	Hydroxide ion	[]
O_2	Oxygen	[%]
P	Power	[W]
PC	Personal Computer	[]
Q_f	Calorific value	[Mj/kg]
R	Radius	[m]
SCO	Specific carbon monoxide	[ppm.$^{-1}$]
SCO_2	Specific carbon dioxide	[ppm.$^{-1}$]
SNO_x	Specific nitrogen oxides	[ppm.$^{-1}$]
SO_2	Specific oxygen	[%.W^{-1}]
STHC	Specific total unburnt hydrocarbons	[ppm.$^{-1}$]
T	Torque	[Nm]

TDC	Top dead centre	[°crank angle]
THC	Total unburnt hydrocarbons	[ppm]
t	Time	[s]
wt	Weight	[%]
ω	Angular velocity	[rads.s^{-1}]
λ	Excess air ratio	[]

1 Introduction

1.1 Overview

In 1892 German engineer Rudolf Diesel patented the engine that bears his name, an internal combustion engine that does not require a spark to ignite the fuel-air mixture. Diesel was born in Paris to German parents and grew up in London, Paris and Munich. In the 1880s he worked as a refrigerator engineer in Munich, but returned to Paris to experiment with engines.

In 1892 he won a patent for the diesel engine, but he continued to work on its development for years. The diesel engine allowed trains and ships to operate more efficiently with oil instead of coal, and Diesel quickly became a rich man. In 1913 he vanished overboard from a steamer bound for London, his body washed up ten days later. Some believe he committed suicide and cite his neurotic personality and numerous "breakdowns," and some believe he was murdered by either Germans (who resented his lack of nationalism) or by coal industrialists (who resented his engine) [1].

The first successful diesel engine was built in the United States, thanks to the financial backing of Adolphus Busch, famous brewer of Budweiser [1].

The four-stroke compression ignition engine soon become the single most popular source of power within the industrial sector, especially for applications involving high torque applications. The engine ran on a fuel that was essentially a processed end product of coal, and because of the availability of fossil fuels in many countries at the time became an extremely popular automotive fuel. The fuel was also subsequently named after Diesel.

In the past, not many people knew or cared about the dangers that diesel emissions carried. The greatest disadvantage of using diesel fuel, other than the decline in worldwide coal reserves, is the fact that its waste products from the combustion process are highly toxic and are extremely detrimental to the environment. Carbon monoxide (CO) and mono-nitrogen oxides (NO_x) are of particular concern. Government legislation and public concern over the past decade have resulted in ever-tightening emission standards in almost all developed countries and many emerging markets. For example, the European Union have introduced 2000/2005 emission standards and were accompanied by an introduction of more stringent fuel quality rules that require a minimum diesel cetane number of 51 (year 2000), maximum diesel sulphur content of 350 ppm (parts per million) in 2000 and 50 ppm in 2005, and a maximum petrol sulphur content of 150 ppm in 2000 and 50 ppm in 2005. Therefore, with the standards only likely to become even more stringent, there exists a need for continual research into innovative ways in which these standards may be met. The emission standards can be seen in Figure 1-1 and Table 1-1 below.

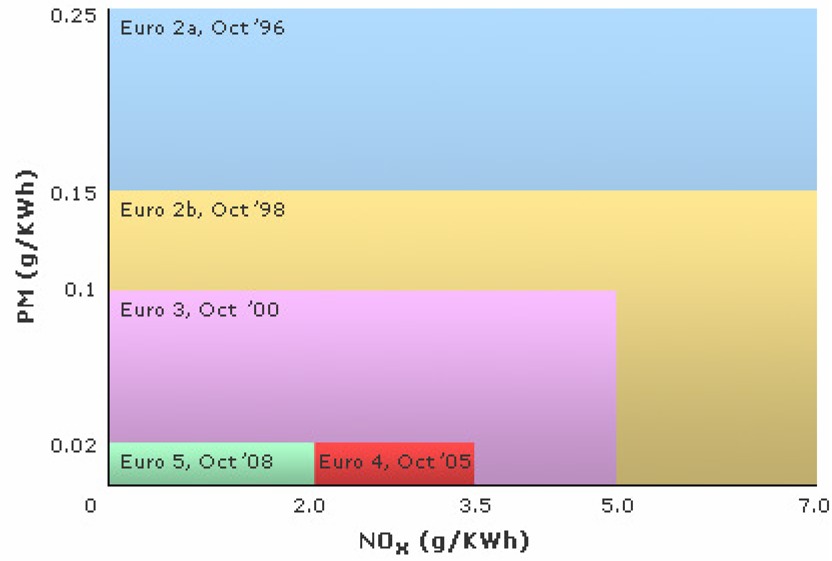

Figure 1-1: European Emission Standards [2]

Table 1-1: European Emission standards for Light commercial Vehicles [3]

EU Emission Standards for Light Commercial Vehicles [g/km]								
Fuel	**Class**	**Tier**	**Date**	**CO**	**HC**	**HC+ NO_x**	**NO_x**	**PM**
Diesel	N1, Class I <1350kg	Euro 1[i]	1994	2.72	-	0.97	-	0.14
		Euro 2, IDI[ii]	1998	1	-	0.7	-	0.08
		Euro 2, DI[ii]	1998	1	-	0.9	-	0.1
		Euro 3[iii]	2000	0.64	-	0.56	0.5	0.05
		Euro 4[iv]	2005	0.5	-	0.3	0.25	0.025
		Euro 5[v]	2008	0.5	-	0.25	0.2	0.005

One such solution involves the modification of the existing diesel engine and, more precisely, the fuel injection equipment such that conventional diesel may still be used. This however, would be accomplished at great expense and the long-term feasibility of such an approach remains uncertain. Another possibility is to limit the use of diesel as a fuel for compression ignition engines, which in turn will increase the need for alternate fuel.

[i] European Union Directive 93/59/EEC

[ii] European Union Directive 96/69/EC

[iii] European Union Directive 98/69/EC

[iv] European Union Directive 98/69/EC

[v] European Union Proposed Com(2005)68

1.2 Types of Emissions

The main pollutants emitted from the exhaust of a typical diesel engine include hydrocarbons (HC), oxides of nitrogen (NO_x), particulate matter (PM) and carbon monoxide (CO). Other emissions such as hydrogen (H_2), oxygen (O_2) and water (H_2O) are not considered to be pollutants since they are not known to produce detrimental effects.

1.2.1 Hydrocarbons

Hydrocarbons describe the large family of emissions composed of hydrogen and carbon in a variety of chemical bonds. Hydrocarbons (HC) are formed when fuel is not adequately oxidised, or burned. In diesels, incomplete combustion of the fuel results in soot formation, visible as large clouds of black smoke containing up to 0.5% of the fuels mass. During start-up, and subsequent misfire, unburned fuel may condense and produce clouds of white smoke. Overall, the level of HC emitted as a pollutant is strongly dependant upon the fuel distribution and resulting combustion inside the cylinder.

1.2.2 Particulate Matter

Particulate formation is a major concern in the diesel engine combustion and consists mainly of carbonaceous conglomerations. These clumps are formed mostly through incomplete combustion of fuel with small contributions from the lubricating oil.

1.2.3 Nitric Oxides

The principal oxide of nitrogen formed in combustion processes is nitric oxide, NO. Nitric oxide is a high-enthalpy species relative to N_2 and O_2 from the standpoint of basic thermodynamics. Therefore, its presence is favoured by the existence of high temperature. The most undesirable toxic effect of nitric oxide (or any of the oxides of nitrogen) is the very small, but cumulative joining with moisture in the lungs causing respiratory problems.

1.2.4 Carbon Dioxide

Carbon Dioxide (CO_2) is one of the primary emissions for perfect combustion. The amount of CO_2 produced depends on the equivalence ratio, with the largest amount being produced at an equivalence ratio of unity. Therefore, running the engine slightly rich, or even slightly lean results in a reduction in CO_2.

1.2.5 Carbon Monoxide

The appearance of carbon monoxide in combustion processes is generally a simple result of oxygen insufficiency, either on an overall or local basis. In principle, the concentration of carbon monoxide contained is exhaust products should correspond to a chemical equilibrium state represented by the water gas equation:

$$H_2O + CO \Leftrightarrow H_2 + CO_2$$

1.2.6 Odour

Due to the high sensitivity of the human nose and the inability of chemical instruments to measure the presence of materials in extremely low concentrations, the source of odour currently cannot be established.

1.2.7 Sulphur

Diesel fuel for vehicle use normally contains from 0.1% to 0.5% sulphur by weight. The great majority of sulphur emissions arise from the combustion of coal and quantity contribution by internal combustion engines is comparatively small, and diminishing under the pressure of legislation.

1.3 Alternative Fuel Vehicles

Alternative fuel vehicles (AFV) can operate on fuels other than gasoline or diesel. Using alternative fuels helps reduce the dependence on fossil fuels, like oil, and improves air quality.

AFVs range in size and shape, from small commuter cars to large 18-wheeler trucks. Currently, automobile manufacturers offer light-duty vehicles (LDVs) capable of operating on compressed natural gas (CNG), propane (LPG), electricity, E85 (a blend of 85% ethanol and 15% gasoline), and biodiesel. Cars that can use E85 are often referred to as flexible fuel vehicles (FFVs) because they can be refuelled using either E85 or gasoline.

In addition to personal transportation, AFVs are well suited for fleets in certain "niche" markets. Taxi fleets, for example, with high-mileage vehicles that drive fairly centralized routes, may benefit from using a less-expensive alternative fuel such as natural gas or propane. Local delivery fleets-with low-mileage, high-use vehicles that frequently idle in traffic or must often start and stop may be good candidates for electric vehicles. Medium- and heavy-duty AFV applications include transit buses, airport shuttles, delivery trucks and vans, school buses, refuse haulers, and street sweepers. Heavy-duty manufacturers often provide the option to install specialized fuelling systems and engines optimised for alternative fuel use in the vehicles they produce. The alternative fuels commonly used in heavy-duty vehicles include natural gas, propane, electricity, and biodiesel. Dimethyl Ether (DME), however, has also become an attractive alternative fuel for compression ignition engines.

2 Dimethyl Ether (DME)

2.1 Description

Dimethyl Ether (DME) is a flammable, colourless gas with a slight ethereal odour at room temperature and atmospheric pressure. It is shipped as a liquefied gas under its own vapour pressure of 430 kPa @ 20 °C[4].

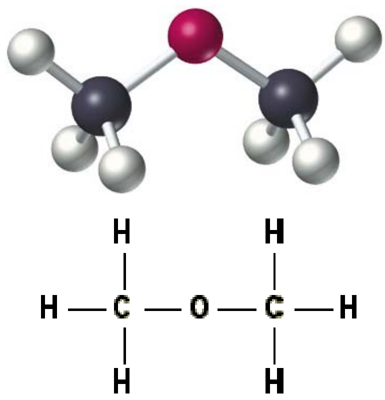

Figure 2-1: Dimethyl Ether Molecular Structure

2.1.1 Uses

Dimethyl Ether finds commercial use as a refrigerant. It has also been used as a solvent, as an extraction agent, as a propellant in aerosols, and as a fuel for welding, cutting, and brazing. But more recently, it has been found to be a very attractive alternative fuel for compression ignition engines.

2.1.2 Toxicity

- Concentrations of 5-20 % by volume cause such symptoms as intoxication, in-coordination, blurring of vision, anesthesia, headache, dizziness, excitation, and unconsciousness, depending on the duration of the exposure[4].
- Contact of the liquid or concentrated vapour with the skin can cause frostbite.
- Dimethyl Ether has a low order of inhalation toxicity.

2.1.3 Materials of construction

Since Dimethyl Ether is non-corrosive to metals, any common or commercially available non-sparking material may be used. However, it reacts corrosively with most rubbers and plastics with the exception of PTFE and butyl-n rubber.

2.1.4 Commercial Preparation

Dimethyl Ether is prepared by the dehydration of methanol with sulphuric acid or by dehydration over alumina at high pressures and temperatures. Currently DME is manufactured from natural gas-derived methanol, but may also be manufactured from methanol derived from coal and biomass, thus securing future availability [4].

2.1.5 Vapour Pressure

The vapour pressure for DME may be calculated using the following Antoine vapour pressure equation [4]:

$$\log_{10} p = 7.31646 - \frac{1025.56}{256.05 + t}$$

p - mmHg

t - °C

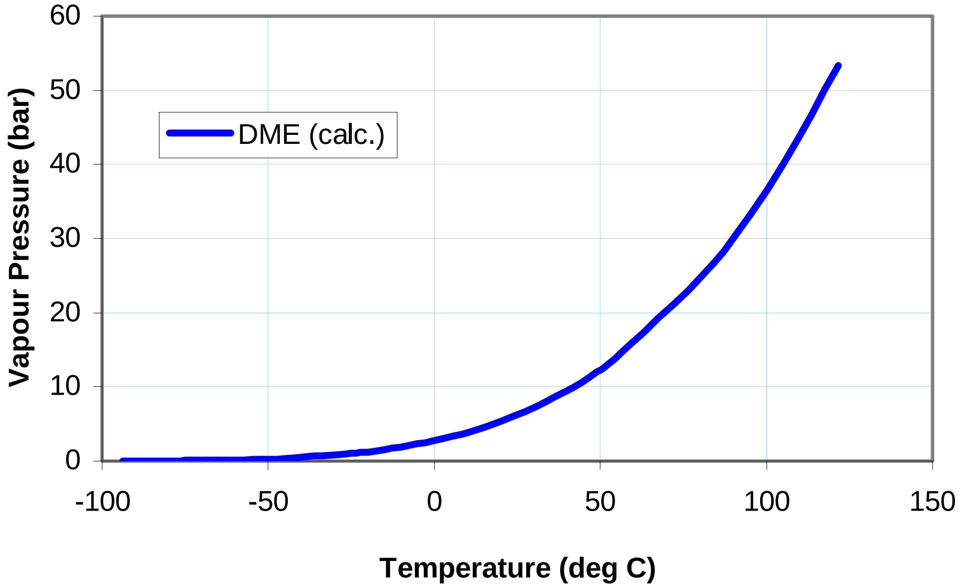

Figure 2-2: Antoine vapour pressure equation [4]

2.1.6 Chemical Properties

Table 2-1: Chemical Properties of Dimethyl Ether [5]

Chemical Composition	**CH_3-O-CH_3**
Boiling Point [°C]	**-24.9**
Vapour Pressure @ 20 °C [MPa]	**0.51**
Liquid Density @ 20 °C [$kg.m^{-3}$]	**668**
Specific Density (gas)	**1.59**
Lower Heating Value [$MJ.kg^{-1}$]	**28.43**
Auto Ignition Temperature @ 1 atm [°C]	**235-350**
Explosion/Flammability Limit in Air [Vol%]	**3.4-17**
Cetane Number	**55-60**
Stoichiometric Air/Fuel Ratio	**9**
Latent Heat of Evaporation [$kJ.kg^{-1}$]	**460**
% wt Carbon	**52.2**
% wt Hydrogen	**13**
% wt Oxygen	**34.8**

2.1.7 Comparison of DME Properties to Diesel

- DME has better ignition quality due to higher cetane number and lower auto-ignition temperature.
- DME has better atomisation due to its lower boiling point.
- The low viscosity of DME is regarded as a disadvantage as it affects the conventional film between the needle and sleeve of the injector, resulting in leakage and wear. Usually a 1-2% (by volume) lubricant is added during DME testing.
- The low boiling point of DME also demands a pressurised delivery line in order to keep it in the liquid state.
- The calorific value of DME is less than that of diesel. A larger supply of DME is needed to obtain the same power output.
- The latent heat of evaporation of DME is much higher and it will be beneficial to the NO_x reduction due to the large temperature drop of the mixture in the cylinder.
- DME has also been shown to be cheaper on a per mass basis, although slightly more fuel is required than diesel to obtain the same power.

3 Literature Survey

3.1 Introduction

The literature survey primarily focuses on the use of DME as an alternative fuel. Sections on exhaust emissions, performance characteristics, injection characteristics, and combustion characteristics were studied to gain knowledge on current world wide DME research. It also serves as a guide for trouble shooting problems of similar experiments.

3.1.1 Comparison of Heat Release and NO_x Formation in a DI Diesel Engine Running on DME and Diesel Fuel [6]

Introduction

This paper deals with the heat release and NO_x formation of both DME and Diesel fuel. The emphasis was on creating similar injection conditions for both fuels, this entailed using the same injection system, injection pressure, injection timing, and duration. The only differences were the diameters of the nozzle holes.

In order to study the contribution of the total NO_x and other emission at full load from the different stages of combustion, the injection duration was varied. This was accomplished by maintaining the start of injection as constant and varying the time for the end of injection.

Results

The results showed that the mass of NO_x per unit of supplied fuel energy decreased with injection duration. This was the case for both Diesel and DME. It was believed that formation of NO_x was also dependant on the timing of the injection of the fuel. Early-injected fuel gave the combustion products longer residence time in the cylinder. This meant that the early-injected fuel spent longer times at high temperatures than fuel that was injected later, thus resulting in a higher NO_x formation.

It was noticed that the general level of NO_x was about the same for the two fuels. However, at shorter durations DME gave slightly lower NO_x levels, while at longer durations the inverse was true. This was attributed to the rates of heat release as well as the lower adiabatic flame temperature of DME.

Since most of the NO_x was produced before 30° after TDC, it was reasonable to assume that the mixing between combustion zones and the air is limited while most of the NO_x is formed.

Thus, the difference in NO_x formation could be explained by the local conditions in which the fuel is converted to combustion products.

Discussion and conclusion

The low NO_x emission potential of DME was believed to be due to the possibility to burn the fuel at high equivalence ratios without experiencing excessive soot emissions. The combination of low injection pressure, large nozzle hole diameters, and fast vaporisation led to worse spray penetration and fuel/air mixing than that of diesel, which resulted in high local values of equivalence ratios. Since most of the NO_x was formed in the early burning zones, it was suggested that rich initial burning resulted in low NO_x formation.

It was concluded that:

- No fundamental differences were found when comparing the heat release of the two fuels.
- The emissions of NO_x are about the same for the two fuels.
- If the same local conditions, with respect to the equivalence ratio and residence time could be achieved with DME and diesel fuel, DME would give somewhat lower NO_x concentration than diesel due to the lower adiabatic flame temperature.
- The low injection pressures used in this study gave worse mixing and higher local equivalence ratios than usual for diesel fuel. Thus, the NO_x formation was less than usual and reached the low levels found with DME.

3.1.2 Effects of Fuel Injection Characteristics on Heat Release and Emissions in DI Diesel Engine Operated on DME [7]

Introduction

An experimental investigation was conducted using a direct injection single-cylinder diesel engine equipped with a common rail fuel injection system to clarify how DME injection characteristics affect the heat release and exhaust emissions.

The experiment was conducted using two different configurations of injector nozzles, where both had identical total nozzle hole area. The first injector had five holes, each with a diameter of 0.55 mm, whereas the second comprised of three holes, each with a diameter of 0.7 mm. The effects of the injection rate and swirl ratio on NO_x emission was also investigated.

Results and Discussion

The results showed that the NO_x emissions relating to the 5-hole injector nozzle were higher than those of the 3-hole across the entire injection quantity range. It was also recorded that as injection quantity increased, the difference in NO_x between the two nozzle configurations decreased.

The 5-hole injection nozzle had faster atomisation and quicker vaporization around the spray core than the 3-hole. This explained the higher levels of NO_x, as NO_x tends to increase with increasing combustion temperatures. Thus conclusively, the faster atomisation and quicker vaporization of DME through the 5-hole injector increased the combustion temperature due to better air/fuel mixing.

The NO_x emission results for both nozzles as a function of swirl ratio were also graphically represented for two values of injection fuel quantity. Here again, it was recorded that NO_x levels were higher for the 5-hole injector nozzle, across the range of swirl ratio and for both injection rate settings.

However, the difference in NO_x levels between the 5-hole and 3-hole injectors were more prominent for the smaller injection rate setting, and gradually decreased as the injection rate and swirl ratio increased. The overall NO_x concentration increased, for both the 5-hole and 3-hole nozzle, as the injection rate and swirl ratio increased.

Conclusion

It was concluded that:

- The NO_x levels were higher for the 5-hole injector nozzle for both injected quantities, due to the fact that the 5-hole nozzle possessed faster atomisation and quicker vaporization. This resulted in higher flame temperatures, and lower fuel-cylinder penetration, which inherently increases the NO_x levels.
- Due to the difference in injection process of the nozzles, when a large quantity of fuel is injected, the 3-hole injection nozzle, with an equivalent energy consumption rate of the 5-hole nozzle, results in less NO_x emissions.

3.1.3 Engine Performance and Exhaust Characteristics of Direct-Injection Diesel Engine Operated with DME [8]

Introduction

DME was investigated as a suitable alternative to diesel fuel by measuring engine performance and exhaust emissions. In addition, responses to injector needle lift, fuel feed pressure and heat release were also investigated.

Due to the high elastic modulus of DME, the needle lift of a conventional injector was expected to shift. Should it have shifted, even by a few crank angle degrees, the subsequent combustion process would be remarkably altered, thus, affecting both the performance and emissions.

The tests were carried out at two different injection timings, the first being the recommended manufacturer's injection timing for diesel (17° bTDC) and the other for a delayed injection time of 5°bTDC.

Results

During the first test, the injector was set to respond at 17° bTDC. However the actual (dynamic) opening occurred at 13° bTDC for DME and 9° bTDC for diesel fuel, respectively. This difference was considered to occur by a combined effect of several variables, namely the feed pressure, the preset nozzle opening pressure, and the elastic modulus of the fuel.

The results obtained, showed that the NO_x emissions for DME were greater than those for diesel. This was the case when the engine was operated at the manufacturer's injection timing. The higher levels were thought to come as a result of early combustion when using DME.

However, changing the timing to 5° bTDC, the NO_x emissions obtained for DME were much lower than those of diesel. This was attributed to the high rate of fuel injection for diesel, which produced high-temperature combustion products with the piston still near TDC. This however was not the case for DME, as the prolonged injection resulted in a continuous combustion with the piston still moving away from TDC.

It was also noticed that the combustion products of DME produced negligible soot emissions, whereas diesel had a distinct trade-off between NO_x formation and soot emissions.

Therefore, the hindrance of NO_x formation by means of retarded injection timing would not result in an increase in soot emission.

Conclusion

It was concluded that:

- When the engine ran on DME, using the manufacturer's injector settings (17° bTDC), it produced higher levels of NO_x than diesel. This was due to early injector (needle lift) opening which was attributed to the increased feed pressure necessitated by the high vapour pressure of DME.
- The NO_x emissions for DME decreased as the injection timing was delayed. The same was found for diesel, however, as the timing was retarded the soot emissions increased significantly for diesel, but remained almost negligible for DME.

3.1.4 Experimental Study on Performances and Combustion Characteristics of a DME powered Vehicle [9]

Introduction

The development of clean alternative fuels for internal combustion engines has become an ever-increasing concern to the world. These developments are aimed at solving severe petroleum resource shortages and more importantly, the protection of the environment.

This paper presents research results of a DME powered engine and vehicle. The main parameters of the combustion system, such as the plunger diameter, nozzle type, fuel delivery advance angle, the distance of nozzle tip into cylinder, and the swirl ratio were optimised. The combustion characteristics and emissions were also compared against those of diesel.

The tests were carried out using both a single cylinder and a multi cylinder engine. The multi cylinder comprised a 4 cylinder, 3.2 L, 66 kW engine, while the single cylinder comprised a 0.9 L 11 kW engine.

Results

The test results showed that the optimum timing angle for DME is 19° bTDC at rated operational condition and 15° bTDC at low speed.

The optimum air swirl ratio for the highest thermal efficiency of the engine was found to range from 1.4 to 1.8, which is lower than that of diesel operation (2.3), due to the easy evaporation of DME and mixing with air.

From the five different nozzles that were tested, it was found that a 5-hole nozzle with hole diameters of 0.32 mm achieved the best thermal efficiency. It was also discovered that the optimum distance that a DME injector nozzle should protrude into the cylinder was 5 mm. This was 2 mm deeper than that of a diesel injector. It was believed that the spray angle for DME became much larger soon after being injected. Therefore, by moving the injector deeper into the cylinder prevented the spray from coating the bottom plane of the cylinder head.

It was also recorded that the maximum cylinder pressure for DME was on average 20 bar lower than that of diesel, DME also had a much slower rate of pressure rise. This has its advantages, as it allows for low mechanical loads and combustion noise.

From an emissions point of view, it was observed that DME produced a smokeless combustion along with NO_x levels that are half those of diesel.

Modifications and Trial Operation Results of a DME Powered Vehicle

An original diesel engine was modified to accommodate DME, the modifications were done according to the optimised data obtained from the test bench.

The vehicle's engine had two parallel fuel systems, one for diesel and the other for DME. It could be run using either of the fuels. The vehicle has already done more than 500 km highway driving, generating the following preliminary results:

- The noise of the vehicle was equivalent to that of a gasoline powered vehicle, along with smokeless combustion.
- The maximum speed (115 – 120 km/h for DME) and accelerating performance was similar to that of diesel.
- By adding a lubricant to the DME, apparent wear on all components was minimised.

Conclusion

It was concluded that:

- The preliminary operating results of the DME powered vehicle showed that the combustion noise was equivalent to that of a gasoline powered vehicle.
- Under frequently operated speeds, the exhaust gases proved to be smoke free when running on DME.
- The maximum speed and accelerating performance of the DME powered vehicle were equivalent to those with diesel fuelling.
- DME is an excellent and environmentally friendly alternative fuel for diesel engines.

3.1.5 Effects of Fuel Injection Conditions on Driving Performance of a DME Diesel Vehicle [10]

Introduction

Studies specializing in DME spray behaviour, DME combustion, DME lubrication and DME viscosity analysis have all been carried out in the past. In addition, DME vehicles have been developed, and operational tests are currently being carried out.

The figure below illustrates the saturated vapour pressure curve of DME. In experiments to date, the DME fuel supply line has always typically been pressurized to between 13 bar and 20 bar by using nitrogen. From the vapour pressure curve, it could be considered that the backpressure of nitrogen was sufficient in maintaining liquefaction of DME.

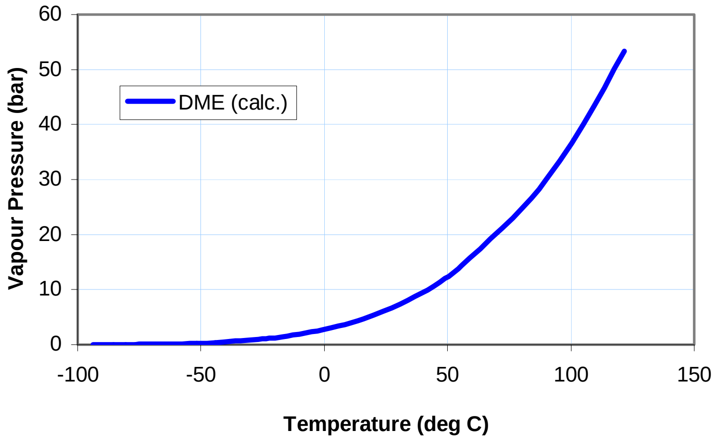

Figure 3-1: Vapour Pressure vs. Temperature [4]

This study focused on controlling the DME temperature with a distributor type injection pump, aiming for an overall reduction in the DME supply line temperature. In addition, the effect of EGR on the NO_x emissions was also examined.

The test engine was a four-stroke, four-cylinder, naturally aspirated, direct injection, diesel engine. The fuel injector nozzles had six holes, each with a diameter of 0.24 mm (diesel fuel 0.175 mm). Furthermore, the engine was fitted with a distributor type injection pump, operated by an electronic control unit (ECU).

For the purpose of this research, two injection timings were used. The first was set to 10 degree bTDC, this was a 6 degree advance from standard diesel operation (4 degree bTDC), and the second was a range between 19 degree and 4 degree bTDC, this was to accommodate the dynamic effects of combustion at different speeds, along with the possibility of reducing NO_x emissions while improving output power at high engine speeds.

The exhaust emissions were analysed using the direct sampling method. CO, THC, and NO_x were continuously analysed using a non-dispersion infrared analyser (NDIR), flame ionisation detector (FID) and chemiluminescence analyser (CLA), respectively. EGR was also used to reduce the levels of NO_x.

Results and Discussion

The fuel delivery capability of the DME fuel system was the first to be investigated, it was observed that for a non-pressure regulated fuel supply line, a 2.9 l/min pump output was measured. Whereas, for a 2.5MPa regulated fuel line, a 2.3 l/min pump output was measured. These figures changed to 5.9 l/min and 4.6 l/min, respectively, when a secondary feed pump was introduced. The secondary feed pump increased the circulation of DME, which in turn brought down the overall fuel temperature, and allowed for the DME to remain in a liquefied state.

The second to be investigated was the engine performance; data was recorded while using an injection timing of 19 to 4 degree bTDC, a fuel flow rate of 4.9 l/min and a fuel supply line pressure of 10 bar. It was discovered that at higher engine speeds the power generated by DME was about 20 to 30% lower than that of diesel. This was as a result of a lower calorific value. However, initial thoughts of increasing the injector hole diameters did not prove to be of any help.

From previous observations it was noted that the engine performance became unstable as the DME supply line temperature increased. This was the result of DME vaporizing in the fuel line causing partial vapour locks. However, through the introduction of a secondary feed pump, the circulation quantity was significantly increased, and the fuel temperature was maintained at 303K (30ºC), allowing for stable engine operation.

The relationship between brake mean effective pressure (BMEP) and NO_x emissions was investigated next. This was done at a speed of 1680 rpm. These tests focused on comparison and examination of EGR effects, and the effect of fuel injection timing. It was reported that, without EGR, NO_x levels were lower at low engine loads, but increased quickly with engine load. However, maximum load NO_x levels decreased somewhat when the EGR valve was opened.

By using EGR, and an injection timing ranging between 19 and 4 deg bTDC, it was possible to decrease the NO_x concentration to 400 ppm at a BMEP of 0.6 MPa.

Development of the DME TRUCK and MINI-BUS

DME fuelled 2-ton Truck

DME Fuelled Courtesy Bus

Figure 3-2: Development of a DME Truck and Mini-Bus [10]

These vehicles are based on standard commercial vehicles using the same type of engine that was used for the bench tests. The engines were not altered, however, modifications had to be made to the fuel injection system to accommodate the unique characteristics of DME. The mini-bus is a handicapped-accessible type, with a wheel chair lift in the rear. This was a major advantage, as it allowed for the wheel chair access point to be closer to the exhaust pipe as a result of much lower emissions.

Conclusion

It was concluded that:

- By increasing the fuel circulation rate in the fuel supply line, a reduction in overall fuel temperature, for a distributor type fuel injection pump, could be achieved.
- Increasing the circulation rate in the fuel supply lines, and hence lowering the fuel temperature, resulted in injection timings similar to those for diesel.
- Since DME undergoes smoke-free combustion, the NO_x reduction effect of EGR is significant, even at high engine loads.

4 Analysis

4.1 Objectives

The objectives of this research project were to design and develop a small compact low pressure DME fuel system. The system had to be designed with the scope of one day being fitted to a small standard diesel light duty vehicle (LDV) (Not discussed in this report). The design was to include features such as: weight, size, robustness, and reliability. The analysis was performed in terms of:

- Engine injector characteristics, engine emissions, energy release and the performance characteristics of the new DME fuelling system.

4.2 Approach

The approach used to obtain the necessary research results was as follows:

- A concept for a new compact fuel system had to be introduced
- Confidence tests along with preliminary test had to be planned
- Tests (engine bench tests) were to be run at loads of 25 Nm, 35 Nm, and 45 Nm for engine speeds ranging from 1100 rpm to 1800 rpm in 100 rpm intervals.
- Testing would only be done using the low pressure DME fuelling system.
- The engine would be used without any modifications.
- Previous results for high pressure DME and diesel testing would be used for comparison purposes.
- Injector pressure trace diagrams would be produced using the supplied software.
- A comparison of the results would be performed.

Extended approach (Not conducted for this report)

- Vehicle tests – a modified version of the Low Pressure DME fuelling system would be custom fitted to a diesel LDV. Rolling road dynamometer tests would be conducted and investigations of the feasibility and efficiency of the Low Pressure DME fuelling system would be conducted.

5 Experimental Facilities and Equipment

The experimental testing was performed in an existing engine test cell in the thermodynamics department within the North West Engineering Laboratory. Figure 5-1 below illustrates the equipment used during the experimentation.

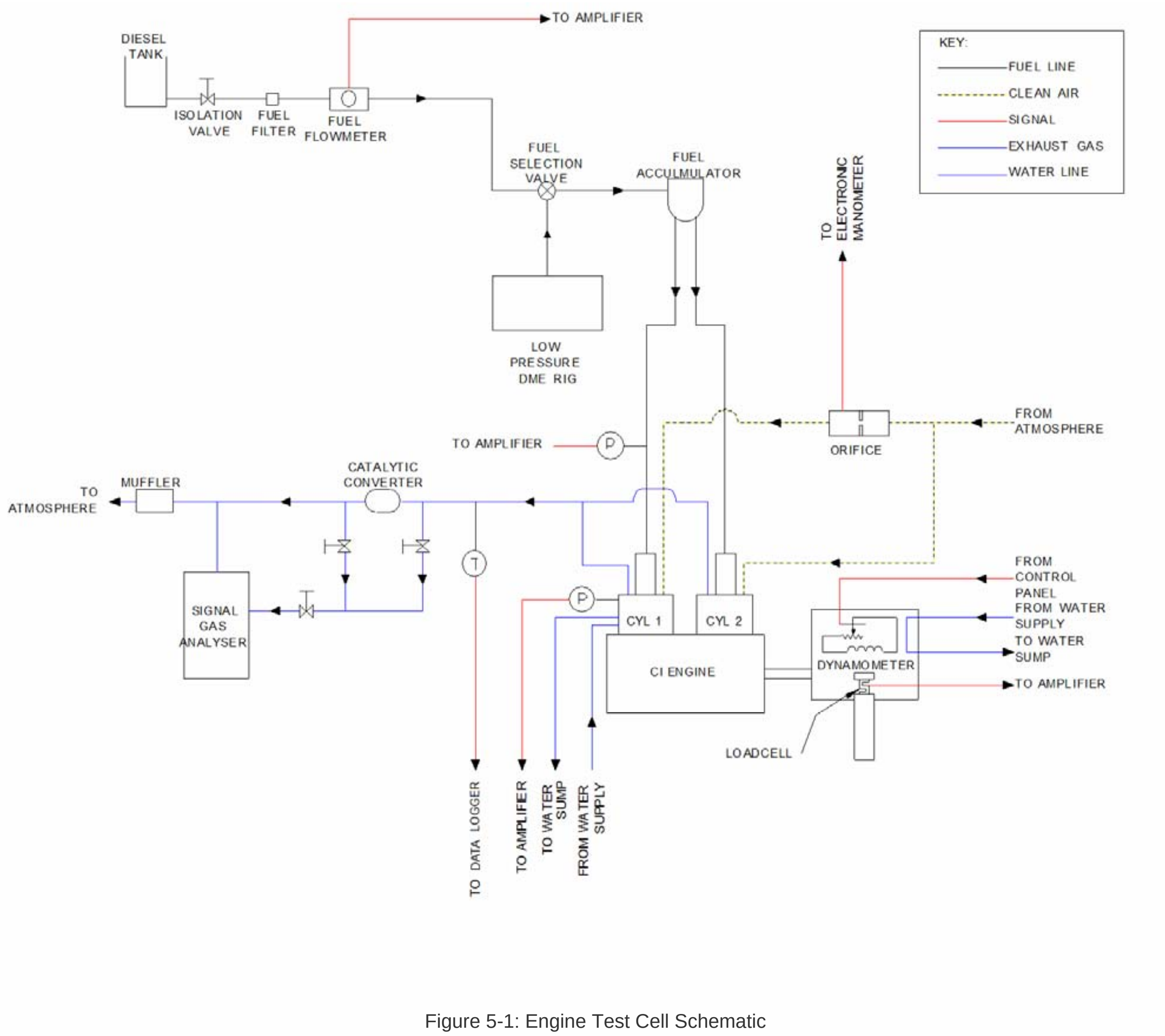

Figure 5-1: Engine Test Cell Schematic

5.1 Compression Ignition Engine

The engine used for the research was a four-stroke Lister Petter direct-injection compression ignition engine. Below is a table listing the engine specifications.

Figure 5-2: Lister Petter Engine

Table 5-1: Engine Specifications

Description	
Manufacturer	Lister Petter
Model	PH2
Displacement	1330 cubic centimetre
No. of Cylinders	2
Bore	87.74mm
Stroke	110.0mm
Maximum Power	13.4 kW @ 2200 rpm
Maximum Torque	59.4 Nm @ 2200 rpm
Compression Ratio	16.5 : 1
Fuel Injection Pressure	
900 rpm – 1099 rpm	137 / 152 bar
1100 rpm – 2000 rpm	197 / 217 bar

Engine Specifications Continued	
Fuel Injection Timing	
0 – 1650 rpm	24° BTDC
1651 – 2000 rpm	28° BTDC
Valve Timing	
Inlet valve open	13.5° BTDC
Inlet valve closed	38.5° ABDC
Outlet valve open	38.5° BBDC
Outlet valve closed	13.5° ATDC

5.2 Fuel Pumps and Injectors

The fuel pumps and injectors were used with no modifications and were according to the manufacturer's original specifications. The injectors used were of the three-hole type and were set to open at 210 bar. Each injector had its own dedicated fuel pump and fuel line.

5.3 Dynamometer

The dynamometer used during the testing was a Borghi & Saveri water cooled eddy current dynamometer. The dynamometer is coupled directly to the engine and is used to apply various loading conditions on the engine.

Figure 5-3: Borghi & Saveri Dynamometer

Table 5-2: Dynamometer Specifications

Manufacturer	Borghi & Saveri
Model	FE 150 S
Maximum Speed	13000 rpm
Maximum Torque	280 Nm
Maximum Power	110 kW
Accuracy	0.1 rpm and 0.1 Nm

5.4 Cooling Fans

Two large fans were placed on either side of the engine pointed at the engine cylinders. An extractor fan at the window is used to aid in ventilation. A fourth large fan is required to blow over the Low Pressure DME fuelling system to help cool the electric motor and compressor.

5.5 Fuel System

5.5.1 Fuel Supply System

The fuel supply system consists of a three-way valve to allow different fuels to be selected. Between the valve and the injector pumps is an accumulator to ensure constant fuel supply to the engine.

Diesel is supplied to the system via a fuel header tank mounted higher than the engine. An isolation valve, fuel filter and fuel flow monitor are all mounted up-stream from the three-way valve.

DME cannot be supplied to the fuel system directly from the storage cylinder. In order to maintain DME in a liquid state before it enters the injector pumps, a separate subsystem was required to pressurise and cool the DME.

5.5.2 Previous DME fuel supply line

The previous DME fuel supply system consisted of a pressurised DME gas cylinder complete with isolation valve, a non-return valve and rotameter as well as a fuel circulation pump, heat exchanger, a pressure reducing valve and discharge valve as depicted in Figure 5-4 below.

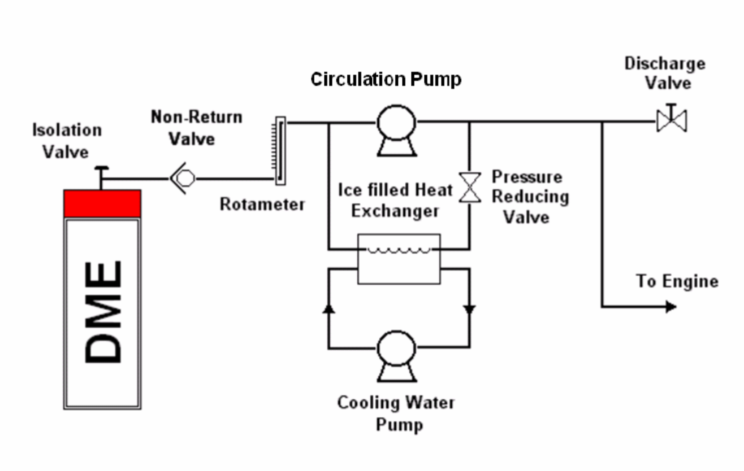

Figure 5-4: High Pressure DME fuel system

The DME was kept in a gas cylinder under its own vapour pressure, generally 4.3 bar, thus ensuring adequate liquefaction. A rotameter was used to record the liquid fuel flow of DME from the cylinder to the circulation pump. A non-return valve prevented liquid with a pressure greater than 4.3 bar from re-entering the cylinder. The liquid DME was allowed to flow through a positive displacement pump, which subsequently pressurised it to 50 bar. The excess fuel from the pump was fed, by means of an overflow line, through a pressure-reducing valve, then through a heat exchanger, and finally rejoining the fuel supply line. The heat exchanger was submerged in ice water to ensure that the fuel in the return line remained in its liquid state before re-entering the pump inlet. Due to the inherent high pressure (50 bar) that this system produces it has been decided, for the remainder of this report, to refer to it as the "*HP DME Fuelling System*", where "HP" refers to "high pressure".

Advantages and disadvantages of the previous system

Advantages

- High pressure guarantees liquefaction of DME.
- The modulus of elasticity tends to increase with increasing pressures. Therefore, under high pressures DME will behave similarly to diesel.

Disadvantages

- Uses ice water to cool down the fuel line.
- Uses a high-pressure electric (220V) positive displacement pump.
- Fuel system requires expensive certified high pressure parts

5.5.3 Development of the Low Pressure Fuel System

Design Summary

Purpose: Maintain continuous operation of a small DME – Diesel engine running on DME fuel.

Issues and Concerns

- *Sub-zero boiling point of DME* – Due to the low boiling point of DME, attention has to be given to the liquefaction of DME.
- *DME needs to be under pressure* – Due to the high vapour pressure of DME, attention has to be given to the design and development of a dedicated pressurisation system.
- *Low Lubricity and Viscosity* – Attention has to be given to the mechanical components and seals that are to be used.
- *DME tends to be corrosive to many rubbers* – Research has to be done on rubbers and seals to ensure prolonged operation.
- *No Original Equipment Manufacturer (OEM) parts available* – Due to the nature of Research and Development, there are no OEM parts for DME – Diesel engines commercially available.
- *Custom build components* – As mentioned above, no OEM parts available, therefore, most components have to be designed and manufactured in-house.
- *Portable and compact* – Size and weight are a major constraint, as the system is to be design with the scope of one day being installed into a diesel light duty vehicle.
- *12V compatible* – Same as above.

Design objective: To design and develop a compact system that will deliver liquid DME from a storage cylinder to the injection system of a small compression ignition engine.

Results to achieve

- Operational compression ignition engine
- Low cost system
- No boiling or cavitation of DME fuel
- Optimal performance
- Lower wear and tear
- Low maintenance
- Robust
- Compact and light weight

- Safety orientated
- Correct flow rate

Results to prevent

- Hidden costs
- Complicated design
- Fuel starvation
- Fuel blockage
- Interfering with external devices
- Unacceptable fuel pulsations

Available Resources

- Computers with Matlab and CAD programs
- Mechanical Engineering Machine Shop
- Skilled personnel
- Libraries
- Large inventory of spare parts

Constraints

- Tight budget
- Physical size
- DME properties
- 12 volt compatible

Functional Analysis

Functions

1. Deliver liquid DME fuel
2. Maintain low fuel temperatures
3. Maintain continuity
4. Maintain extended periods of operation

Design Philosophy

Looking at previous research [11], it was noted that the average DME fuel flow was approximately 75 grams per minute. These values were taken from a test that was run using a two cylinder, 1330 cc, Lister Petter diesel engine, at a speed of 1800 rpm and a load of 55 Nm. The fuel flow value taken from these tests was then adjusted to 100 grams per minute to accommodate for any errors and irregularities that may have occurred during the test. The newly adjusted value was then doubled to account for an additional two cylinders, thus making it 200 grams of DME per minute. This would fictitiously supply a four cylinder engine running at 1800 rpm and a load of 55 Nm. This value was then doubled again, under an assumption, to account for a four cylinder diesel engine running at 3600 rpm. Therefore, by assumption, to run a four cylinder, 2700 cc, diesel engine at 3600 rpm and 55 Nm, a conservative DME mass fuel flow of 400 grams per minute would be required (Note: this is a maximum design fuel flow assumption).

It was next decided to investigate the physical properties of DME, starting with the vapour pressure versus temperature plot (Figure 5-5).

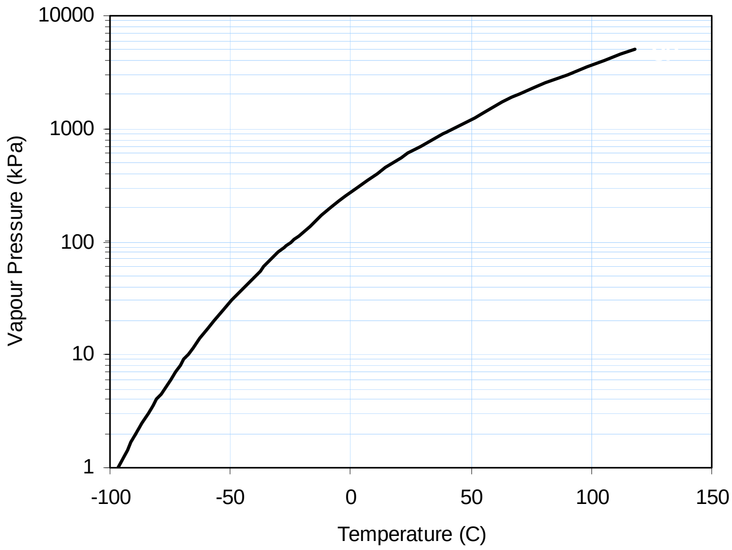

Figure 5-5: Vapour pressure versus Temperature [4]

The vapour pressure versus temperature plot gives a clear indication of the pressures and temperatures required to keep DME in its liquid state. All values found above the vapour pressure line (top left corner) can be considered as liquid and those beneath, as liquid-vapour and vapour. Thus, from a design point of view, an assumption had to be made that the liquid DME would not be exposed to temperatures greater than 50 ºC while being routed to the injector pumps. (This estimate includes the effects of pre-delivery cooling and fuel line insulation)

Looking at the vapour pressure versus temperature plot, it can be seen that the pressure within the fuel line should not be less than 11 -12 bar (1100 – 1200 kPa).

After having done some research [12] it was found that in the past DME was used as an experimental refrigerant known as RE-170. This information led to an even more intensive study on the refrigeration properties of DME along with some common vapour-compression refrigeration systems. In conclusion, it was found that vapour-compression refrigeration systems are one of the most commonly used systems to date. A typical schematic is illustrated in Figure 5-6 below.

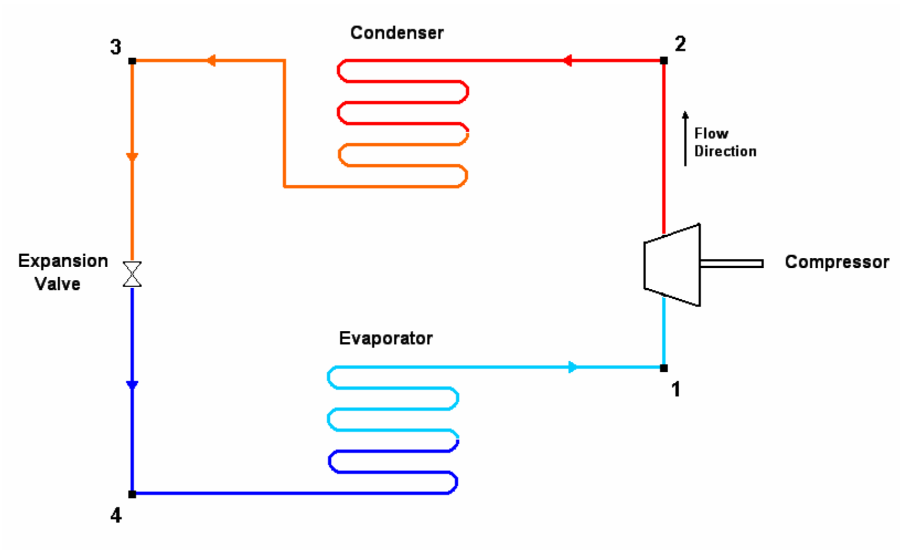

Figure 5-6: Schematic of a vapour compression refrigeration system

The vapour-compression refrigeration cycle, as illustrated above, typically consists of four major components and four major processes. The four components are; the compressor, the condenser, the expansion valve, and the evaporator. The cycle processes are (see Figure 5-6); **process (i)** – *compression* of the refrigerant from state 1 to the condenser pressure at state 2, **process (ii)** – *heat transfer from* the refrigerant as it flows at constant pressure through the condenser and exiting as a liquid at state 3, **process (iii)** – *throttling* process from state 3 to a two-phase liquid-vapour mixture at state 4, **process (iv)** – *heat transfer to* the refrigerant as it flows at constant pressure through the evaporator to complete the cycle.

For the purpose of this design, *process (ii)* is of particular interest, as it states that "*the refrigerant is kept under constant pressure while simultaneously cooling down and finally ending in a liquid state".* What this statement means is that as the refrigerant passes through the condenser at a constant pressure, the condenser inherently transfers heat stored within the gas to the surroundings, which in turn allows the refrigerant to cool down. As the refrigerant cools down, it reaches a point where the pressure and temperature coincides with that of its vapour-pressure. It is at this point where the refrigerant becomes a liquid; any cooling after this point would result in a sub-cooled liquid. This can be seen by means of an example; choosing any constant pressure line and any temperature line from Figure 5-5 above, it is noted that as the temperature decreases the gas approaches the vapour-pressure point. This process is therefore the key in designing the small low pressure DME fuelling system.

Looking at the pressure versus enthalpy chart for RE-170 below, one can see (highlighted in red) how the vapour-compression refrigeration cycle fits in.

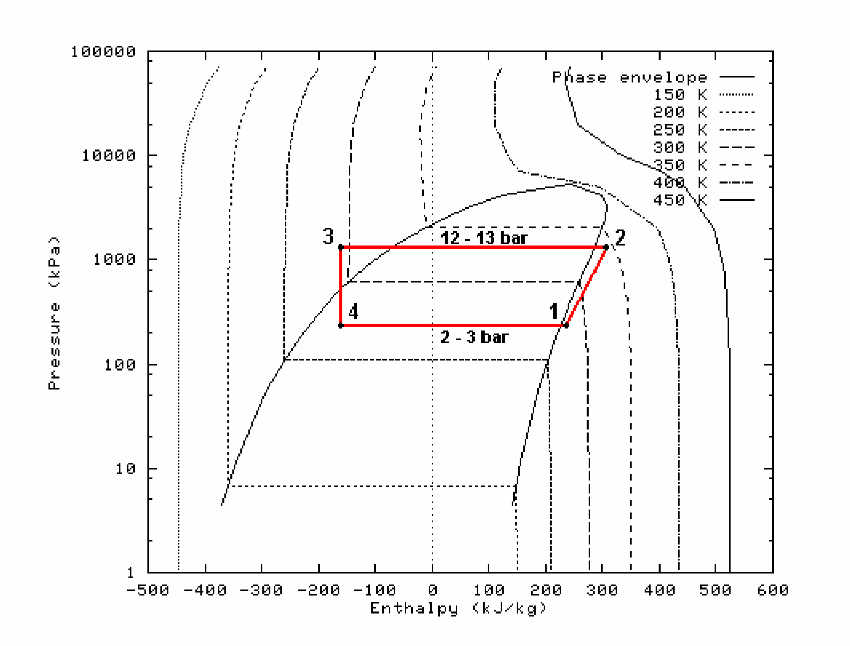

Figure 5-7: RE-170 Pressure versus Enthalpy [13]

Looking at point (1) {state (1)} of Figure 5-7 above, it is noted that it is slightly to the right of the phase envelope. This indicates that DME will be in a gaseous phase before compression so as to avoid hydraulic shock. Moving to point (2) {state (2)}, it can be seen that the DME is still in gaseous form, however, it is now at a pressure of 12.5 bar and carries substantial thermal energy (60 ºC). This energy increase is a result of the compression process which causes the gas temperature and pressure to increase. Moving slowly to point (3) {state (3)}, one notices that the high pressure, high temperature DME vapour crosses into the vapour-dome. This transition causes the vapour to start condensing as it moves towards state 3. This condensation is a result of constant pressure cooling (caused by the evaporator). The DME vapour becomes completely liquid only once it crosses the phase envelope again. Any more cooling after this point will result in a sub-cooled liquid (point (3) {state (3)}). At this point the high pressure sub-cooled liquid is throttled by means of an expansion valve, this process converts the DME back into the vapour dome resulting in a two-phase liquid-vapour mixture.

This throttling process causes the DME to rapidly expand resulting in a large decrease in pressure (from 12.5 bar to 2.5 bar) as well as temperature (from 60 ºC to 11 ºC). The two-phase liquid-vapour mixture then passes through an evaporator where it absorbs heat from the surroundings and ultimately vaporises. This brings the DME back to point (1) {state (1)} where it once again begins the cycle.

Component selection

Having looked at the theoretical side of what happens to DME during its vapour-compression cycle, it was decided to first look at small refrigeration units as a starting point. Initially the focus was on small camping refrigerators and portable ice makers. However, it was soon discovered that these devices did not produce enough cooling power to liquefy the vapourised DME.

Looking for more cooling power, it was found that automotive air-conditioning systems (A/C's) fall within specification. These systems could provide more than enough cooling power, as they are directly coupled to the vehicle's engine. Most A/C's have a displacement of 5 cubic inches per revolution, which is equivalent to a liquid DME flow-rate of 565 g/min at an engine speed of 1800 rpm. This is based on the assumption that the compressor crank rotation is twice that of the engine crank.

The actual compressor used is a Sanden 507, suitable for R12 and R-134a refrigerants. This compressor has a displacement of 7 cubic inch and exceeds the requirements. After having selected the compressor, the next step was to choose a condenser, expansion valve and evaporator. Initially all three of these components were selected from an existing automotive air-conditioning system. Most automotive air-conditioning components are designed to withstand a pressure of about 18 bar, hence the selection of these parts are well within the pressure limits of the designed fuel system.

These components were then connected as depicted in Figure 5-6, however, in addition a gas inlet and a liquid extraction port were added, as can be seen in Figure 5-8 below.

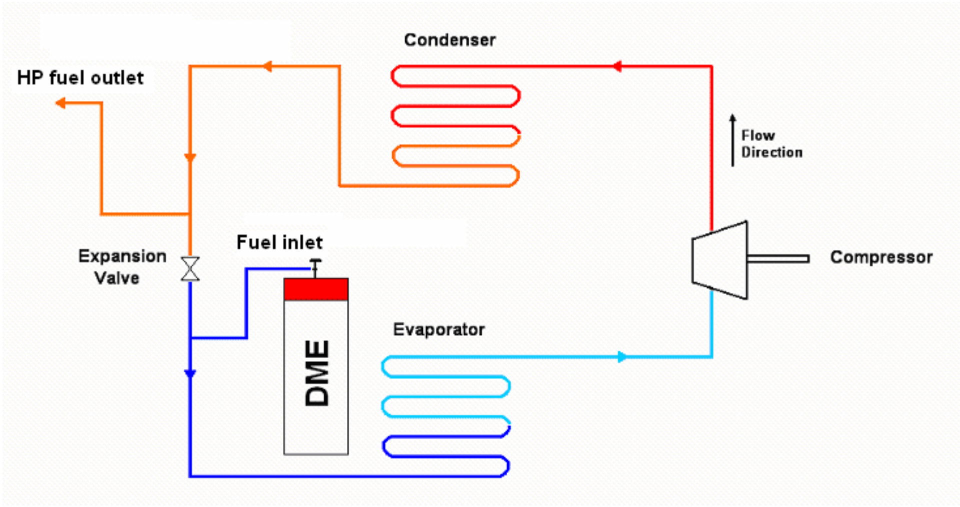

Figure 5-8: Schematic of initial concept

Figure 5-8 depicts the schematic of the very first low pressure DME fuel system. This system was a prototype and inherently had a few flaws. During operation the system allowed two-phase liquid-vapour DME to enter through the inlet, the gas was then allowed to completely evaporate as it passed through the evaporator before being compressed.

It was at this point where the first major flaw occurred. The compressed vapour mixed with the compressor oil and caused it to migrate throughout the system (This is normal for closed loop refrigeration systems) before escaping through the fuel outlet port. This on the one hand had positive aspects, as it produced additional lubrication for the fuel injectors, however on the other hand caused major problems by loosing all the compressor oil. Initially this posed a huge problem as the running time of the system was a maximum of 20 minutes.

This problem initiated further studies on closed loop refrigeration systems. The general conclusion was that most large closed-loop systems used oil separators to control the migration of oil. These devices separate the compressor oil from the refrigerant and pump it back into the sump of the compressor. Oil separators are generally used on large refrigeration systems where most of the compressor oil migrates with the refrigerant. It was therefore decided to install an oil separator downstream of the compressor to reduce oil migration and maintain sufficient oil levels, as shown in Figure 5-9.

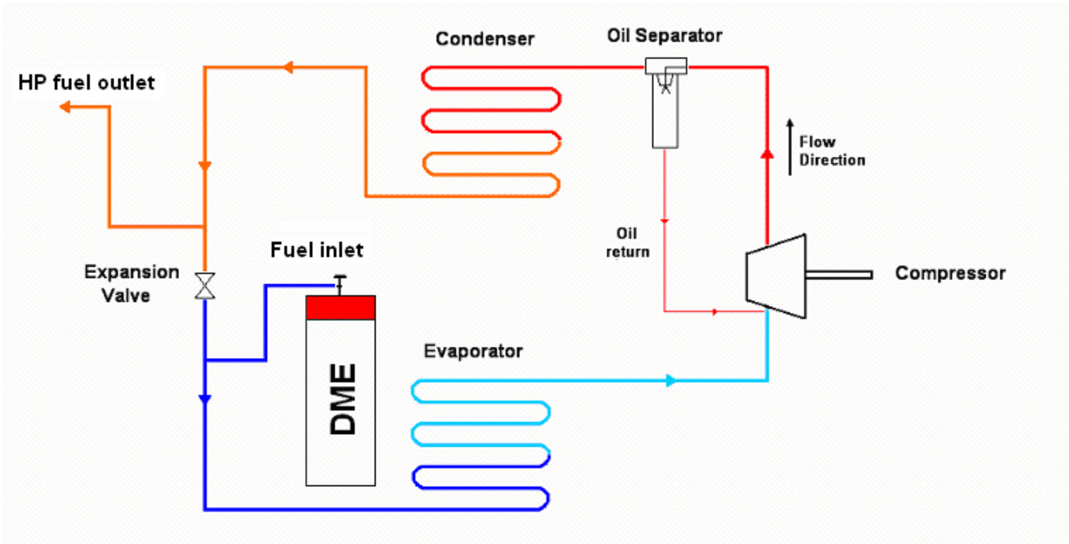

Figure 5-9: Schematic of initial concept with oil separator

Re-running the test with the oil separator installed, verified that the oil migration problem was solved.

The next point of concern was the actual physical size of the system. As seen in Figure 5-9, the system consists of two fair sized automotive air-conditioning radiators. These radiators were considered bulky and it was decided to design a heat exchanger. The heat exchanger was designed to transfer heat from the condenser to the evaporator, which would effectively speed up the condensation and evaporation processes. The selected heat exchanger was a counter flow design which allowed for more contact time between the two incoming fluids. The heat exchanger was sized using empirical methods. The heat exchanger was designed in a coaxial arrangement with a total length of 9m and a coil diameter of 0.28m. The new modified system is illustrated in Figure 5-10 below. For simplicity the heat exchanger is represented as illustrated and not in helical configuration. The actual prototype is shown in Figure 5-11. In addition a liquid receiver was installed just down stream from the heat exchanger. The liquid receiver is used to separate gas bubbles from the liquid line.

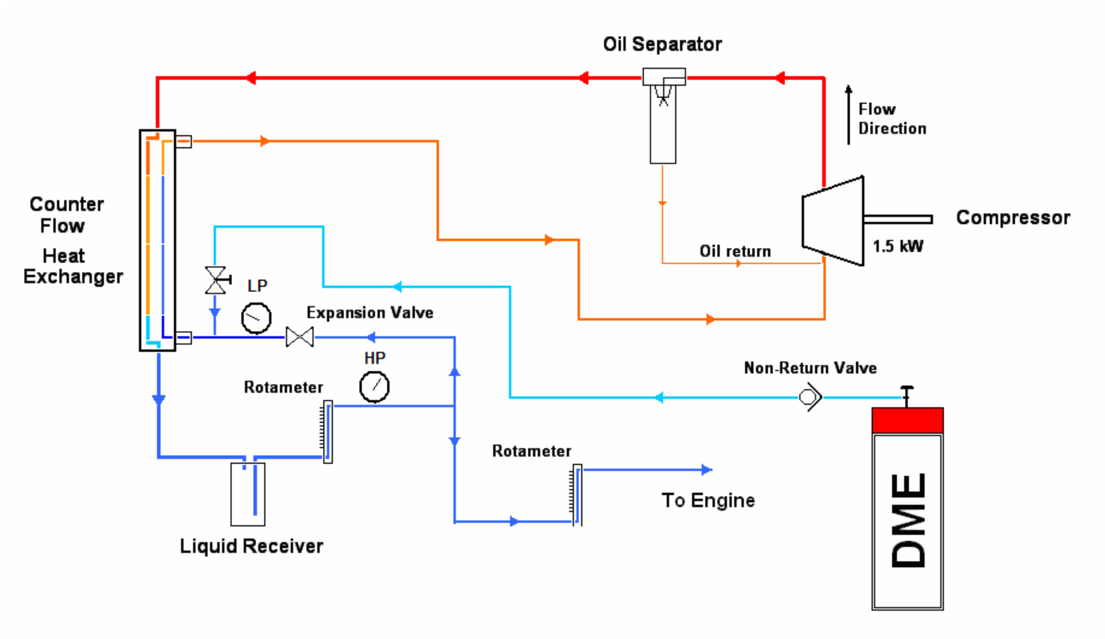

Figure 5-10: Schematic of initial concept with oil separator and heat exchanger

During testing of the prototype heat exchanger it was noticed that the compressor started to overheat. This phenomenon was believed to have been caused by superheated vapour re-entering the compressor. The superheated vapour in turn was believed to have been caused by the heat exchanger, which allowed too much heat to be transferred. The design was then modified to accommodate the extra heat entering the heat exchanger.

Figure 5-11: Prototype helical heat exchanger

The solution was to introduce a smaller radiator upstream from the heat exchanger, this reduced the heat entering the heat exchanger, and ultimately reduced the heat re-entering the compressor. Figure 5-12 illustrates the modified fuel system.

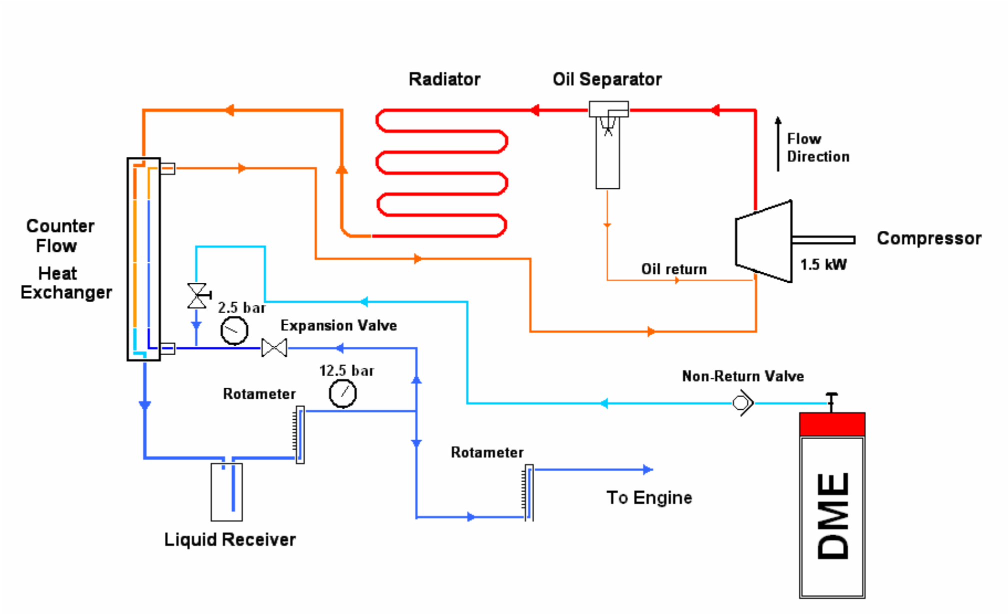

Figure 5-12: Schematic of initial concept with radiator

However, this still resulted in the compressor overheating. This problem was later overcome by mounting a DC fan to the radiator. Figure 5-13 represents the fuel system with heat exchanger, radiator and fan.

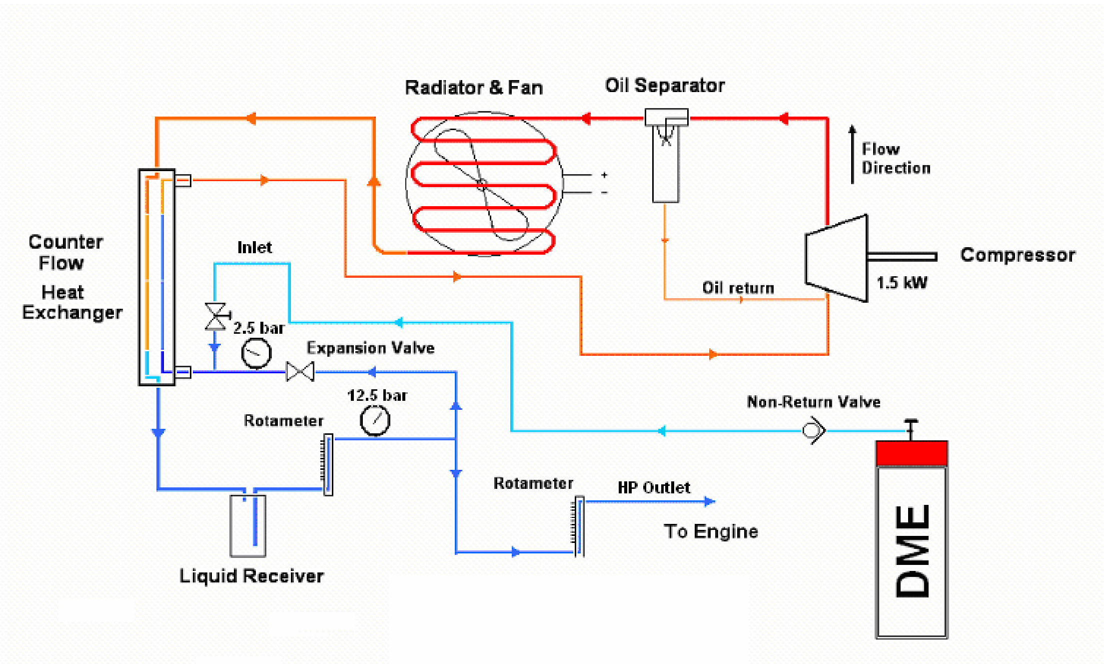

Figure 5-13: Schematic of first working model

Re-running the system produced positive results. The compressor remained within the temperature specifications, the oil remained in the system and the required fuel flow rate was well above limits. The only downfall was that the system had to be operated manually. The actual prototype is shown in Figure 5-14.

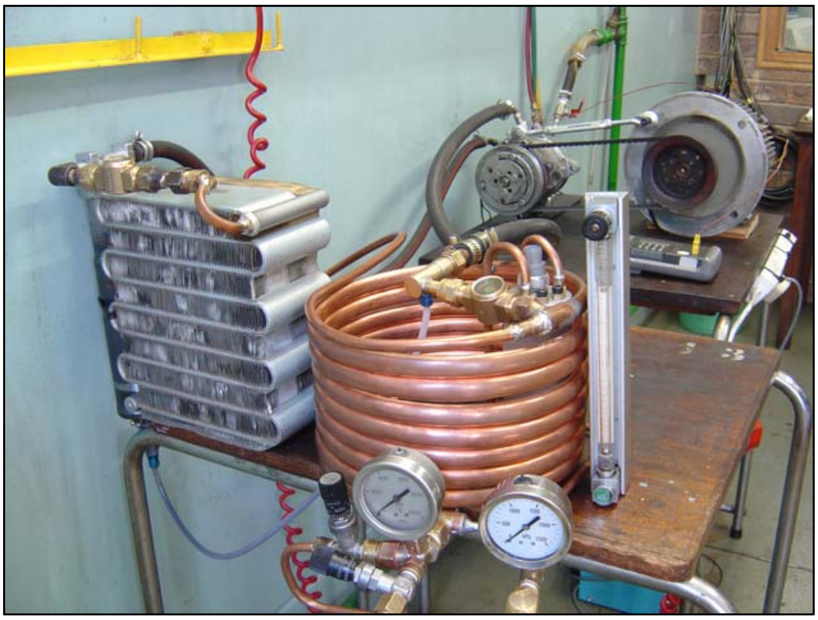

Figure 5-14: Actual first working prototype

A brief summary of how the system works:

DME enters the system from the storage cylinder through a manual flow control valve. The DME vapour passes through the outer tube of the counter flow heat exchanger which simultaneously cools down the liquid in the inner tube (discussed later). The DME vapour is then compressed and passed through an oil separator. The oil separator separates the oil from the DME vapour and returns it to the compressor. A small radiator cools the high temperature vapour before entering the heat exchanger. The fan mounted to the condenser assists with additional cooling. The high temperature vapour (high pressure DME) then passes through the inner tube of the counter flow heat exchanger and is cooled by the expanding DME (low pressure DME) entering through the outer tube (as mentioned above). At this point the high pressure DME is in liquid form and is suitable for engine consumption.

The liquid DME is at a pressure of between 12 and 13 bar, and a temperature of approximately 10°C. The engine fuel consumption is measured using a rotameter installed in-line with the fuel line. Any surplus DME not consumed by the engine is returned to the main supply via an adjustable expansion valve. The pressure of the returning DME is between 2 and 3 bar. For safety purposes a pressure relief valve is installed in the high pressure line and set to trigger at approximately 14.5 bar.

It was next decided to automate the fuel system. This process included selecting sensors such as thermocouples and pressure transducers, as well as hard wiring and programming a microcontroller. The thermocouples and pressure transducer were selected for three critical areas, these areas can be seen in Figure 5-15 below.

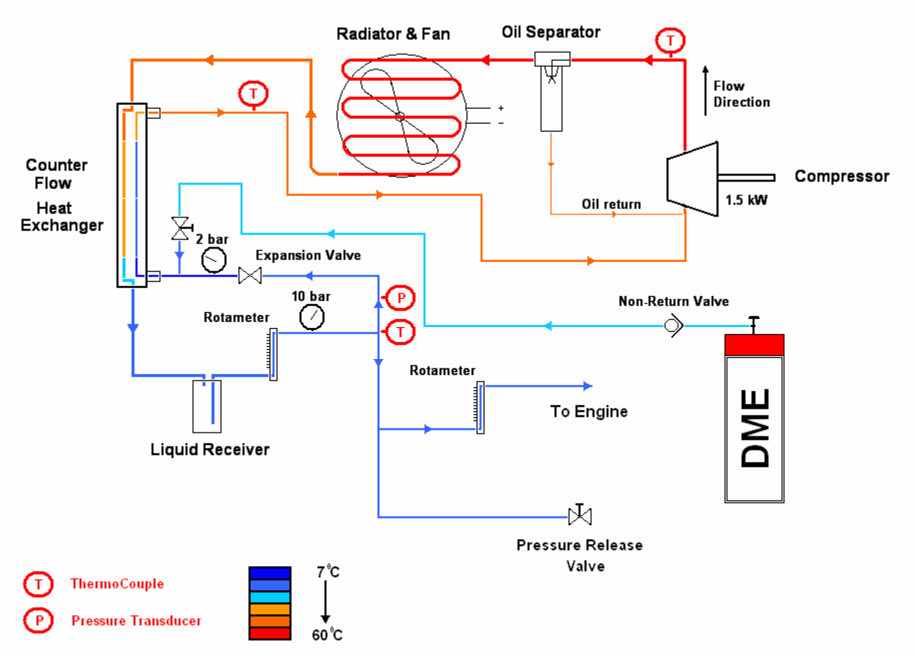

Figure 5-15: Thermocouple and Pressure transducer locations

A PC was used to monitor and control the system. A data acquisition and control card was used to communicate with the sensors as well as the actuators (solenoid valve and fans). A program was developed specifically to do this. Software called Visual Designer was used to develop the code seen in Appendix D.

Using the user interface screen when the code was running, set points and input sample rates were changed to optimise the operation of the system. The interface screen would also allow for live monitoring of the sensors. The user interface screen can be seen in Figure 5-16.

The system was optimised to run automatically after start-up (See Appendix C). The “run” procedure was programmed to run as follows; once the “start-up” procedure has elapsed, the controller would wait until the pressure in the high pressure line reaches 13 bar, at this point the controller engages the fan. The fan helps with the cooling of the vapour which in turn decreases the pressure (Ideal gas behaviour). The fan would then switch off once the pressure drops below 12 bar. At the same time the controller is programmed to monitor the compressor inlet and exit temperatures as well as the liquid DME temperature. The compressor exit temperature together with the pressure reading are used to control the fuel solenoid valve. The solenoid valve would only open once the pressure in the high pressure line is less than 12 bar and the compressor exit temperature is higher than 60 °C. Should any of these condition not be true the solenoid valve will close again. This method was empirically developed to ensure that the correct amount of DME circulates inside the system at any given time.

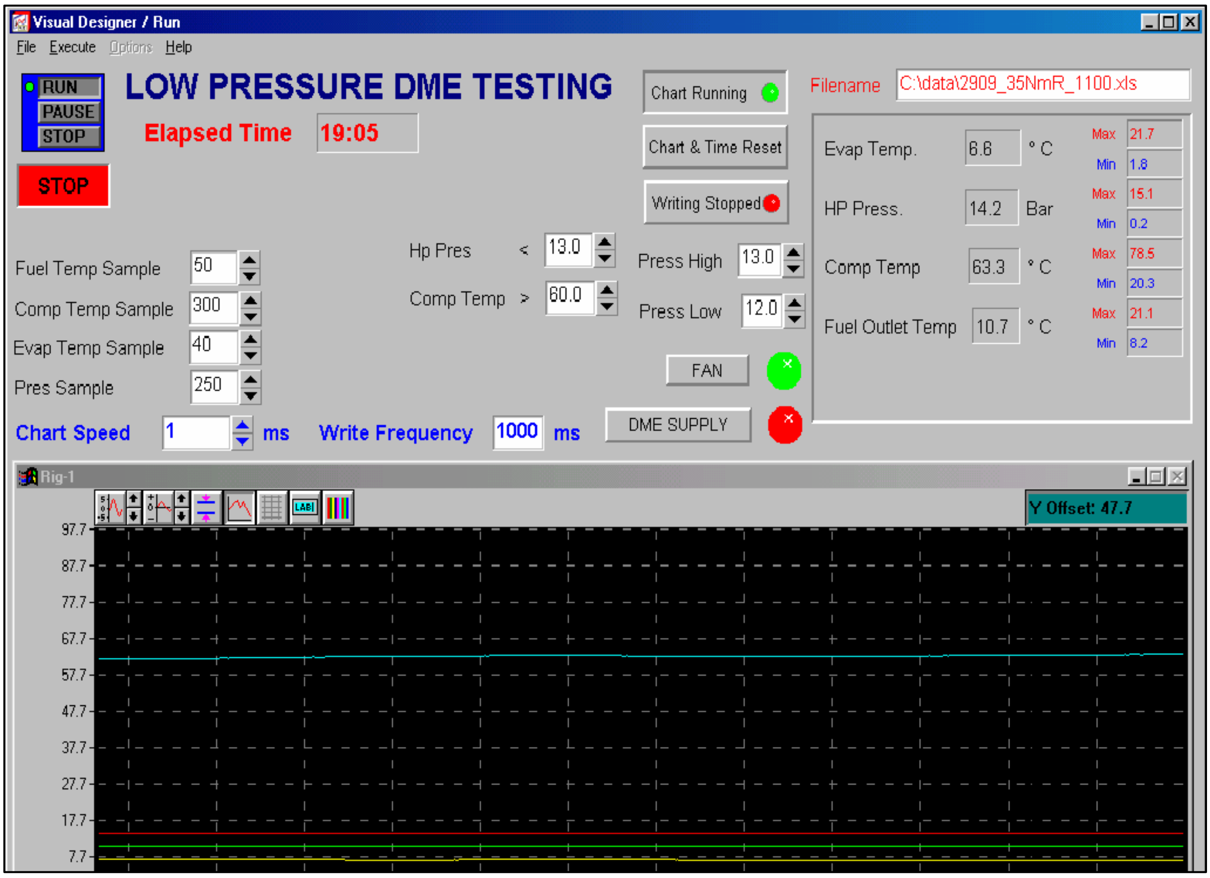

Figure 5-16: Control PC Screenshot

Intelligent Instrumentation PCI-20428K-1 Multi-Function Board Kit - (with Termination Panel)

1. 16 channels of Analogue Inputs with DMA, of either 0-5V, 0-10V ±5V, or ±10V
2. 12-Bit Resolution (1 part in 4096)
3. Gains of 1,10 and 100
4. 2 Channels of Analogue Output of either 0-5V, 0-10V ±5V, or ±10
5. Master Link C/C++ Drivers and Windows DLL's plus 'SYSCHECK' diagnostics.
6. 100KHZ Analogue Throughput
7. 8 Digital Inputs, 8 Digital Outputs
8. One 16-bit high-Speed Counter
9. Two Rate-Generators with 8 MHz Crystal Time-base
10. Termination Panel - This panel plugs directly into the I/O connector of the board, providing connection to all of the above-mentioned inputs and outputs.

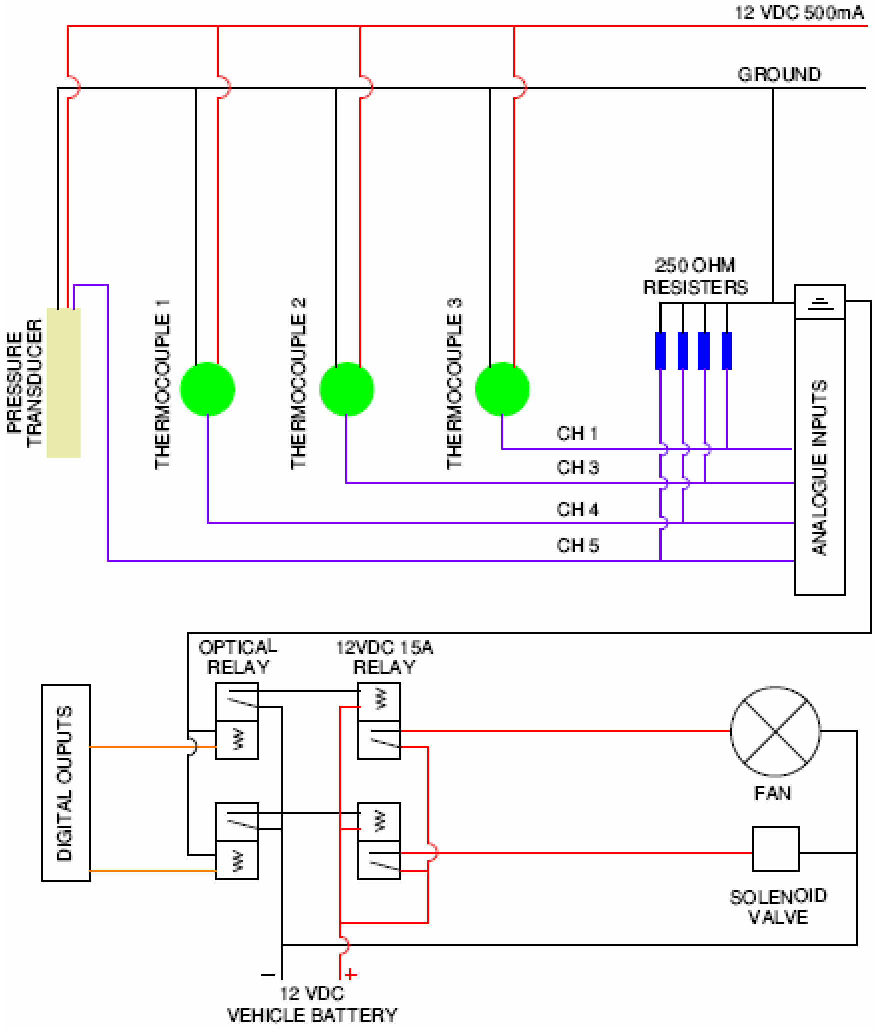

Figure 5-17: Instrumentation Wiring Diagram

5.5.4 Equipment Specification

The following is a specification list of equipment used in the Low Pressure DME Rig:

5.5.4.1 Compressor and Motor

- A Sanden 507 compressor with a 12 VDC electrical mechanical clutch.
- 3 kW 3-phase motor

5.5.4.2 Temperature Thermocouple

Table 5-3: Thermocouple Specifications

Manufacturer	Pyrotec
Model	RTXL
Range	0 - 100°C
Type	PT100

5.5.4.3 Pressure Transducer

Table 5-4: Pressure Transducer Specification

Manufacturer	Wika
Series	891.23.510
Range	0 – 25 bar
Current	4 – 20 mA
Volts	10 – 30 VDC
Part No	2114567

5.5.4.4 Flowmeters

Table 5-5: Rotameter Specifications

Manufacturer	Fischer Porter
Fuel flow rotameter	FP 1/8 – 25 – G – 5/81
System output rotameter	FP 1/4 – 20 – G – 5/81

5.5.4.5 Controller

The Low Pressure DME fuelling system was controlled via a personal computer (PC). The PC was fitted with a data acquisition and control card. The control card was used to monitor thermocouples and pressure transducers as well as control relays. Specific software called Visual Designer was used to develop a program which in turn would read and control the peripherals mentioned above. The flow diagram can be seen in Appendix D.

Using the *user interface screen* when the code was running, set points and input sample rates could be changed to optimise the operation of the system in addition to live monitoring of the system. The user interface screen can be seen in Figure 5-16.

5.6 Instrumentation

The data acquisition system, situated in the control room, consisted of two computers connected to a variety of sensors. One computer was used to capture the engine performance data and display running plots. A program by TLC called *Engine Test* was used to do this. A second program on the computer called *Heat Release and Combustion Analysis (HRCA)* was used to automatically calculate engine performance characteristics and produce performance plots. The second computer was used to captured all the engine emission readings.

The necessary variables needed to calculate performance were:

5.6.1 Cylinder Pressure

A pressure transducer was mounted in a custom made water jacket which screwed into the cylinder head through to the combustion chamber above cylinder 1. The water jacket was used to cool the transducer to protect it from the excessive heat from the engine. Cleaning of the transducer was done in an ultrasonic bath to ensure accurate readings.

5.6.2 Ambient Pressure

A pressure transducer and amplifier were interfaced with the computer to measure the atmospheric pressure.

5.6.3 Injector Line Pressure

Injector line pressure was measured using a pressure transducer fitted to the fuel line on cylinder 1.

5.6.4 Air Flowrate

Air was drawn through an orifice plate. An electronic manometer was connected to a pressure tapping located directly behind the orifice plate. This reading was referenced to ambient pressure. The flowrate was calculated using a calibration equation for the orifice.

5.6.5 Fuel Flowrate

The fuel flowrate of diesel was measured using an electronic rotameter situated in the fuel line. To measure the DME flowrate, manual readings had to be taken from a rotameter. These readings had to be manually entered into the computer to calculate the fuel flowrate.

5.6.6 Exhaust Temperature

A thermocouple was mounted in the exhaust pipe about 500mm from the engine.

5.6.7 Crank Angle and Speed

A crank angle encoder was used to determine the crank angle. The encoder produced a pulse every 0.2 degrees of crank angle. A second pulse was produced when cylinder 1 was at TDC. Using these two pulses and the time between them, speed and position of the shaft could be established.

6 Experimentation

Engine testing was performed at constant load, namely 25Nm, 35Nm and 45Nm, and at varying engine speeds ranging from 1100 rpm to 1800 rpm in increments of 100 rpm. Approximately five readings were taken at each load and speed setting in order to obtain good data averages.

6.1 Procedure

1. The equipment is calibrated as detailed in Appendix A.
2. The copper sulphate crystals used by the equipment to measure the oxygen are to be dried in the oven until they turn blue before being replaced.
3. The pressure transducer is to be cleaned in a supersonic bath for 20 minutes and reinstalled.
4. Ensure that a three-hole injector is installed and it is set to 210 bar.
5. The computer and electronic equipment must be switched on.
6. The performance data acquisition PC must be set up as per Appendix B.1
7. The water supply to the dynamometer must be turned on.
8. The water supply to the pressure transducer cooling jacket must be turned approximately 1/3 on.
9. The engine must be cranked over once and special attention needs to be given to the pressure transducer to note if there are any leaks. If this was the case, the pressure transducer needs to be refitted.
10. The Low Pressure DME Rig must be set up, started and allowed to stabilise as per Appendix C.
11. The diesel supply must be turned on and the three-way fuel valve turned to diesel.
12. The cooling fans must be placed on either side of the engine and near the LP DME Rig compressor and turned on.
13. Turn on the extractor fans.
14. The engine must be turned on and allowed to run at around 1300 rpm and low applied torque for a few minutes.
15. The three-way fuel valve must be turned to the DME supply.
16. The engine must be allowed to run for a few minutes to ensure that a total fuel cross over has taken place. When almost no visible exhaust smoke is being emitted, testing can take place.
17. The required speed at torque setting must be selected using the dynamometer control unit and the throttle on the engine.
18. Readings on both data acquisition PC’s must settle to steady state.

19. Between four and six sets of data for engine performance and emissions must be taken. Values for load, speed, air flowrate and emission averages from the PC's must be written down. Values for fuel flowrate and fuel overflow from the rotameters must be recorded.
20. The speed and/or torque must be varied and new data recorded for each interval.
21. Once testing has been completed, turn off the DME cylinder and press the red *STOP* button on the control PC screen. Decrease the engine speed and torque and allow the engine to use the remaining fuel in the system.
22. Switch off engine.
23. Purge the LP DME Rig of any remaining DME and turn off the compressor.
24. Turn the three-way fuel valve back to diesel.
25. Start the engine again to purge the system and ensure that each engine cylinder is operating on diesel.
26. The performance data can be analysed using the program *Heat Release and Combustion Analysis* (HRCA) and results can be printed.

6.2 Precautions

The following precautions need to be taken note of to prevent damage to equipment and erroneous data capturing.

6.2.1 Equipment Precautions

- Check battery water levels.
- Check engine oil levels.
- Check compressor oil levels (LP DME fuel system)
- Check battery on all electronic equipment.
- Check injector operation pressures and even spray distribution.
- Inspect the pressure transducer to ensure cleanliness and free from blockages.
- Ensure that the copper sulphate crystals are blue in colour.
- Ensure that there is enough fuel to complete the test session as testing cannot be restarted due to the possibility of data variations.

6.2.2 Testing Procedure Precautions

- Engine temperatures and emissions must have settled before data can be recorded.
- Cylinder and injector pressure traces must be monitored to ensure correct operation of the engine.
- Check that the data files are being correctly recorded in the correct folders and that filenames correlate to the test being performed.
- Check that the LP DME Rig is operating within the correct pressure boundaries.
- Check that the LP DME Rig compressor is not overheating.

7 Results and Discussion

The most important objective of this research was to design and develop a compact low pressure DME fuelling system. The design went through a number of changes before any real results were achieved, some changes included complete new concepts. During the testing phase data was recorded for both performance and emissions.

7.1 Overview

The initial design started with the concept of cooling down the DME as it passed from the storage tank to the injector pumps, illustrated below (Figure 7-1).

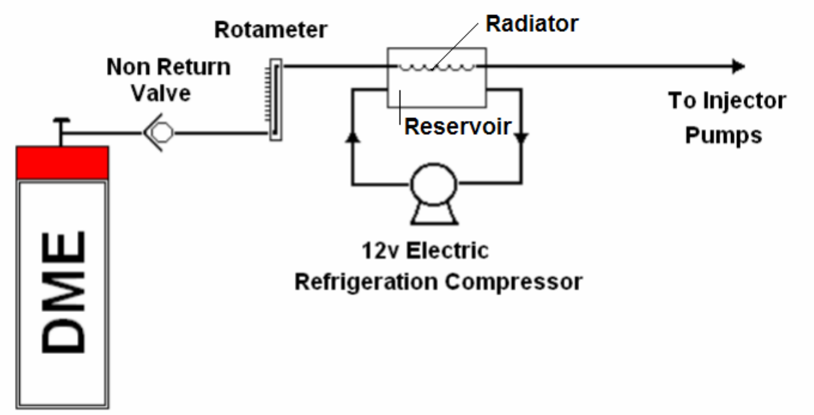

Figure 7-1: Initial DME fuelling concept

This concept made use of an electric hermetically sealed compressor which was used to cool down a reservoir containing a solution of water and anti-freeze. A radiator through which the DME passed was then submerged in the solution. In theory this would have cooled the DME enough to liquefy it, thus allowing smooth and continuous operation of the engine. However, the chosen compressor did not produce enough cooling power and the design was modified.

Having done some research on the thermodynamic properties of DME, it was later found that DME was previously used as a refrigerant. This new finding lead to the idea of using DME as the refrigerant to “cool itself”. This would effectively increase the efficiency of the overall unit as there would no longer be any losses due to heat transfer between the refrigerant, the anti-freeze solution, and the DME.

The “self cooling” concept is discussed in detail in Section 5.5.3. This was then regarded to as the “Low Pressure DME fuelling system (LP DME)”. Below is the final schematic of the working prototype (Figure 7-2).

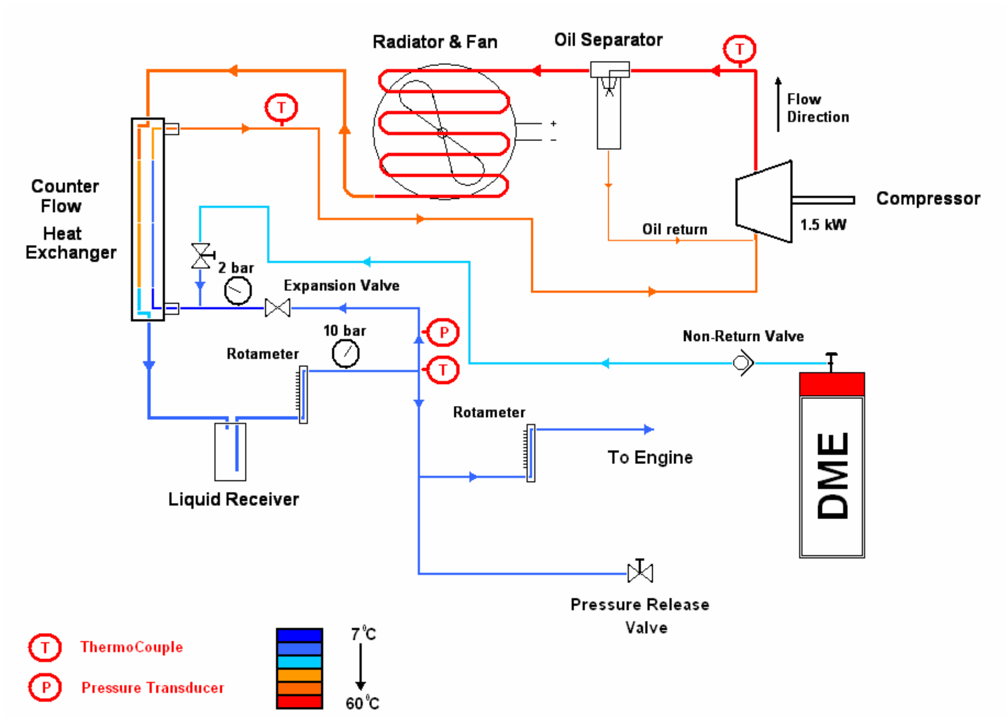

Figure 7-2: Schematic of first working DME fuelling system

The working prototype operates as follows,

DME enters the system from the storage cylinder through a manual flow control valve and then a non-return valve. The liquid/vapour solution then passes through the outer tube of the counter flow heat exchanger. This process simultaneously cools down the liquid in the inner tube and boils off the liquid/vapour in the outer tube. The pure vapour is then compressed and passed through an oil separator (most modern refrigeration systems have migrating oil). The oil separator separates the oil from the vapour and returns it to the compressor. A small condenser is used to cool the high temperature vapour before entering the heat exchanger. A fan mounted to the condenser assists with additional cooling. The high temperature, high pressure vapour is then passed through the inner tube of the counter flow heat exchanger where it is cooled by the expanding low pressure DME entering through the outer tube (as mentioned above). At this point the DME is completely in its liquid form and suitable for engine consumption.

The pressure of the liquid DME is typically between 12 and 13 bar, and at a temperature of approximately 10°C. The engine fuel consumption is measured using an in-line rotameter.

Any surplus DME not consumed by the engine is returned to the main supply via an adjustable expansion valve. The typical pressure of the returning DME is between 2 and 3 bar. For safety purposes a pressure release valve was installed on the high pressure line and set to trigger at approximately 14.5 bar.

The system was later optimised to run automatically after start-up (Appendix C). The “run” procedure was programmed to run as follows; once the “start-up” procedure has elapsed, the controller would wait until the pressure in the high pressure line reaches 13 bar, at this point the controller engages the fan. The fan helps with the cooling of the vapour which in turn decreases the pressure (Ideal gas behaviour). The fan would then switch off once the pressure drops below 12 bar. At the same time the controller is programmed to monitor the compressor inlet and exit temperatures as well as the liquid DME temperature. The compressor exit temperature together with the pressure reading is used to control the fuel solenoid valve. The solenoid valve would only open once the pressure in the high pressure line is less than 12 bar and the compressor exit temperature is higher than 60 °C. Should any of these condition not be true the solenoid valve will close again. This method was empirically developed to ensure that the correct amount of DME enters and circulates within the system at any given time.

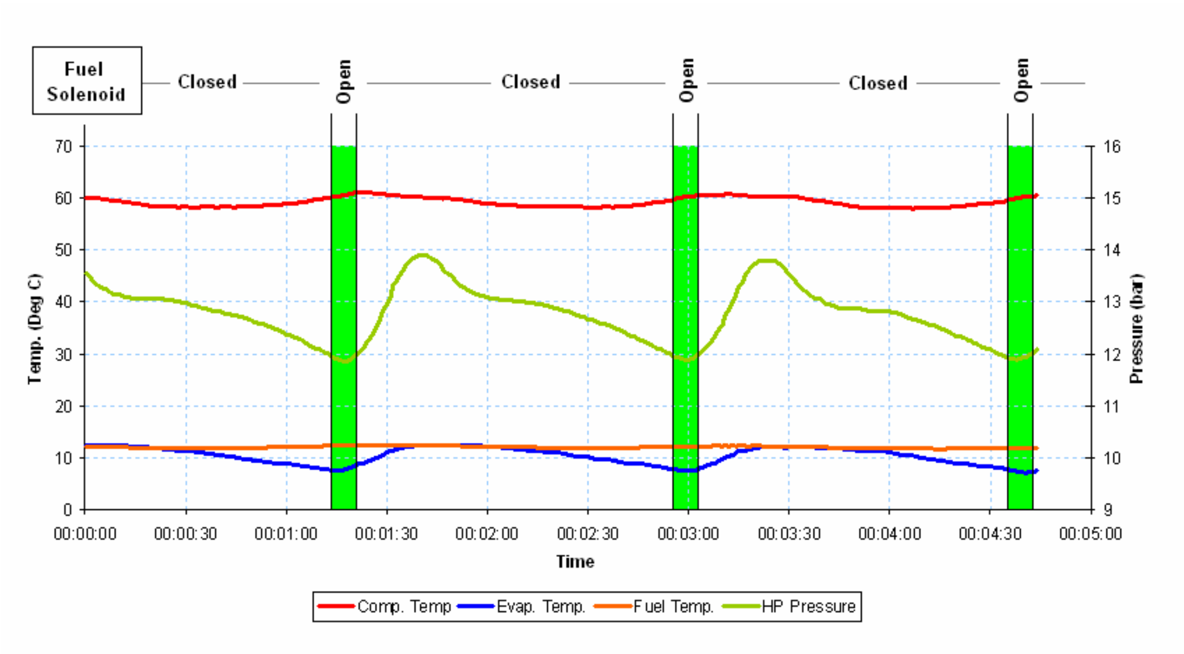

Figure 7-3: Typical operational pressures and temperatures of the LP DME fuel system

Figure 7-3 above represents the typical life cycle between openings of the fuel solenoid. This particular trace comes from the 1600 rpm, 35Nm test. The trace clearly illustrates that as the pressure drops below 12 bar and the compressor exit temperature goes above 60 ºC the fuel solenoid opens (Green bands). For this particular test the fuel solenoid opens for approximately 10 seconds at a time. During these times the system receives enough DME to restore and balance the refrigeration cycle again. Half way during the openings of the solenoid it can be seen how the system pressure begins to rise sharply. This is due to large amounts of gaseous DME entering the system. Later it is noticed that as the DME is compressed and cooled the pressure begins to decrease again, this reduction can also be attributed to the effects of the cooling fan. However the overall reduction in pressure is caused by the continuous outflow of saturated liquid DME as engine fuel.

The Low Pressure DME fuel system demonstrated repeatability and robustness during operation. The only concern came at high loads and low engine speeds, where the engine struggled to perform. The concern along with the comparison of previous research was investigated through a study of the engine injector fuel line pressures.

7.2 Injector fuel line pressure

The trace below (Figure 7-4) typically illustrates how the injector fuel line pressure varies with crank angle. This particular trace is taken from the 25 Nm, 1800 rpm diesel test.

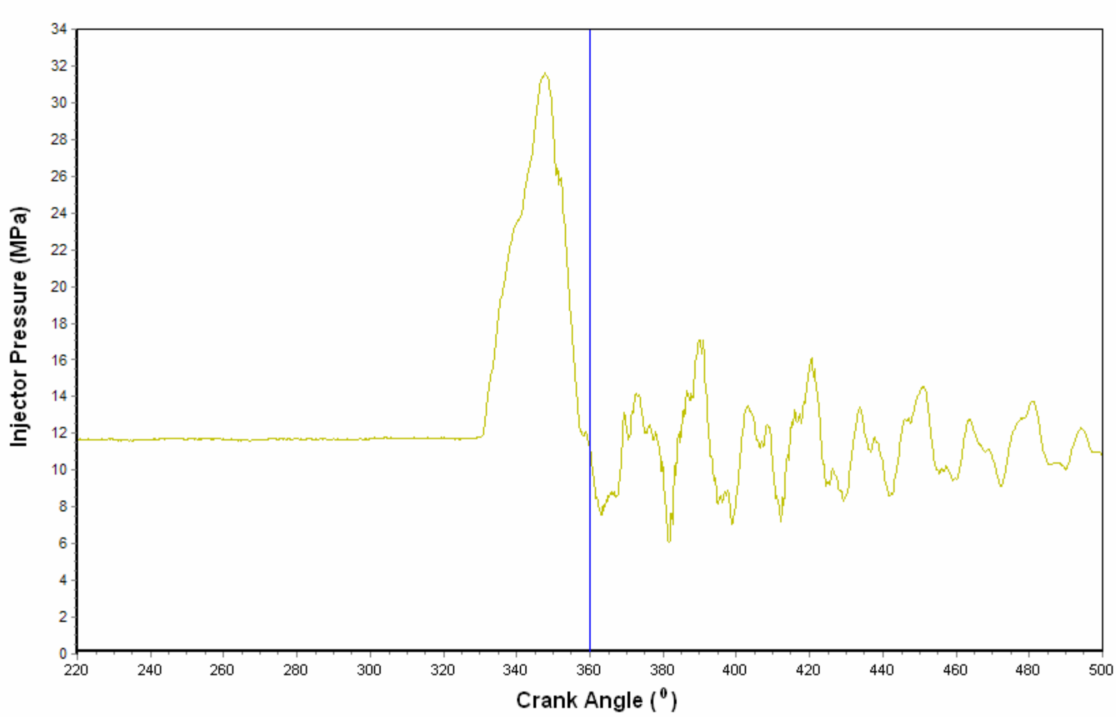

Figure 7-4: Injector pressure versus crank angle for diesel

From Figure 7-4 it can be seen how the pressure remains constant at 11.5 MPa (115 bar) before the injection. At about 330º crank angle (30º before Top Dead Centre) the injector pump begins to compress the diesel. The pressure continues to rise until it reaches the preset spring tension of the injector nozzle. The injector nozzle opens and the fuel is sprayed into the cylinder. The jagged spikes occurring after the injection are attributed to the bounce of the injector spring, the bulk modulus of the fuel, and the scavenging (opening and closing) effects of the pump.

Having a look at the 25 Nm results, it can be seen how the different fuels tend to influence the injector fuel line pressures. Figure 7-5 shows the fuel line pressure for diesel, HP DME and LP DME fuelling systems, all at a load of 25 Nm and a speed of 1100 rpm.

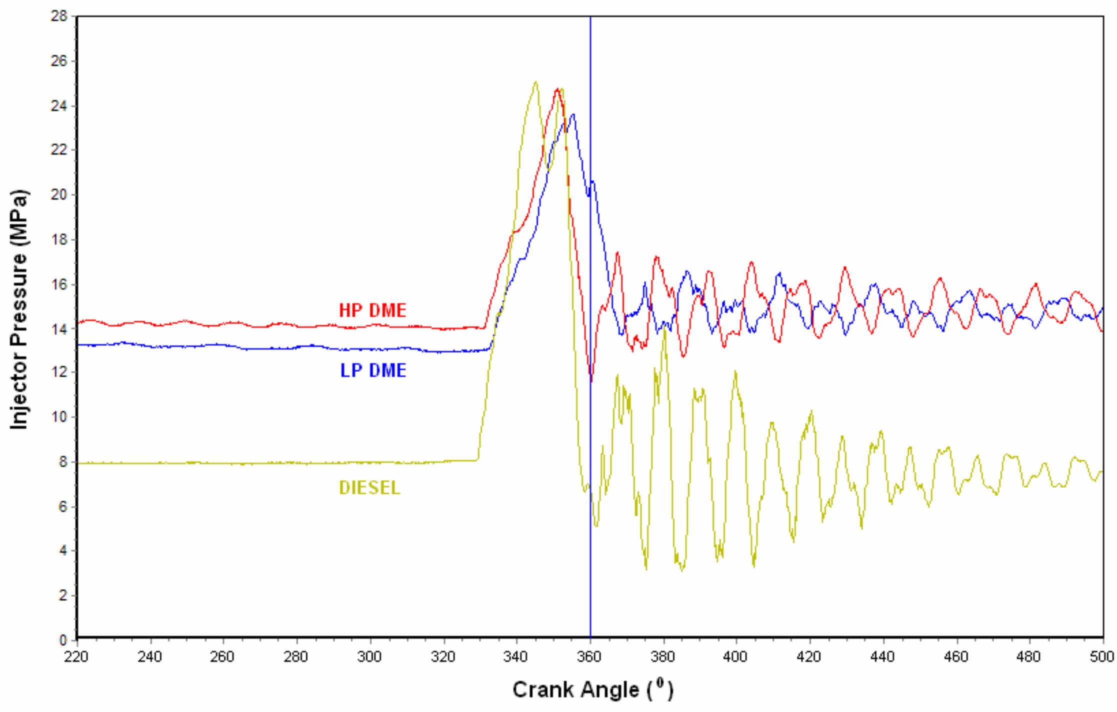

Figure 7-5: Injector pressure trace for diesel, HP DME and LP DME versus crank angle

It is evident that the different fuels have a significant effect on the injector fuel line pressure. As noted in the figure, both DME supply systems show a significant increase in injector fuel line pressure (before injection), with respect to diesel. This is believed to have come from the fact that both DME systems are pressurized, and as the injector pumps open for more fuel, more is forced in at elevated pressures. This scenario is supported by the fact that the HP DME system delivers fuel to the injector pumps at 50 bar, the LP DME system delivers fuel at

12.5 bar and diesel delivers at atmospheric pressure. The constant pressure lines seen before the steep pressure rise (for all three fuels) are taken to be the initial pressure to which the fuels are pressurized before the injector pumps close, and pressurise the fuels further.

A second point of interest comes from the fact that diesel produces a much steeper pressure rise and also injects earlier than both the DME systems. From the trace above it can be seen that the diesel fuel injects first, the HP DME injects second and the LP DME last. This observation is believed to have been caused by a variation in bulk modulus between the three fuels. The “difference” in bulk modulus noticed between the two DME systems can be explained through different densities due to different initial pressures. The HP system pressurises to 50 bar, whereas the LP system only to 12.5 bar.

Various researchers have studied the effect of temperature and pressure on the bulk modulus of DME [14,15]. Figure 7-6 shows the variation of the bulk modulus of DME with temperature at various pressures. In addition the variation of the bulk modulus for diesel in the temperature range of 20° C to 60° C has been superimposed on the same diagram. Figure 7-6 is based on data from the literature [14,15]. This graph strengthens the argument that bulk modulus plays a major part in injection times and delivery quantities. Take the 25 Nm results from above as an example. The diesel was seen to have injected first, this can now be explained by virtue of a higher bulk modulus. In other words, because the diesel pumps have a fixed displacement per revolution, it can no longer be assumed that the pumps influence the amount of fuel being displaced, but that in fact the physical properties and entry condition of the fuels are what really determine the injection characteristics.

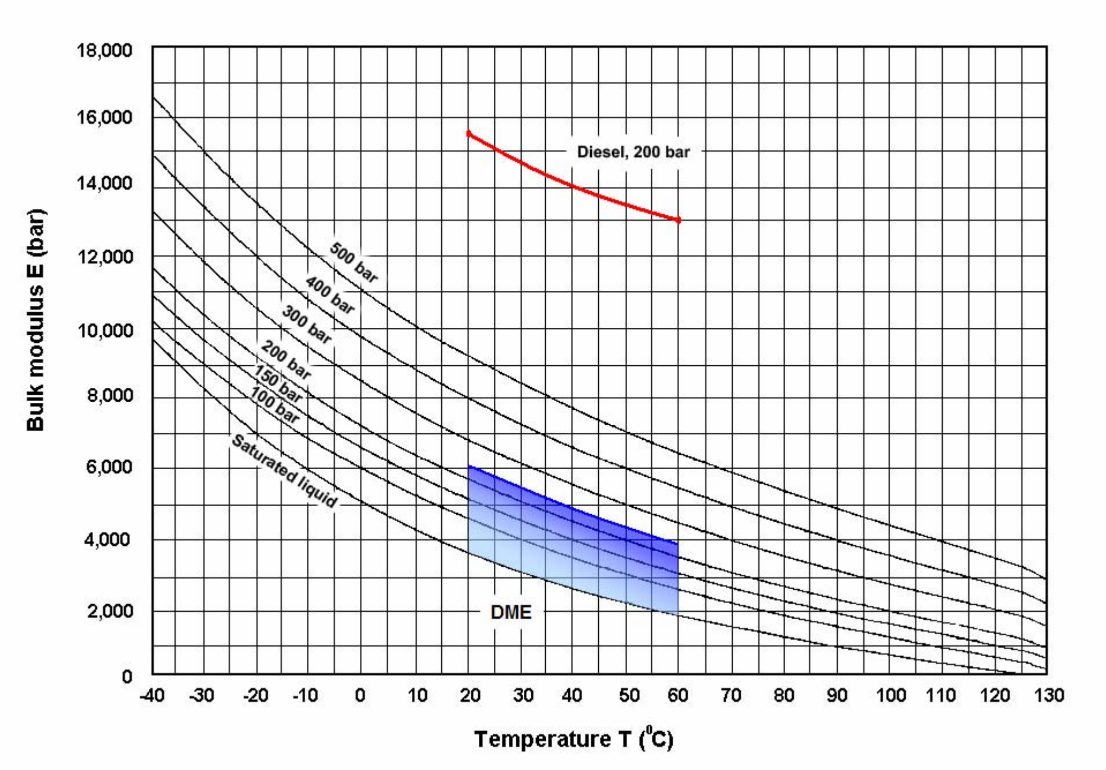

Figure 7-6: Bulk modulus versus Temperature (DME and diesel)

The bulk modulus of diesel is much higher than that of DME and is therefore a lot more resistant to compressibility. This can be seen by the steep pressure rise in Figure 7-6 above. Both DME fuel systems are seen to have a more gradual pressure rise, with LP DME having the most gradual, due to a lower bulk modulus. As mentioned above, the volume displacement of the fuel by the injector pumps is constant, therefore the delay in injection time is attributed to the effect of compressibility for both DME fuelling systems.

The bulk modulus of the fuel is also directly related to its density. When the injector pumps open to take in more fuel they can only accept a certain amount (by volume). Therefore fuels with higher bulk modulus will respond faster (no compressibility) and deliver more fuel (by mass).

For this research the same set of injector pumps was used for all three fuels. This gave diesel the advantage as the pumps were originally designed for that particular bulk modulus. The DME systems were therefore slower to respond as they needed a larger and faster volume displacement. Liquid DME has a density of 80%, and a calorific value of 69% that of diesel, thus indicating that DME already needs a larger and faster volume displacement pump to match the mass flow rate of diesel.

The analysis that follows was performed to investigate the behaviour of the injection characteristics of all three fuelling systems at various loads and speeds.

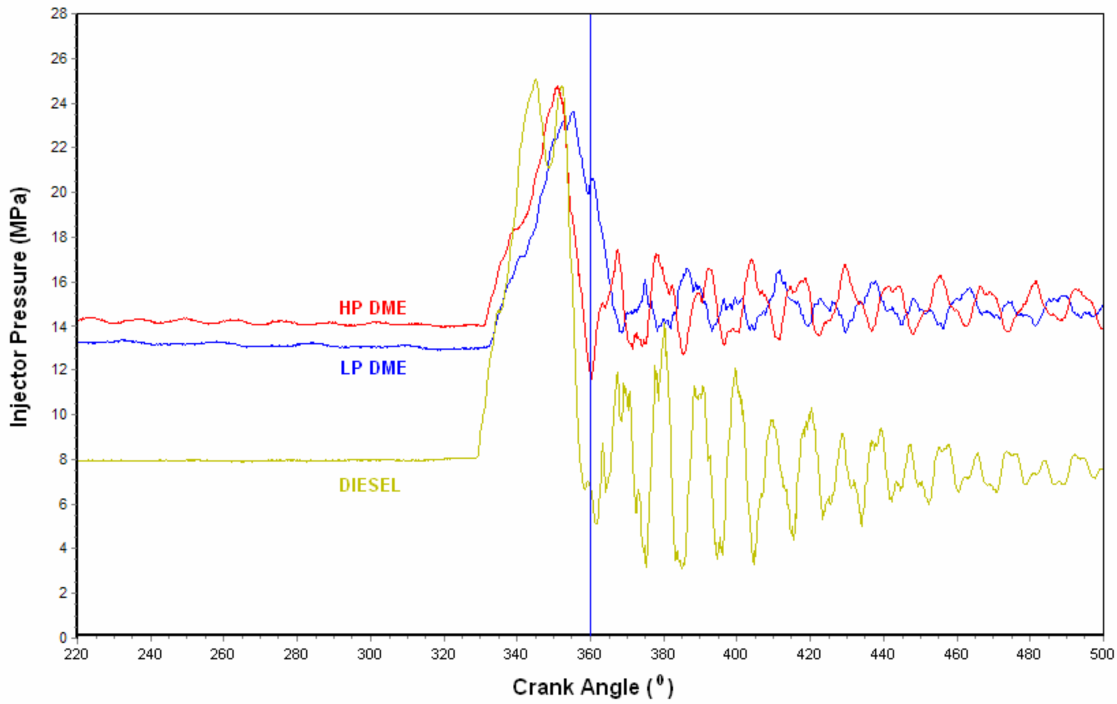

Figure 7-7: Injector pressure versus crank angle for diesel, HP DME and LP DME (25Nm, 1100rpm)

Figure 7-7 shows a trace for the 25Nm, 1100 rpm test. Here it is evident that diesel has a much higher bulk modulus than the other two DME systems. The injection pressures however all seem to be within 230 bar – 250 bar. The fuel flow rates are typically 34 g/min for DME and 32 g/min for diesel.

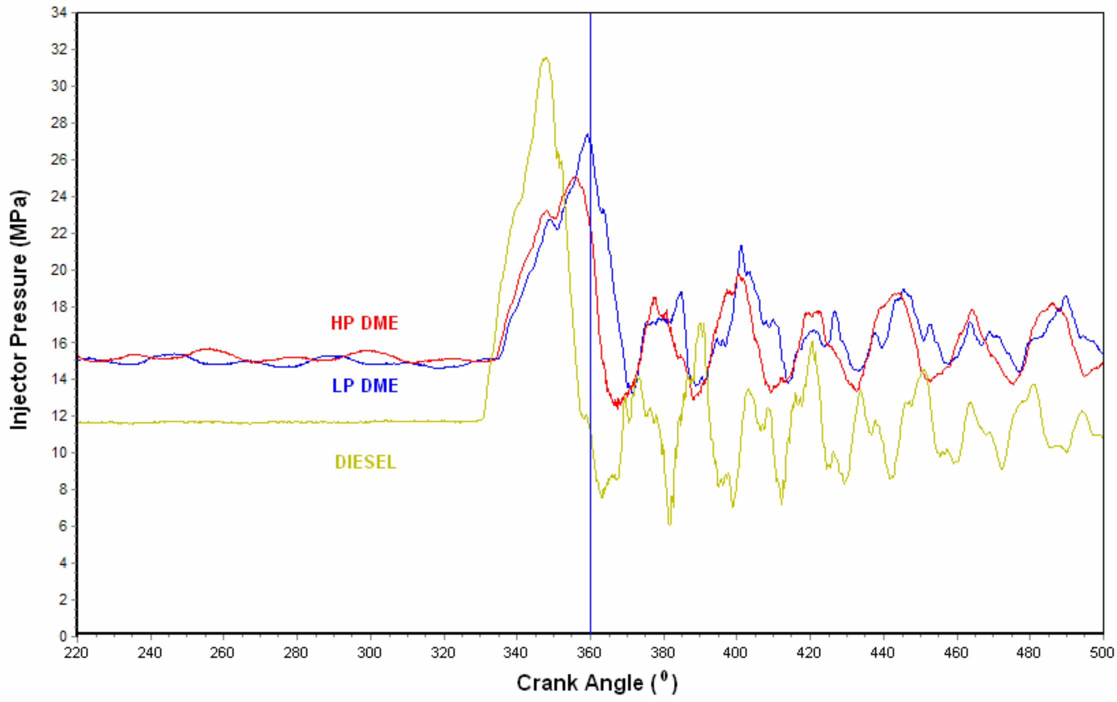

Figure 7-8: Injector pressure versus crank angle for diesel, HP DME and LP DME (25Nm, 1800rpm)

Figure 7-8 depicts the injector pressures for the three fuels at 25Nm and 1800rpm. As before, diesel showed a strong resistance to compression and demonstrated a predetermined injection point. Both DME systems followed behind with a slight injection time delay due to a lower bulk modulus. An interesting observation was made concerning the diesel injection pressure. From the trace above, diesel can be seen reaching a maximum of 318 bar whereas the highest DME fuel only reached 272 bar. This was believed to be related to the injection speed, the injection quantity, the density and the viscosity of the fuel. DME has 1/20 the viscosity of diesel and 1/3 of the bulk modulus. Therefore allowing DME to be injected through the same set injectors, which were optimized for diesel, will result in DME leaking around the injector needles before they have completely opened. The leakage together with a low bulk modulus is the result of a lower injector fuel line pressure. However, this does not take into account the initial pressure increase for all three fuels. (See Figure 7-7 and Figure 7-8)

This explanation comes from the fact that as the engine runs faster it inherently consumes more fuel. Therefore the overall injector fuel line pressure increases as more fuel is injected during the same time interval using the same volume displacement. Table 7-1 below tabulates the maximum and minimum of the fuel line pressures. The values were recorded between 1100rpm and 1800rpm during the 25Nm test. Studying Table 7-1 it may be noticed that as the engine speed increases the maximum injector pressures for HP DME tend to be the lowest of the three. This finding is believed to be the result of comparing different sets of data to each other, keeping in mind that only the LP DME fuel system was tested during this research and compared against previous recorded data (HP DME and diesel). For example, it is believed that calibrating/setting the injector springs may vary from test to test and can therefore produce a discrepancy when comparing results from different tests. The diesel injector pressures are inherently higher and may therefore also have a discrepancy and may not be as evident. The data is still regarded as valid, as the slope of the pressure trace is more important than the actual maximum. This argument also holds for Table 7-2 and Table 7-3. Typical fuel flow rates for 25Nm, 1800rpm are 45 g/min for DME and 40 g/min for diesel.

Table 7-1: Maximum and Minimum injector pressures for diesel, HP DME and LP DME (25Nm, 1100rpm – 1800rpm)

RPM	1100		1200		1300		1400		1500		1600		1700		1800	
25Nm	Max (MPa)	Min (MPa)	Max (MPa)	Min (MPa)	Max (MPa)	Min (MPa)	Max (MPa)	Min (MPa)	Max (MPa)	Min (MPa)	Max (MPa)	Min (MPa)	Max (MPa)	Min (MPa)	Max (MPa)	Min (MPa)
LP DME	23.6	12.8	24.1	13.0	24.3	13.1	24.8	13.6	25.7	12.7	26.5	12.6	26.8	12.7	27.3	13.2
HP DME	24.7	11.6	25.1	10.1	24.8	9.8	25.3	10.5	24.8	10.5	23.8	10.9	24.3	11.2	25.0	12.3
DIESEL	25.3	2.9	26.7	2.9	27.9	3.4	28.5	3.6	29.9	4.2	30.2	3.8	31.3	5.9	31.8	5.9

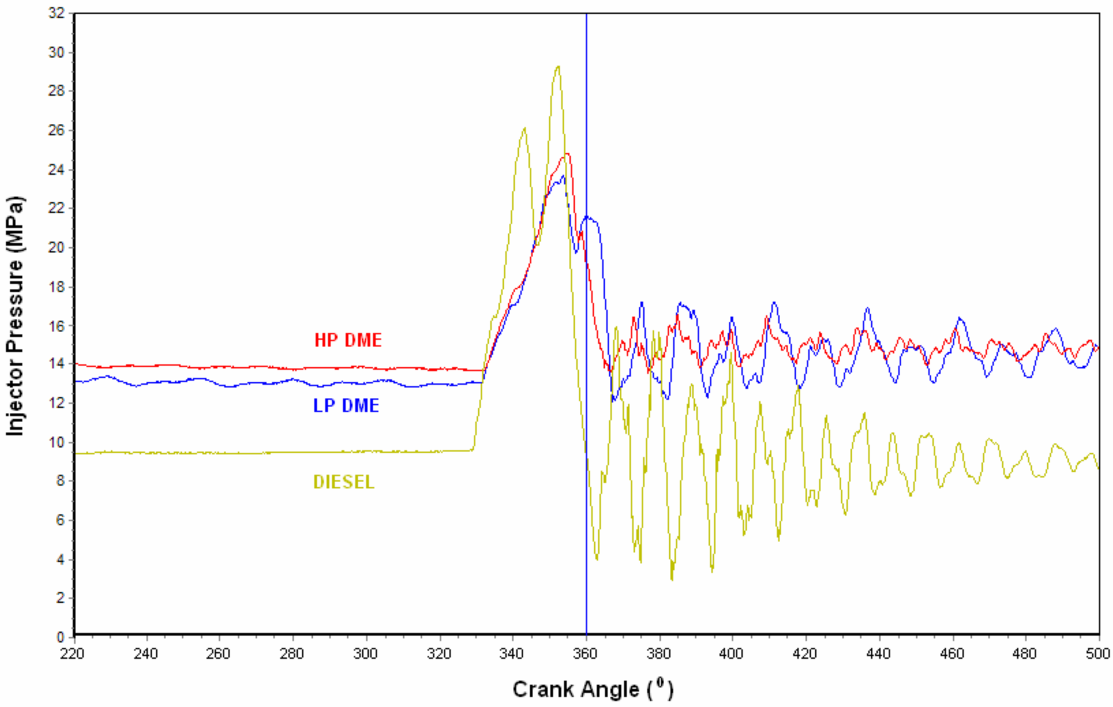

Figure 7-9: Injector pressure versus crank angle for diesel, HP DME and LP DME (35Nm, 1100rpm)

Figure 7-9 shows a similar trend to that of 25Nm, with the only difference being an increase in overall pressure with respect to Figure 7-7. Again it is noticed that diesel has a much higher injection pressure than DME. The explanation is similar to that stated above for 25Nm. The double peaks from the diesel trace are unexplained and could be caused by the injector needle “sticking” to the walls of the nozzle. This phenomenon has been witnessed on numerous occasions and is believed to have been caused by the accelerated wear of the injector needles during the operation of DME. DME has almost no lubricity and wear down the injectors at a much higher rate. The same set of injectors has been used for all tests and can therefore be expected to show this particular behaviour. The typical fuel flow rates for the 1100rpm, 35Nm test are as follows, 45 g/min for DME and 42 g/min for diesel.

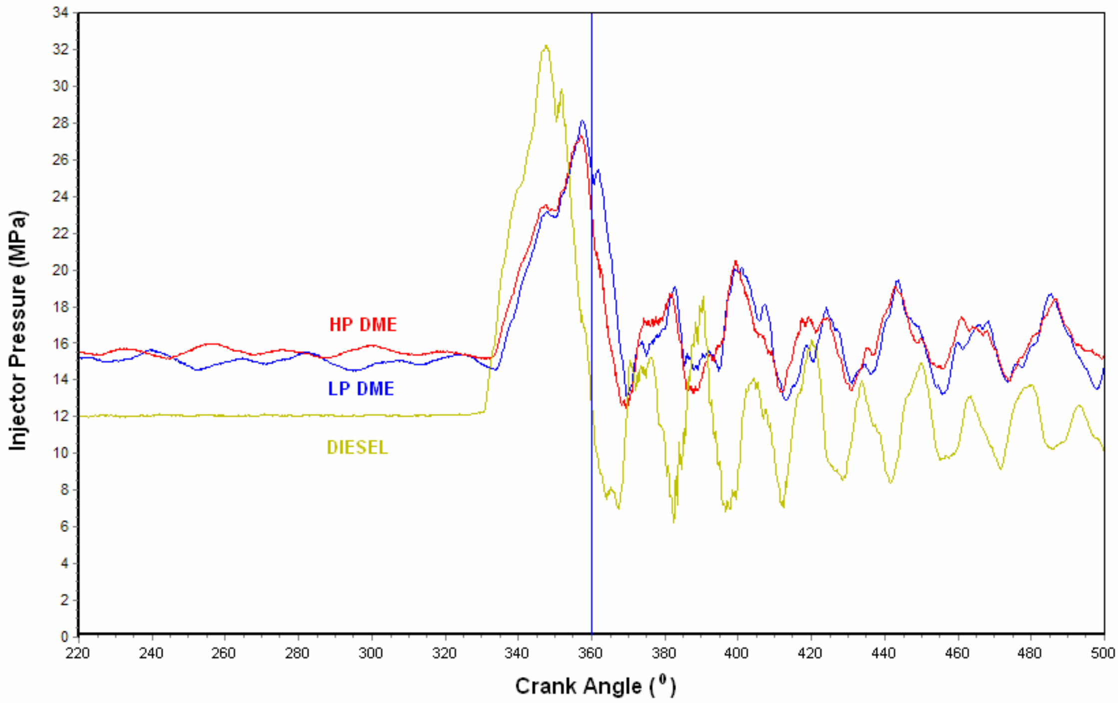

Figure 7-10: Injector pressure versus crank angle for diesel, HP DME and LP DME (35Nm, 1800rpm)

The 35Nm, 1800rpm results (Figure 7-10) indicate that as the engine requires more fuel the injector pressures increase due to an increase in fuel flow rate. In general, the overall trend is similar to those of the previous traces. Looking at Figure 7-8 and Figure 7-10 it can be seen that as the engine speed increases the injection points of both DME traces move closer to top dead centre, while that of diesel remains constant. This again is believed to be as a direct result of the lower bulk modulus of DME. DME however, has a much higher vapour pressure than diesel and will therefore mix faster with the air in the cylinder before combustion, thus decreasing the overall effect of a late injection. The 35Nm, 1800rpm fuel flow rates were 66 g/min for DME and 49 g/min for diesel.

Table 7-2 below tabulates the maximum and minimum fuel line pressures. The values were recorded between 1100rpm and 1800rpm during the 35Nm test.

Table 7-2: Maximum and Minimum injector pressures for diesel, HP DME and LP DME (35Nm, 1100rpm – 1800rpm)

RPM	1100		1200		1300		1400		1500		1600		1700		1800	
35Nm	Max (MPa)	Min (MPa)	Max (MPa)	Min (MPa)	Max (MPa)	Min (MPa)	Max (MPa)	Min (MPa)	Max (MPa)	Min (MPa)	Max (MPa)	Min (MPa)	Max (MPa)	Min (MPa)	Max (MPa)	Min (MPa)
LP DME	23.6	12.0	23.9	11.1	24.8	12.2	25.9	13.6	26.0	14.1	26.1	13.9	27.5	12.5	28.1	12.8
HP DME	24.8	13.5	25.9	13.9	25.9	12.8	27.8	12.3	27.0	12.6	26.8	11.4	28.1	12.8	27.3	12.4
DIESEL	29.5	2.8	28.0	2.9	27.9	3.4	29.2	2.3	29.8	3.3	30.9	3.9	31.1	4.6	32.2	6.1

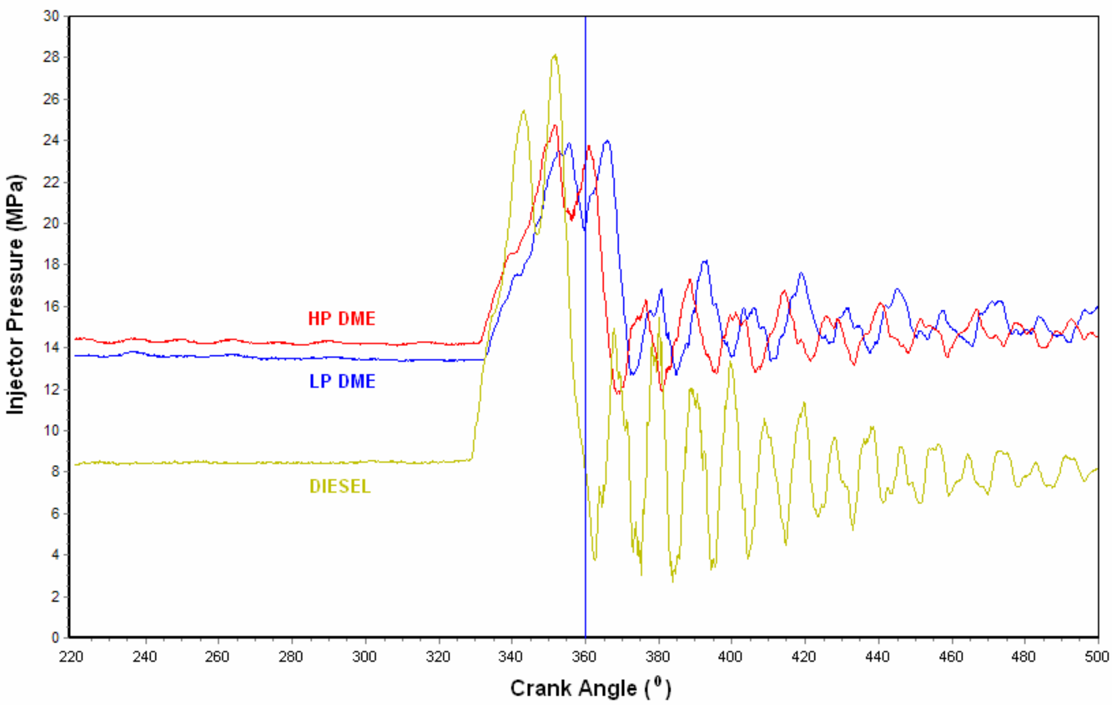

Figure 7-11: Injector pressure versus crank angle trace for diesel, HP DME and LP DME (45Nm, 1100rpm)

During the 45 Nm Low Pressure DME test, the engine could not sustain a constant 45 Nm load at low engine speeds. The engine could only sustain the 45Nm load from 1200rpm and above. Therefore the LP DME trace illustrated in Figure 7-11 was tested at 40Nm. This load setting was only used for the 1100 rpm LP DME test. All other remaining tests including diesel were done at 45Nm.

The 45 Nm results showed similar trends to those before. All three traces however had distinct double peaks, with LP DME being the worst. These peaks are again believed to have been caused by the "sticking" of the injector needles. From Figure 7-11 it can be seen that LP DME was still being injected well past the top dead centre mark. This reduces the overall brake power of the engine, thus reducing the load carrying capability. HP DME also showed a similar trend. The cause is believed to be a direct result of the bulk modulus and density of DME. As the engine requires more fuel (power) the throttle opens to allow more in, this is the reason for the extended injection period. However, due to the extra time needed for DME to be injected the engine timing would have to be 'advanced' a lot further than that of diesel. As previously stated the test engine has not been modified, and therefore running DME will be to a disadvantage. In order to see the true potential of DME at this load it is suggested that the engine timing be 'advanced'. Typical fuel flow rates for 45 Nm, 1100 rpm are 50 g/min for DME and 43 g/min for diesel.

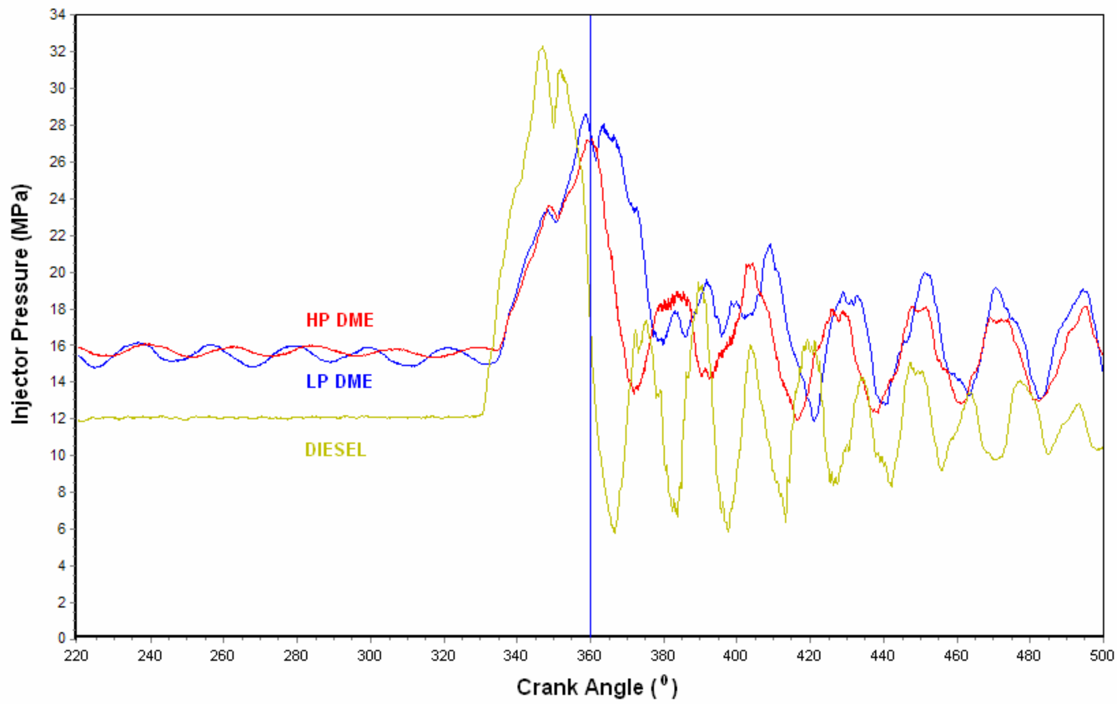

Figure 7-12: Injector pressure versus crank angle trace for diesel, HP DME and LP DME (45Nm, 1800rpm)

Figure 7-12 shows the last test, here it is clearly visible that both DME fuels are being injected too late. This, as discussed above, is the reason for loss of power and inadequate operation. The typical fuel flows were as follows; 84 g/min for DME and 62 g/min for diesel.

Table 7-3 below tabulates the maximum and minimum of the fuel line pressures. The values were recorded between 1100 rpm and 1800rpm during the 45 Nm test.

Table 7-3: Maximum and Minimum injector pressures for diesel, HP DME and LP DME (45Nm, 1100rpm – 1800rpm)

RPM	1100		1200		1300		1400		1500		1600		1700		1800	
45Nm	Max (MPa)	Min (MPa)	Max (MPa)	Min (MPa)	Max (MPa)	Min (MPa)	Max (MPa)	Min (MPa)	Max (MPa)	Min (MPa)	Max (MPa)	Min (MPa)	Max (MPa)	Min (MPa)	Max (MPa)	Min (MPa)
LP DME	24.0	12.7	25.6	13.1	25.9	12.1	25.9	12.2	26.3	12.9	26.4	12.3	27.4	13.9	28.5	11.8
HP DME	24.74	11.8	25.6	11.9	25.7	13.3	26.6	14.1	27.1	13.6	26.9	12.2	25.9	11.8	27.2	11.9
DIESEL	28.4	2.7	29.4	2.2	26.7	2.6	31.1	4.3	29.5	3.4	30.1	4.1	31.2	5.2	32.5	5.6

7.3 Energy Release

This section discusses the energy release characteristics of the engine for the three different fuelling systems. The results are illustrated in diagrams below. Curve [green] is that of total cumulative energy released with heat transfer adjustments, representing the total energy released, and curve [red] is the apparent cumulative energy released with no heat transfer adjustments.

7.3.1 Low Pressure DME Energy Release

The total cumulative energy released (green line) for the engine operating on the Low Pressure DME system is shown in Figure 7-13 and Figure 7-14 below. These figures are for 25Nm, 1100 rpm and 25Nm, 1800 rpm respectively. A comparative diagram of the energy release at 45 Nm and 1800 rpm is shown in Figure 7-15.

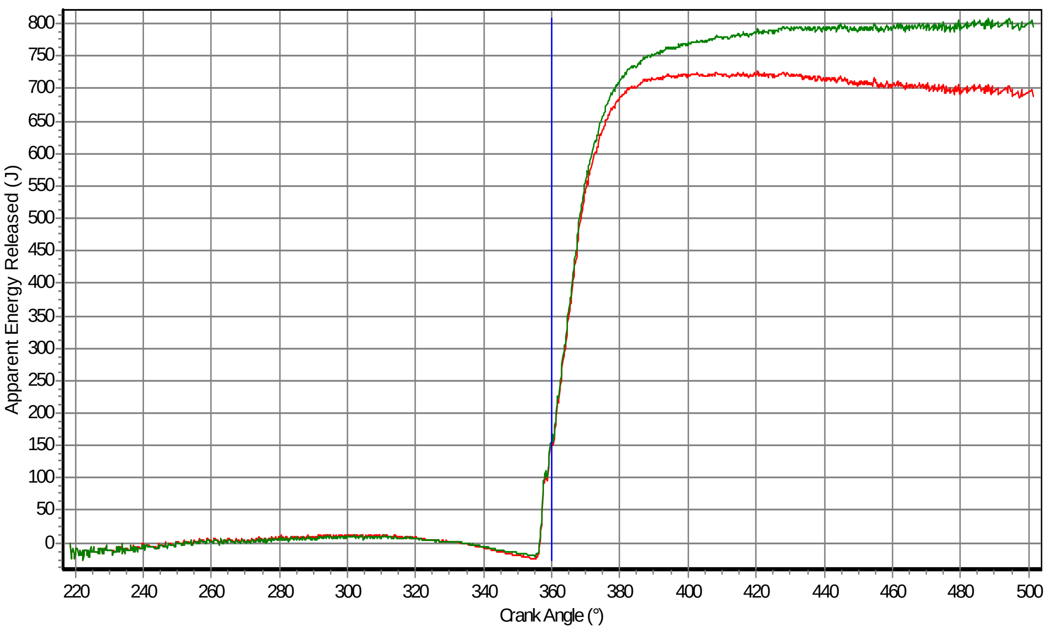

Figure 7-13: LP DME cumulative Energy Release versus crank angle at 25Nm and 1100rpm

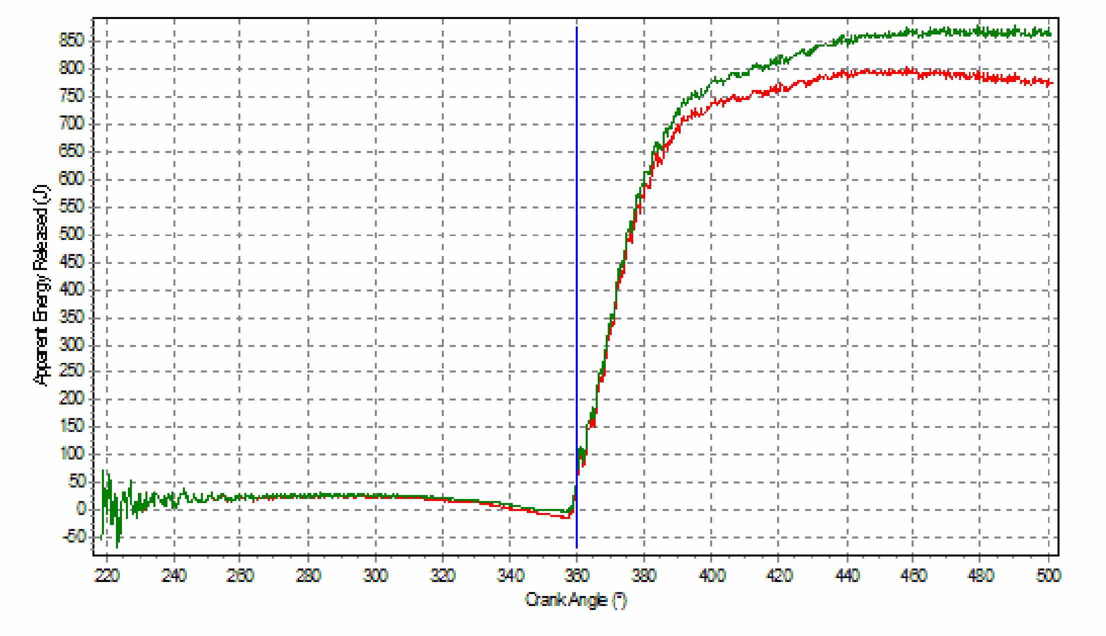

Figure 7-14: LP DME cumulative Energy Release versus crank angle at 25Nm and 1800rpm

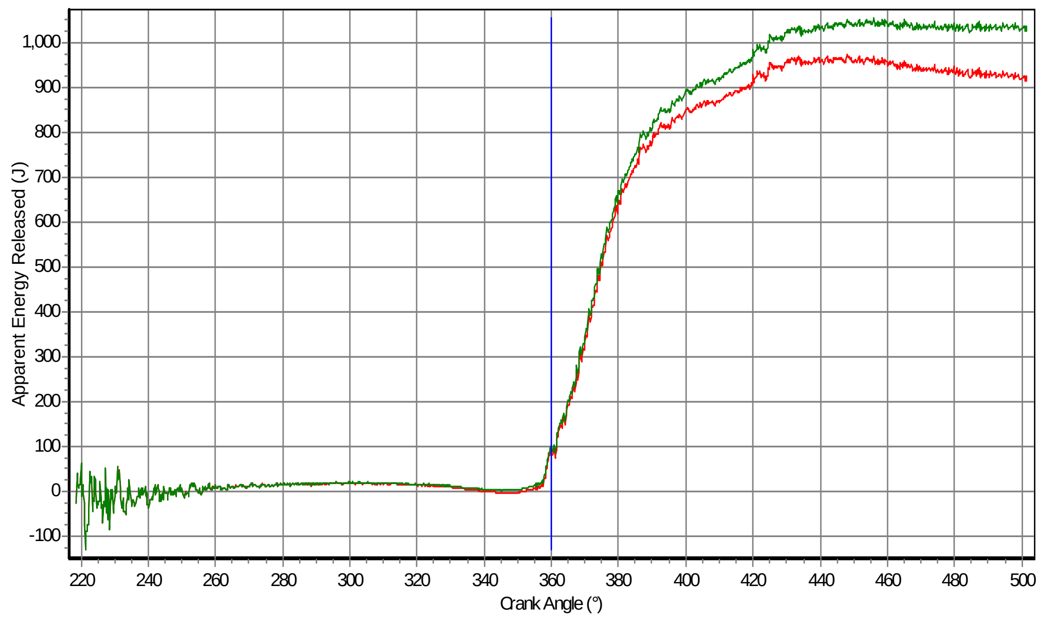

Figure 7-15: LP DME cumulative Energy Release versus crank angle at 45Nm and 1800rpm

Looking at Figure 7-13, Figure 7-14 and Figure 7-15, it can be seen that the performance of the engine is very good when operating on the new low pressure DME fuelling system. The energy release curves are smooth, indicating even release of energy and smooth engine operation. The only downfall, evident in all three cases, is the fact that the energy only starts to be released just before TDC and carries on releasing to a maximum well past TDC. This therefore reduces the efficiency as the piston is already on its way down as the maximum energy release peak occurs. However, as expected the energy released increases with increasing rpm and engine load with values reaching 850 J and 1000 J for 25Nm and 45 Nm respectively.

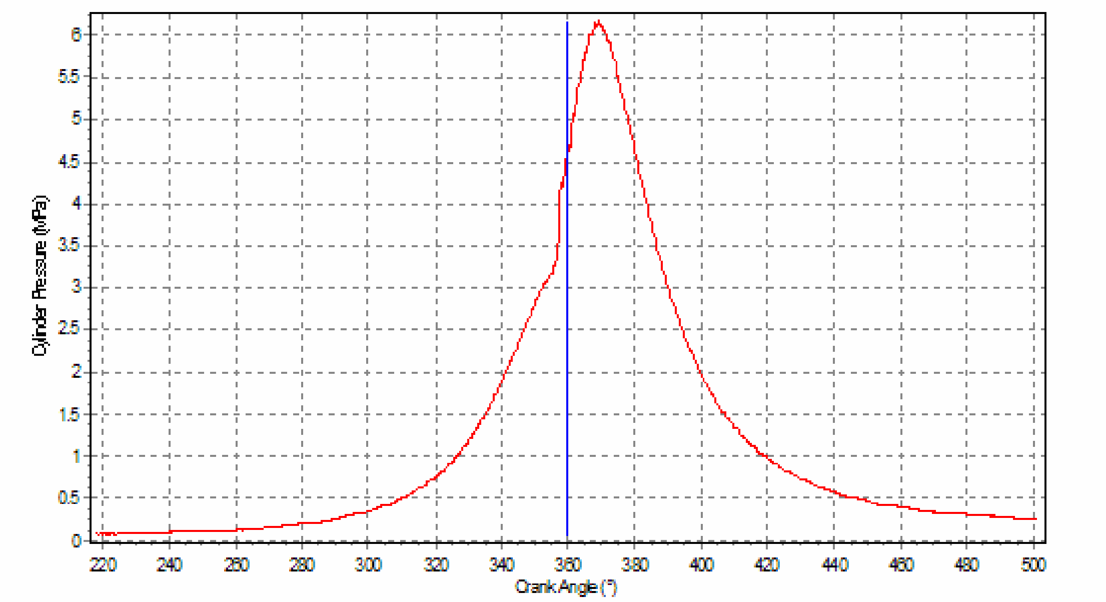

Figure 7-16: LP DME Combustion chamber Pressure versus crank angle at 25Nm and 1100rpm

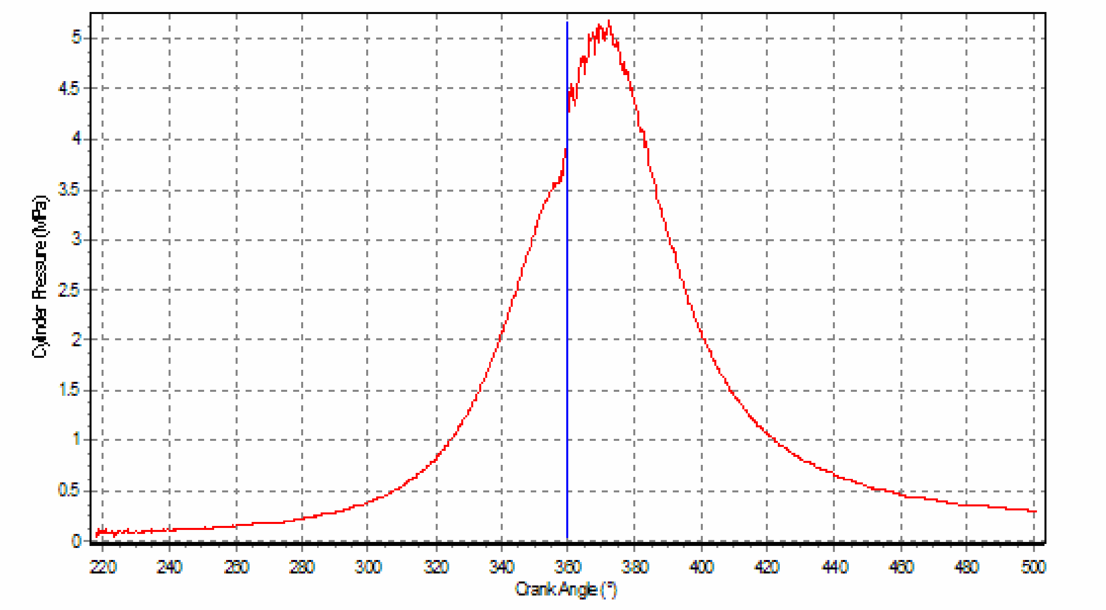

Figure 7-17: LP DME Combustion chamber Pressure versus crank angle at 25Nm and 1800rpm

Looking at the pressure traces in Figure 7-16 and Figure 7-17 it can be noted that the cylinder pressure decreases with increasing rpm. This trend correlates with the energy release plots. At low engines speeds the energy release rate "seems" to be faster (steeper slope) than at higher engine speeds. This release rate is relatively constant therefore as the rpm increases the maximum peak of the energy released is shifted to the right of TDC. This effectively reduces the cylinder pressure as the piston is already on its way down during the period of maximum energy release. Adding more energy to the system (more fuel) will allow for sufficient operation as the rpm and load are increased, changing the fuel injection timing is another solution.

7.3.2 High Pressure DME Energy Release

The results for high pressure DME fuelling system are very similar to those of the low pressure DME fuelling system. These results were expected as both systems deliver the same fuel (DME). The only difference between the two can be seen at low engine speeds where the energy, for the High Pressure system, is released just before TDC (See Figure 7-18). This situation is typically ideal as the total released energy is at a maximum just as the piston starts its power stroke (downwards). As the engine speed and load increase, however, the maximum peak migrates further right of TDC. This maximum point then occurs typically where the piston is already half way down the cylinder.

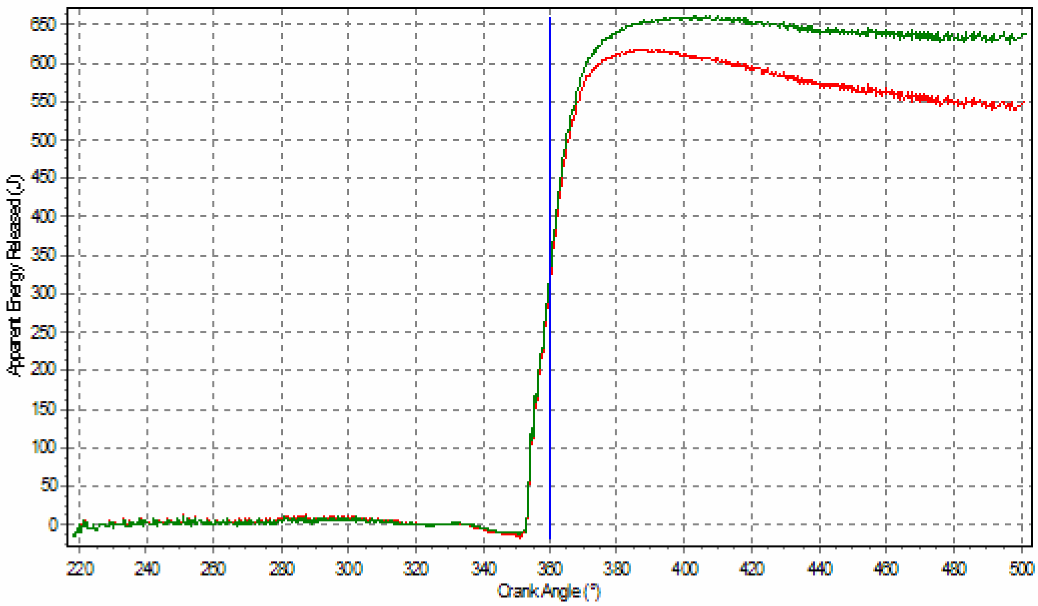

Figure 7-18: HP DME cumulative Energy Release versus crank angle at 25Nm and 1100rpm

Comparing Figure 7-18 to Figure 7-19 it can be seen, as before, that as the engine speed and load increase so does the total released energy. This again is credited to the additional fuel supplied in order to maintain continuous operation. As mentioned above, when the maximum peak of released energy is shifted to the right of TDC the cylinder pressure will decrease. (Compare Figure 7-20 to Figure 7-21)

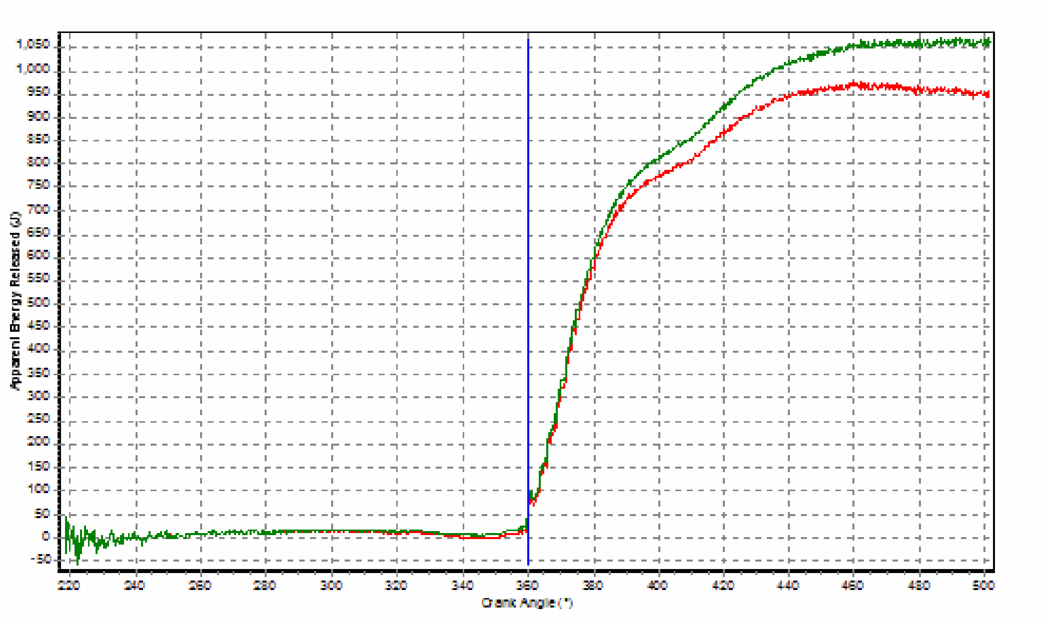

Figure 7-19: HP DME cumulative Energy Release versus crank angle at 45Nm and 1800rpm

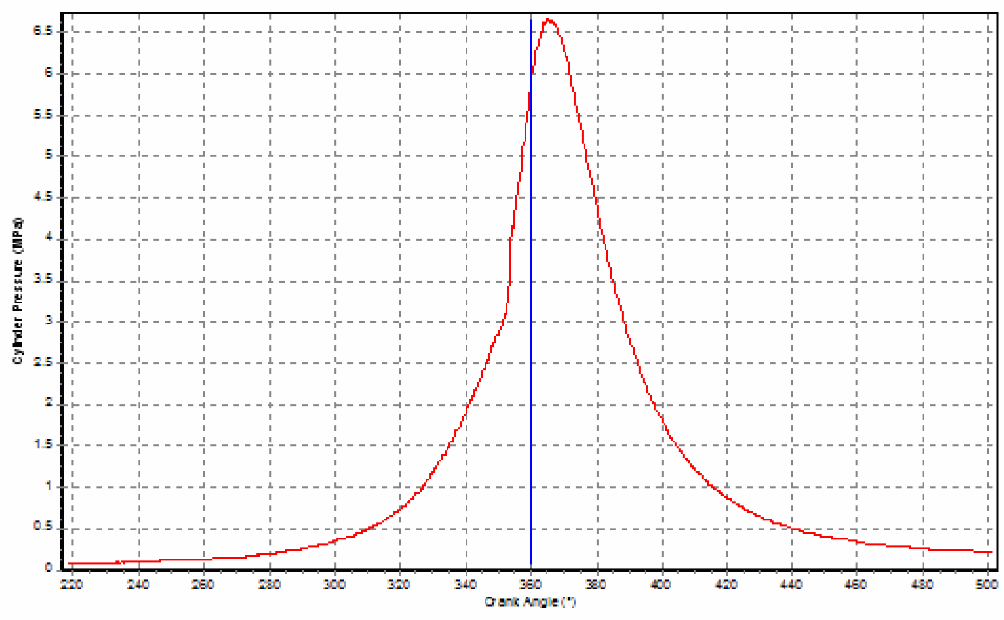

Figure 7-20: LP DME Combustion chamber Pressure versus crank angle at 25Nm and 1100rpm

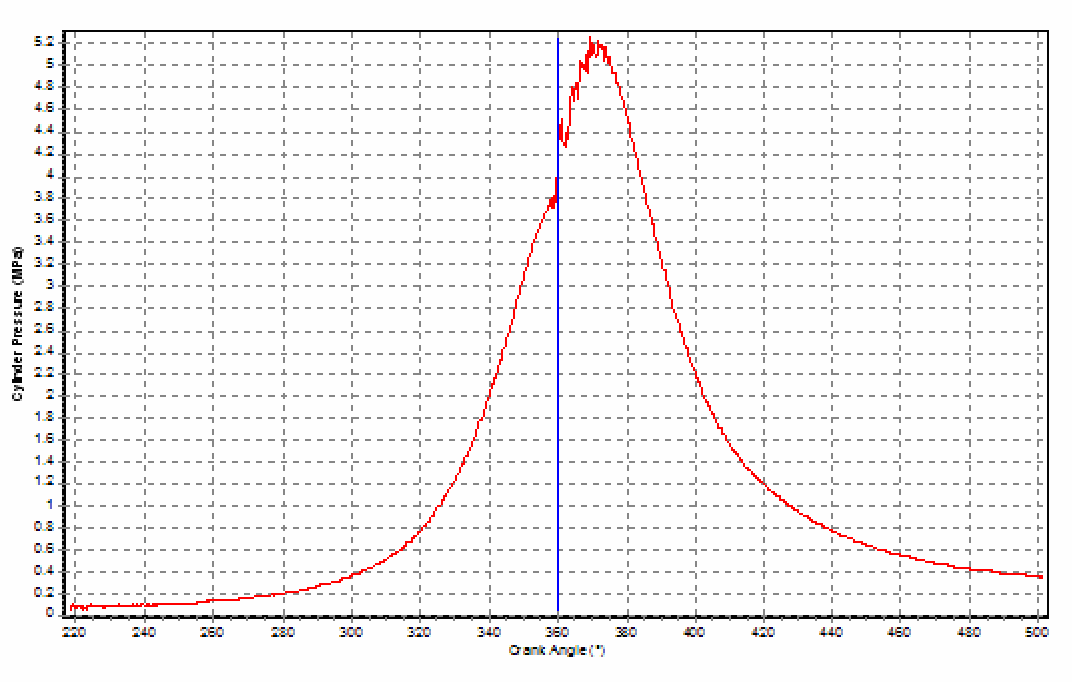

Figure 7-21: LP DME Combustion chamber Pressure versus crank angle at 45Nm and 1800rpm

7.3.3 Diesel Energy Release

The energy release for 25 Nm and engine speeds of 1100 rpm and 1800 rpm can be seen in Figure 7-22 and Figure 7-23 respectively.

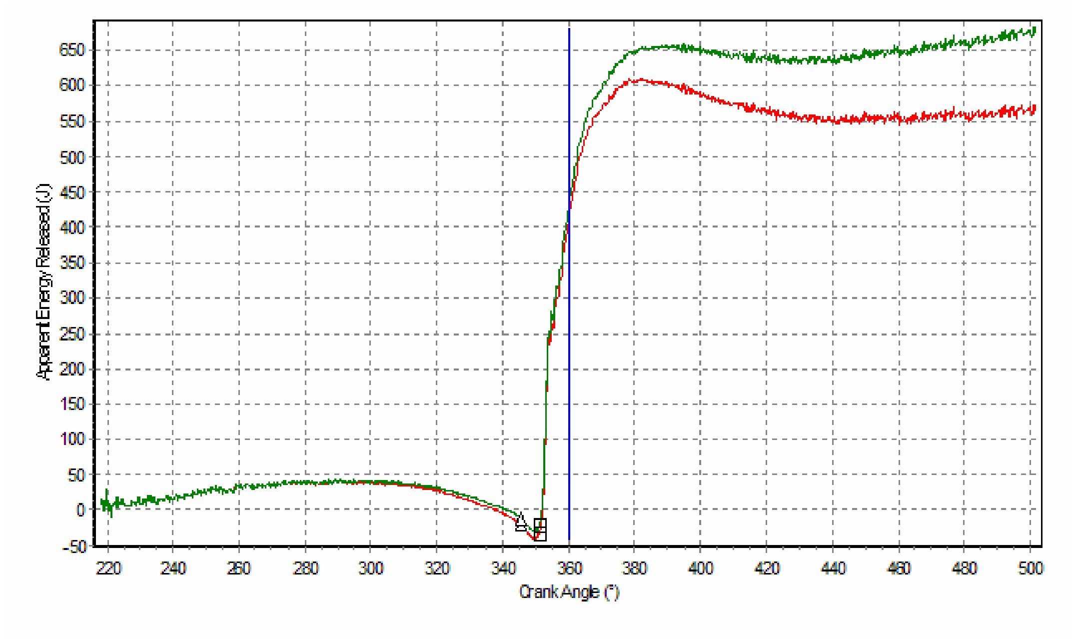

Figure 7-22: Diesel cumulative Energy Release versus crank angle at 25Nm and 1100rpm

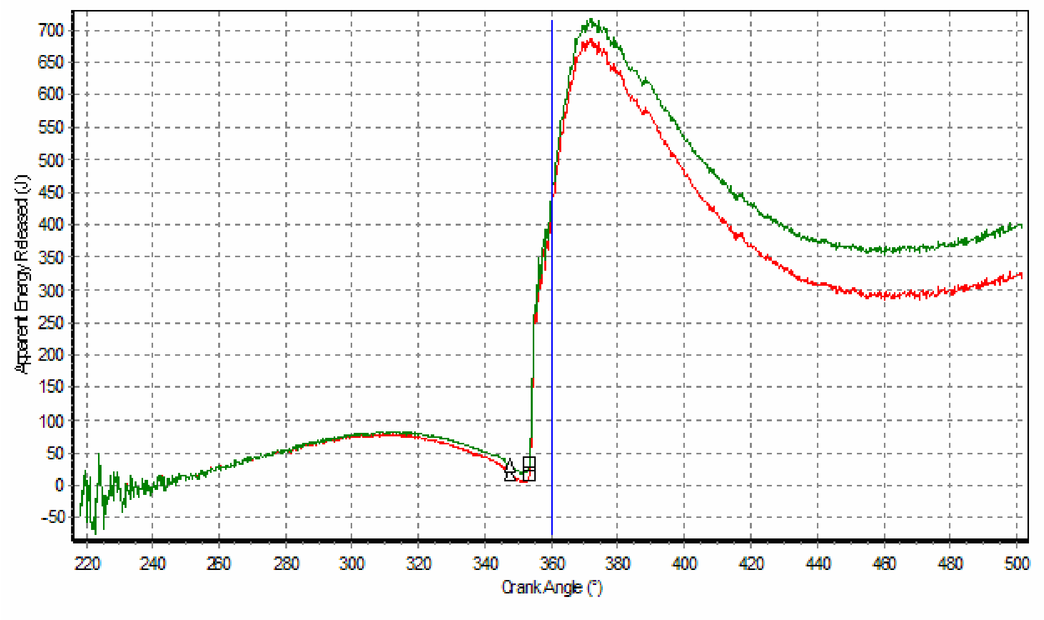

Figure 7-23: Diesel cumulative Energy Release versus crank angle at 25Nm and 1800rpm

It can be seen that the energy release plots are significantly different. During compression, the energy release increases and then drops just before injection [Δ] and ignition [□]. Upon ignition, the diesel exhibits a very sharp rise in energy. For both engine speeds it can be seen that the energy release is a maximum just after TDC. At 1100 rpm the maximum energy released remains constant, however, for the 1800 rpm run it was noted that the release energy decreased suddenly after it had reached its maximum, and then increased slightly just after 460° crank angle.

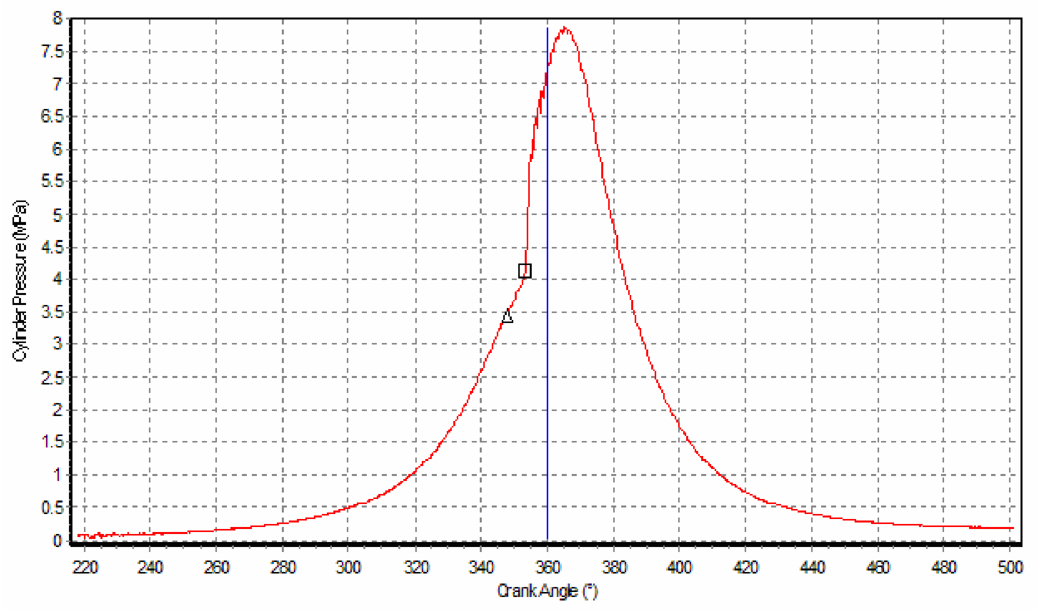

Figure 7-24: Diesel Combustion chamber Pressure versus crank angle at 25Nm and 1800rpm

When run on Low pressure DME the overall energy release is higher when compared to diesel at any specific engine speed and torque. However, most of these DME traces illustrate that much of the usable energy is only released once the piston is on its way down. This will inherently reduce the overall cylinder pressure which effectively will reduce the output power. Again the statement can be made that the injection timing does not suit DME, neither do the injector pumps.

7.4 NO_x Emissions

For the purpose of this report only NO_x emission are discussed. The NO_x emissions are considered most critical and most influenced by the use of a new fuel/fuelling system. A comparison of NO_x emissions is made between different load settings and different fuelling systems.

7.4.1 Low Pressure DME NO_x Emissions

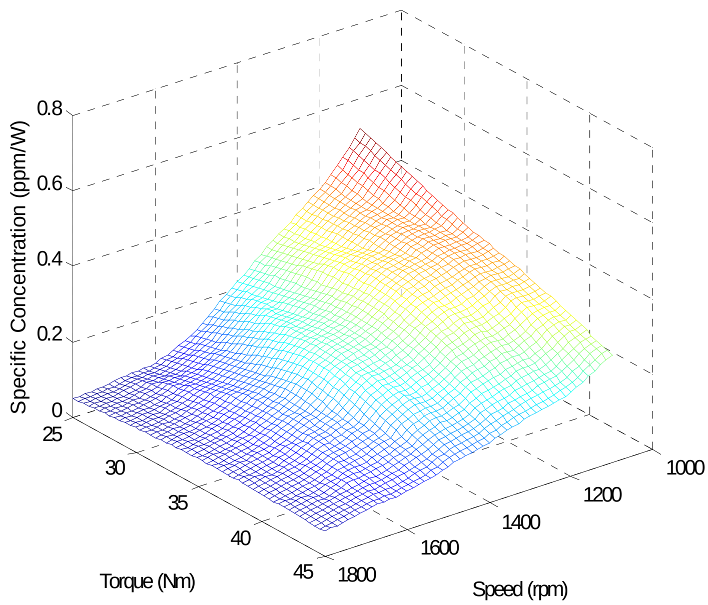

Figure 7-25: Surface Plot of NO_x Emissions for LP DME

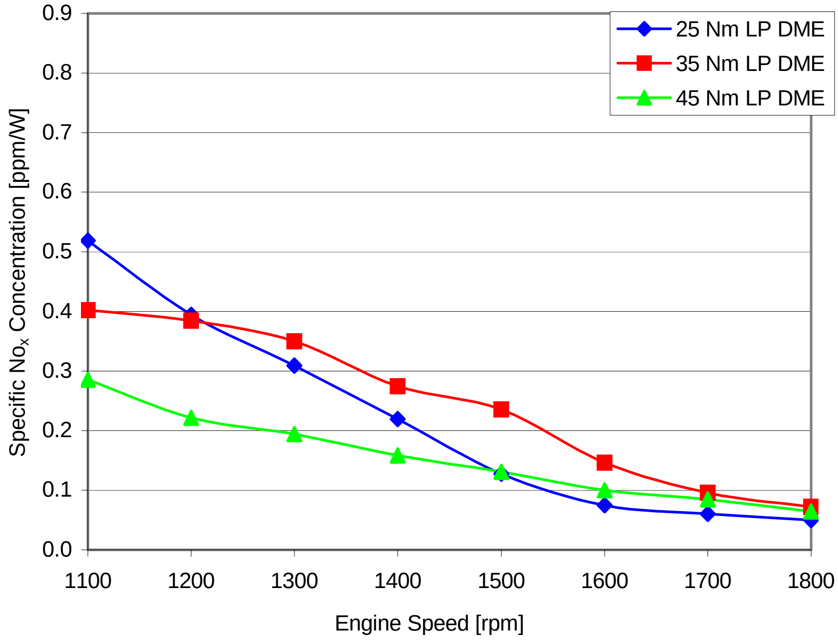

Figure 7-26: Graph of Specific NO_x Emissions vs. Engine Speed for LP DME

Figure 7-25 and Figure 7-26 above show the variation of specific mono-nitrogen oxide (NO_x) emissions with engine speed and engine load. All three load settings produce similar trends of emissions decreasing with increasing engine speed. It may also be notice that at lower engine speeds the rate at which NO_x emissions decrease is greater than at higher speeds. From about 1600 rpm onwards the NO_x emissions tend to converge. This indicates that after 1600 rpm, varying load doest not appear to have a significant effect NO_x emissions. The maximum specific NO_x concentration was 0.5189 ppm/W and occurred at 1100 rpm and a torque of 25 Nm. The average NO_x concentration was 0.2065 ppm/W.

7.4.2 High Pressure DME NO_x Emissions

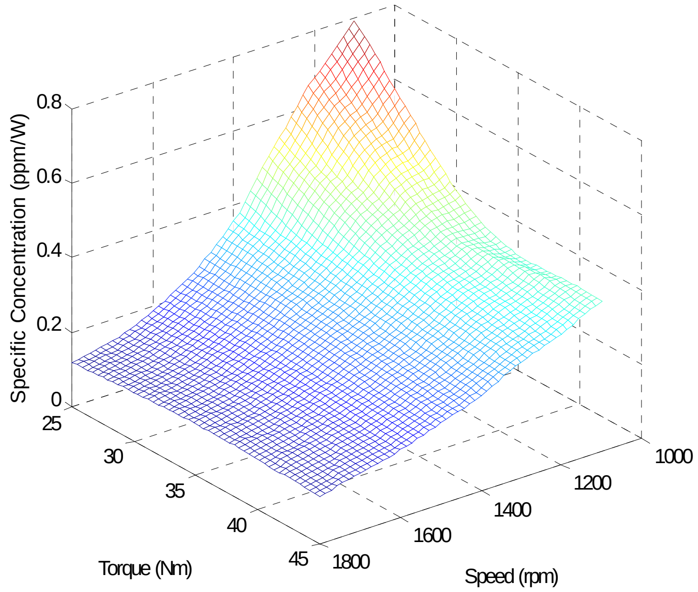

Figure 7-27: Surface Plot of NO_x Emissions for HP DME

Figure 7-27 and Figure 7-28 show the NO_x emissions for HP DME where a similar trend to that of the Low Pressure System is observed. The concentrations decreased with increasing engine speed and engine load. As above the emission levels for all three loads tend to decrease rapidly as the engine speed increases. The emissions also tend to taper off as they approach the maximum engine speed. The maximum NO_x concentration was 0.7923 ppm/W and occurred at 1100 rpm and 25Nm torque. The average NO_x concentration over the range of testing was 0.3049 ppm/W.

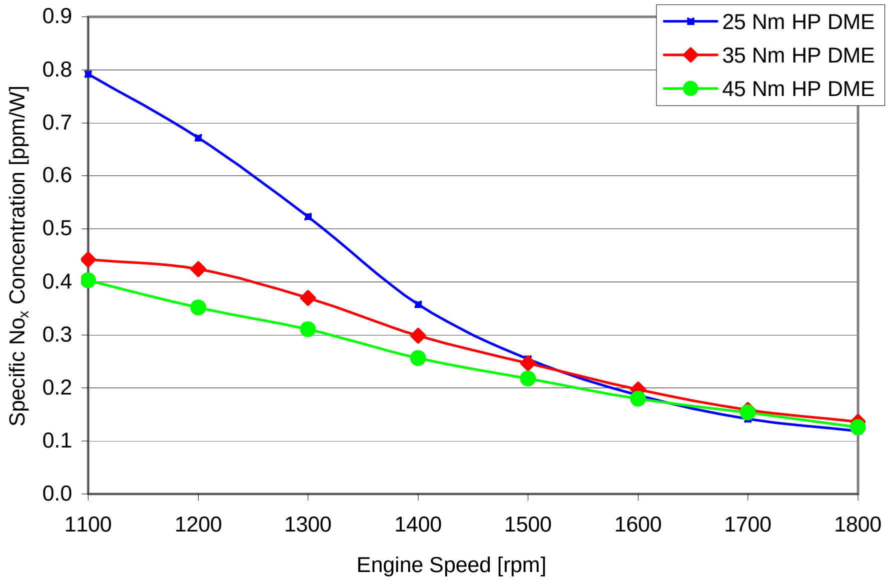

Figure 7-28: Graph of Specific NO_x Emissions vs. Engine Speed for HP DME

7.4.3 Diesel NO_x Emissions

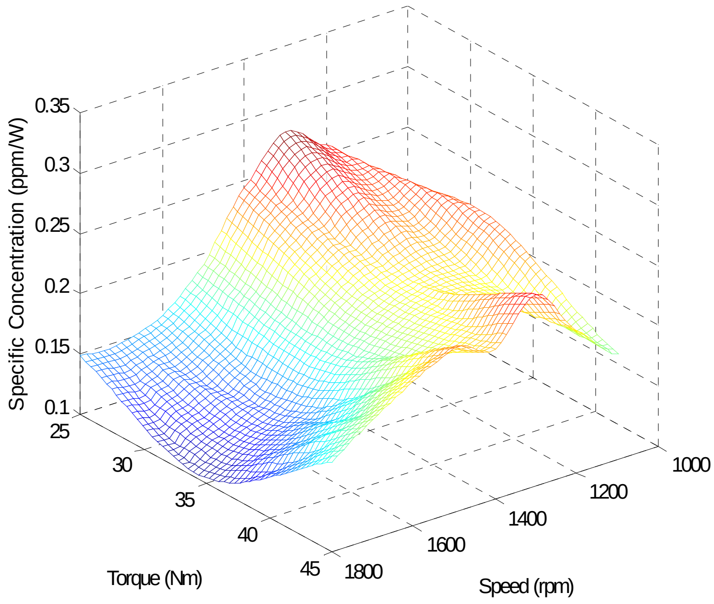

Figure 7-29: Surface Plot of NO_x Emissions for Diesel

Figure 7-29 shows the specific emissions for diesel fuelling. Here specific NO_x emissions increase, peak and then decrease with increasing engine speed. This is a general trend across all load ranges, however it was noticed that the emissions were higher for the 25 Nm and 45 Nm tests. Looking at Figure 7-30, the emissions peaked at 1300 rpm and then gradually decreased with the 25 Nm values levelling off at higher engine speeds. The 35 Nm emissions decreased steadily throughout the engine speed range. The maximum NO_x emissions measured were 0.2794 ppm/W and occurred at 1300 rpm and at 25 Nm with an average measurement of 0.199 ppm/W.

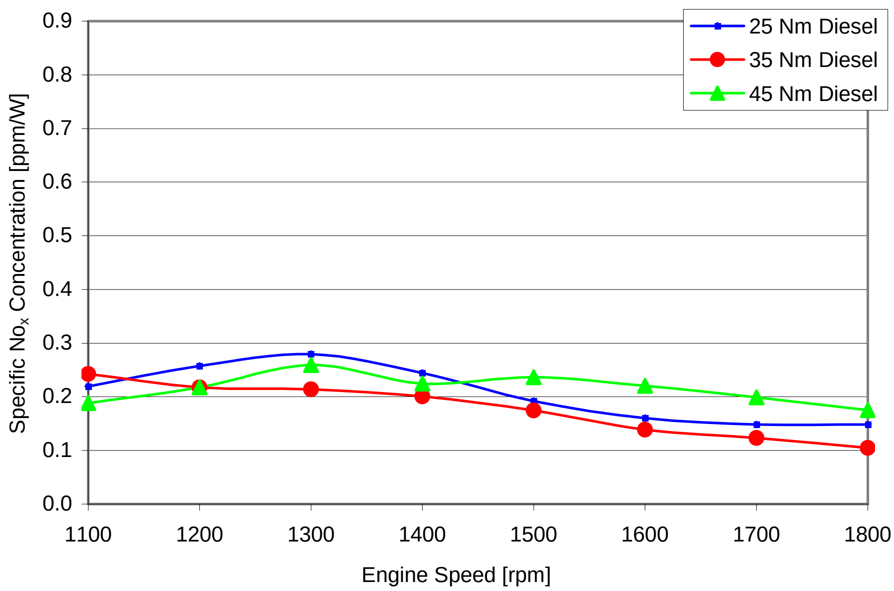

Figure 7-30: Graph of Specific NO_x Emissions vs. Engine Speed for Diesel

The results for the specific emission concentrations were compared against each other in order to determine the engine performance when using the three different fuelling systems.

7.4.4 Comparison of NO_x Emissions

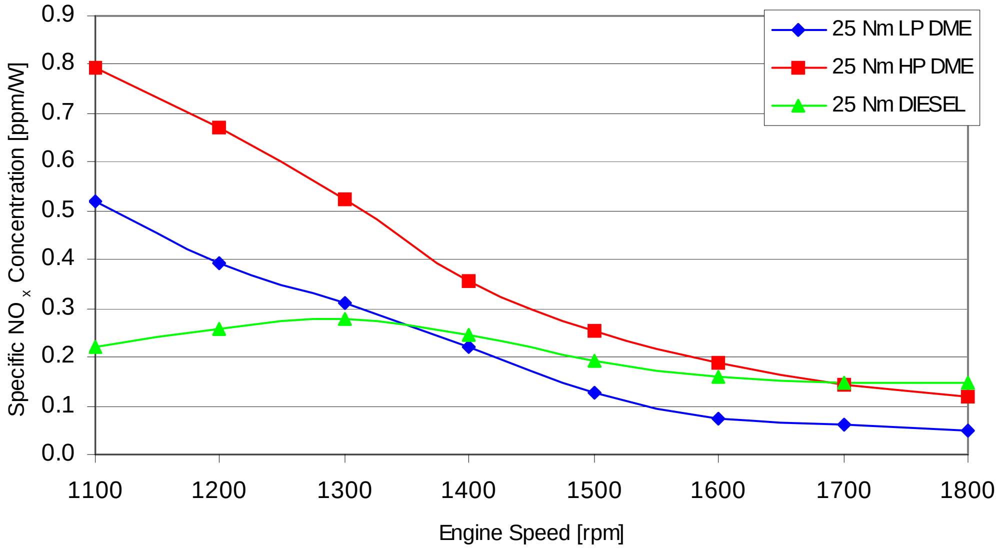

Figure 7-31: Comparison of Fuel NO_x Emissions at 25 Nm

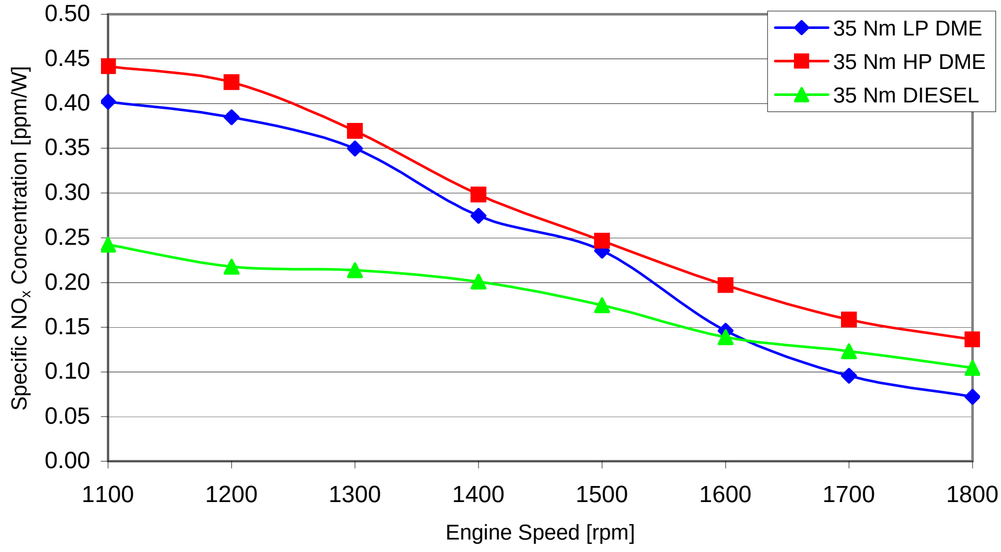

Figure 7-32: Comparison of Fuel NO_x Emissions at 35 Nm

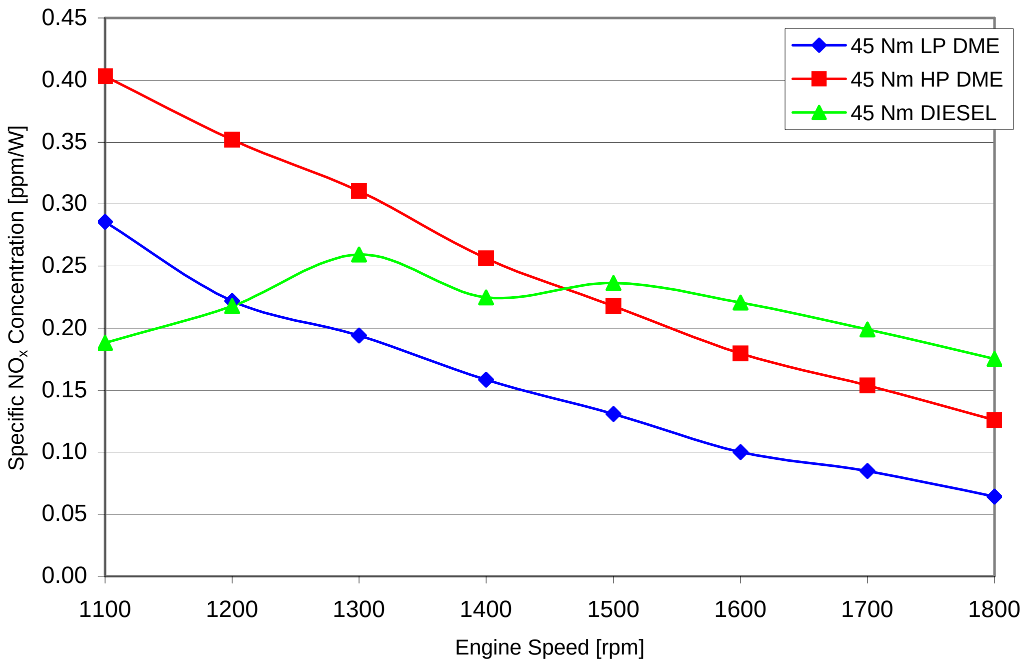

Figure 7-33: Comparison of Fuel NO_x Emissions at 45 Nm

Figure 7-26, Figure 7-28 and Figure 7-30, it may be notice that the two DME tests tend to follow a similar trend. The Low Pressure DME system, however, consistently performs better than the High Pressure system. The overall trend for NO_x emissions, for all three fuelling systems, tends to start off high at low engine speeds, and decreases gradually as the speed is increased. Another interesting find is that throughout the speed range the emissions produced by diesel tend to be more constant, whereas those from the DME tend to start off higher than diesel and end lower.

Figure 7-31, Figure 7-32 and Figure 7-33 clearly shows that the NO_x emissions are lowest with the Low Pressure DME system at high engine speeds, particularly at high loads. Figure 7-33 distinctly shows that the Low Pressure DME system has an advantage over the High Pressure system and conventional diesel.

8 Conclusion and Recommendations

8.1 Conclusion

The LP DME system ran without any problems. Oil levels and compressor temperatures remained normal throughout the tests. The LP DME system produced satisfactory results and showed definite potential for future development.

On the results side it was found that the bulk modulus of the fuel played a vital role in the injection and engine performance. It was found that the higher the bulk modulus, the better the injector performance. The performance went from best to worst as follows; first came diesel, second the HP DME system and lastly the LP DME system. Keeping in mind, however, that the current injection system was designed for diesel, this put both DME systems at a disadvantage. In order for DME to match the injection characteristics of diesel, a larger volume displacement injector pump would be required, along with an advance in injection timing.

From the energy release side it was observed that the Low Pressure DME system performed satisfactorily. The energy release was smooth and continuous. The only downfall for both DME systems was that most of the usable energy was only being release after TDC. This subsequently reduced the cylinder pressure as the piston was already on its way down when the released energy was at a maximum. Advancing the injector timing would most definitely increase the injector performance and engine efficiency.

The emissions revealed that in all three cases the NO_x concentration reduced as the engine speed was increased. Both the High pressure and Low pressure DME systems showed a tendency to have a high concentration of NO_x at low speed which tapers down relatively quickly as the speed increases. Diesel on the other hand showed more of a constant NO_x concentration with increasing speed. However, in all three cases, especially 45Nm, the Low Pressure DME system produced the lowest NO_x concentration for high engine speeds.

In General the LP DME fuelling system performed well. Slight adjustments to the injection timing will ensure that the engine will cope at high loads and high speeds.

8.2 Recommendations

- Conduct further tests to get a better understanding of the new Low Pressure DME fuelling system.
- Conduct further research using a common rail injection system and the Low Pressure DME system.
- Repeat test using a four hole injector and compare results.
- Automate the Low Pressure DME system.
- Finally, install a prototype Low Pressure DME system into a Light Duty Vehicle (LDV) and record the actual results using a rolling road dynamometer.

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16. Heat Release and Combustion Analysis (HRCA) Software, version 1.0.1.0.

A Appendix – Calibration

The equipment used during the research was all previously calibrated unless otherwise stated. The data and procedures from the calibrations are shown below.

A.1 Diesel Fuel Flow Calibration

- Diesel is to be bled through the fuel flow meter into a container positioned on an electronic scale.
- While the diesel is running through the meter the input voltage to the data acquisition system is recorded.
- The time taken to collect a certain mass of diesel is noted. From this information the mass flow rate can be calculated.
- The fuel flow is increased for each consecutive reading.
- The results are tabulated and then plotted. A linear curve is fitted to the data so as to determine the calibration constants for the data acquisition system.

Table A-1: Diesel Fuel Flow Calibration Data

Reading Number	Mass (g)	Time (s)	Voltage (V)	Flow (l/h)	Mass Flow (g/s)
1	0	0.00	-0.002	0.0	0
2	15.6	121.04	0.127	0.4	0.1289
3	31.5	121.50	0.259	1.0	0.2593
4	58.5	121.72	0.487	1.9	0.4806
5	91.1	121.75	0.762	3.0	0.7483
6	113.0	120.30	0.962	3.8	0.9393
7	154.3	120.30	1.309	5.2	1.2826
8	178.0	120.47	1.519	6.0	1.4775
9	210.2	120.18	1.796	7.2	1.7490
10	233.3	120.28	1.988	7.9	1.9396
11	263.8	119.59	2.257	9.0	2.2059
12	298.3	120.24	2.555	10.2	2.4809
13	325.6	120.24	2.784	11.1	2.7079
14	353.7	120.96	3.010	11.8	2.9241
15	297.7	120.85	2.540	10.1	2.4634
16	238.8	121.03	2.000	8.1	1.9731
17	174.5	120.99	1.485	5.9	1.4423
18	117.4	121.07	0.993	4.0	0.9697
19	59.7	121.20	0.502	2.0	0.4926
20	0.0	0.00	-0.007	0.0	0

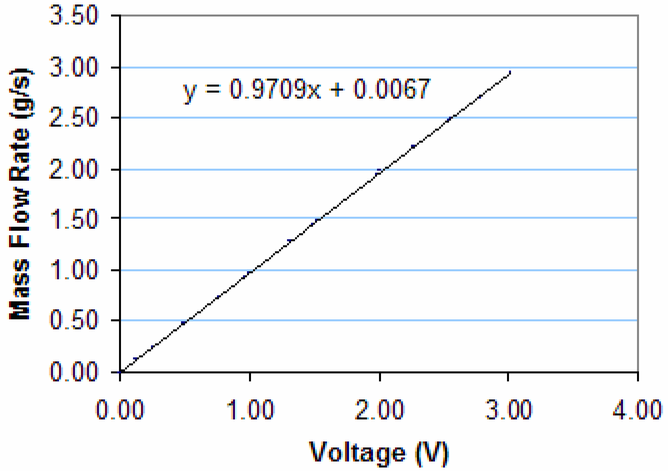

Figure A-1: Fuel Flow Calibration

A.2 DME Fuel Supply Flow Calibration

Tube: FP-1/8-25-G-5

Float: FP-CA-18 (Carboloy)

N-Number: 8325

Fluid: DME

Density: 0.661 kg/l

Viscosity: 0.15 cP

Table A-2: DME Fuel Flow Calibration Data

Reading Number	Flow (l/min)	Mass Flow (g/s)
1	0.0028	2
2	0.0104	7
3	0.018	12
4	0.026	17
5	0.036	24
6	0.044	29
7	0.054	36
8	0.064	42
9	0.074	49
10	0.084	56
11	0.094	62
12	0.104	69
13	0.114	75
14	0.125	83
15	0.135	89

Reading Number	Flow (l/min)	Mass Flow (g/s)
16	0.145	96
17	0.155	102
18	0.165	109
19	0.18	119
20	0.195	129
21	0.205	136
22	0.215	142
23	0.225	149
24	0.235	155
25	0.245	162

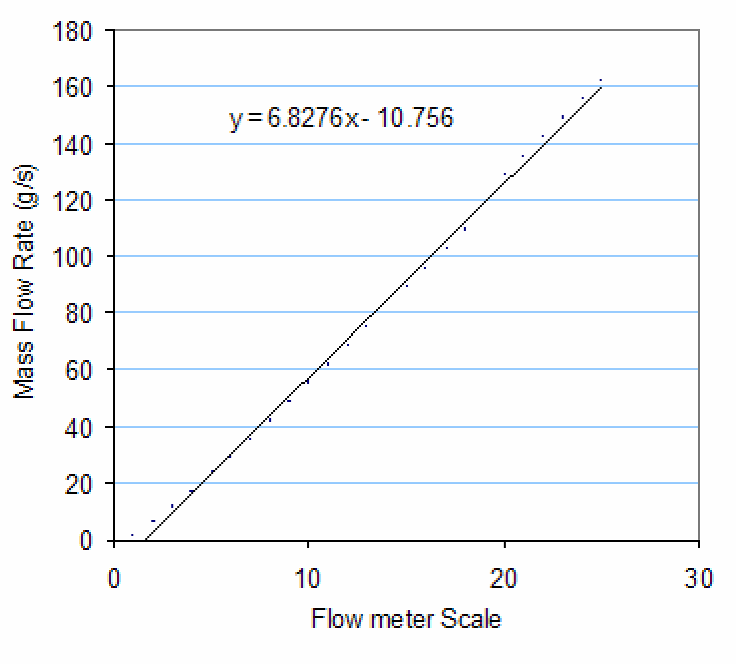

Figure A-2: DME Fuel Supply Flow Calibration

A.3 DME Fuel Circulation Flow Calibration

Tube: FP-1/4-16-G-5

Float: FP-CA-14 (Carboloy)

N-Number: 23530

Fluid: DME

Density: 0.661 kg/l

Viscosity: 0.15 cP

Table A-3: Diesel Fuel Flow Calibration Data

Reading Number	Flow (l/min)	Mass Flow (g/s)
1	0.0028	2
2	0.0104	7
3	0.018	12
4	0.026	17
5	0.036	24
6	0.044	29
7	0.054	36
8	0.064	42
9	0.074	49
10	0.084	56
11	0.094	62
12	0.104	69
13	0.114	75
14	0.125	83
15	0.135	89
16	0.145	96
17	0.155	102
18	0.165	109
19	0.18	119
20	0.195	129
21	0.205	136
22	0.215	142
23	0.225	149
24	0.235	155
25	0.245	162

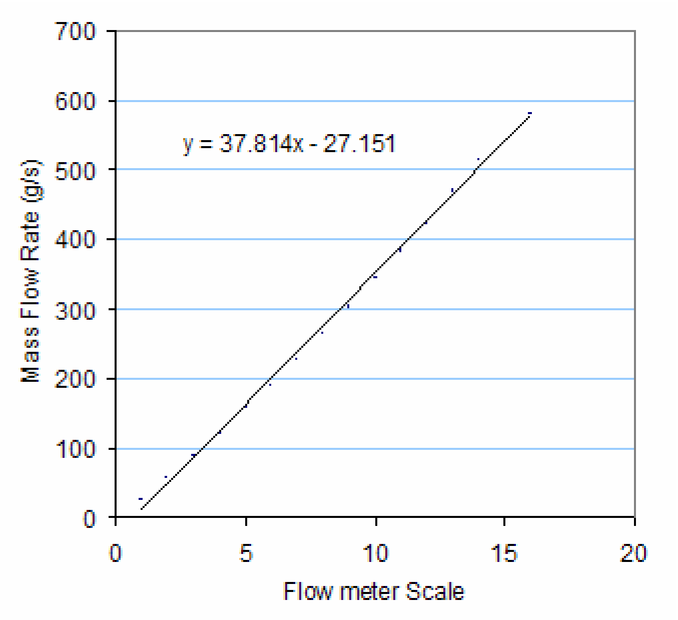

Figure A-3: DME Fuel Circulation Flow Calibration

A.4 Dynamometer Calibration

- Mass pieces are suspended from the static torque arm of the dynamometer.
- The input voltage to the data acquisition system from the load cell is measured. Note that an amplifier voltage of 5 Volts is used.
- This process is repeated for increasing and decreasing loads, from which an average voltage is determined.
- The length of the torque arm is established to be 0.4003 meters from which the actual torque is calculated.
- Torque versus Average Voltage is plotted and a linear curve is fitted to the data.

Table A-4: Dynamometer Calibration data

Reading Number	**Mass (Kg)**	**Calculated Torque (Nm)**	**Voltage (V)**	**Controller Display (Nm)**
1	0.0000	0.000	0.025	0
2	0.6198	4.355	0.183	5
3	1.6170	11.361	0.433	12
4	2.6170	18.387	0.683	19
5	2.8920	20.319	0.754	21
6	3.8890	27.324	1.007	28
7	4.8890	34.350	1.260	35
8	5.1650	36.289	1.331	37
9	6.1650	43.315	1.583	44
10	7.4330	52.224	1.903	53
11	8.4330	59.250	2.154	60
12	9.7070	68.201	2.478	69
13	10.7070	75.227	2.731	76
14	11.7700	82.695	2.996	83
15	12.7700	89.721	3.251	91
16	14.0400	98.644	3.569	99
17	15.0400	105.670	3.826	106
18	14.0400	98.644	3.573	99
19	11.7700	82.695	3.000	83
20	9.4940	66.704	2.427	67
21	5.1610	36.261	1.332	36
22	2.8930	20.326	0.761	20
23	0.6198	4.355	0.185	4
24	0.0000	0.000	0.027	0

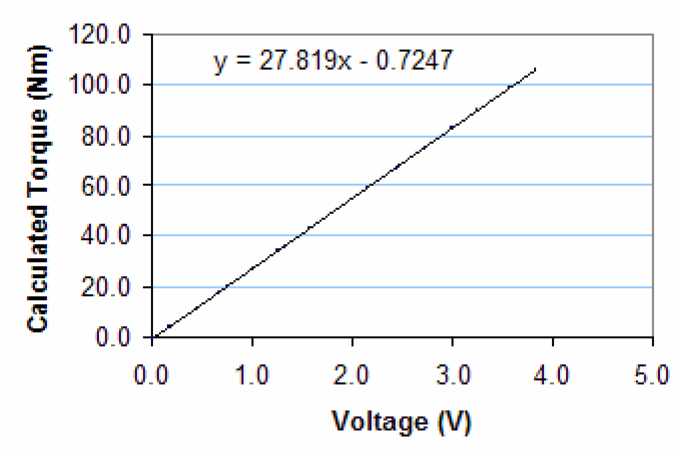

Figure A-4: Dynamometer Calibration Curve

A.5 Speed Calibration

Table A-5: Speed Calibration Data

Reading Number	Voltage Average (V)	Controller Speed (rpm)
1	1.170	1160
2	1.210	1200
3	1.260	1250
4	1.315	1300
5	1.361	1350
6	1.416	1403
7	1.470	1455
8	1.512	1503
9	1.566	1550
10	1.611	1600
11	1.661	1648
12	1.714	1700
13	1.763	1750
14	1.814	1800
15	1.864	1850
16	1.915	1898
17	1.963	1950
18	2.015	1999
19	1.917	1902
20	1.815	1801
21	1.713	1700
22	1.663	1650
23	1.612	1602
24	1.500	1488
25	1.319	1307
26	1.215	1203
27	1.160	1150

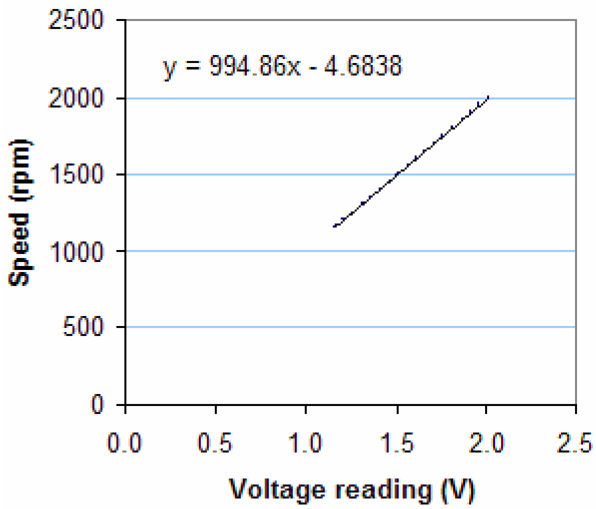

Figure A-5: Speed Calibration Curve

A.6 Air Flow Calibration

- With the engine running pressure readings were taken across the orifice plate. These values were displayed in millimetres of water.
- Voltage readings were recorded from the data acquisition system.
- The results were tabulated and plotted. A linear curve was fitted to the data so as to determine the calibration constants.

Table A-6: Airflow Calibration Data

Reading Number	Voltage Lower (V)	Voltage Higher (V)	Voltage Average (V)	Controller Speed (rpm)	Air Flow (mmH2O)
1	-1.759	-1.898	-1.829	1151	-7.6
2	-2.006	-2.101	-2.054	1200	-8.5
3	-2.131	-2.181	-2.156	1250	-8.9
4	-2.015	-2.155	-2.085	1301	-9.0
5	-2.135	-2.270	-2.203	1352	-9.1
6	-2.304	-2.373	-2.339	1400	-9.7
7	-2.381	-2.460	-2.421	1450	-10.0
8	-2.478	-2.553	-2.516	1501	-10.4
9	-2.758	-2.834	-2.796	1550	-11.4
10	-3.120	-3.235	-3.178	1600	-13.0
11	-3.241	-3.337	-3.289	1652	-13.5
12	-3.011	-3.228	-3.120	1702	-13.1
13	-3.026	-3.144	-3.085	1748	-12.5
14	-3.112	-3.376	-3.244	1798	-13.2
15	-3.492	-3.563	-3.528	1851	-14.6

Reading Number	Voltage Lower (V)	Voltage Higher (V)	Voltage Average (V)	Controller Speed (rpm)	Air Flow (mmH2O)
16	-3.337	-3.753	-3.545	1905	-14.6
17	-3.753	-4.118	-3.936	2000	-16.2
18	-3.701	-3.837	-3.769	1900	-15.6
19	-3.114	-3.390	-3.252	1800	-13.4
20	-3.005	-3.212	-3.109	1700	-13.0
21	-3.037	-3.116	-3.077	1600	-12.9
22	-2.448	-2.497	-2.473	1501	-10.2
23	-2.235	-2.336	-2.286	1404	-9.5
24	-2.072	-2.182	-2.127	1299	-8.5
25	-2.025	-2.112	-2.069	1197.0	-8.4
26	-1.766	-1.866	-1.816	1150.0	-7.4

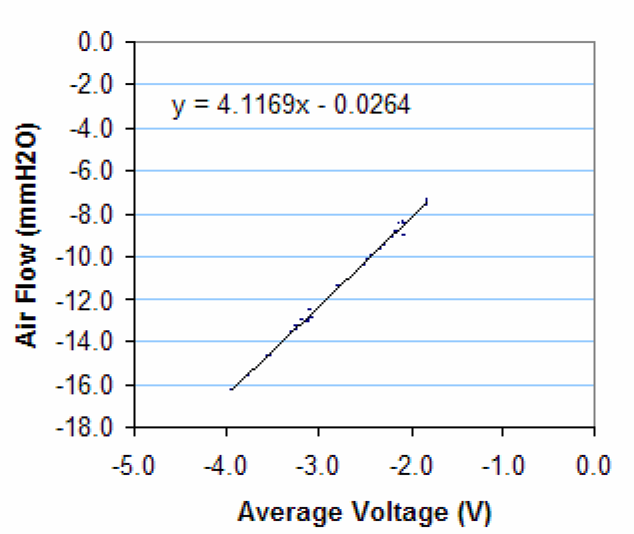

Figure A-6: Airflow Calibration Curve

A.7 Pressure Transducer Calibration

Table A-7: Pressure Transducer Calibration Data

Reading Number	Applied Pressure Psi	Bar	Output Voltage (V) Up	Down	Average Voltage(V)
1	0	0.000	0.000	0.000	0.000
2	100	6.895	0.678	0.690	0.684
3	200	13.790	1.388	1.360	1.374
4	300	20.684	2.079	2.070	2.075
5	400	27.574	2.750	2.750	2.750
6	500	34.477	3.470	3.480	3.475
7	600	41.369	4.160	4.160	4.160
8	700	48.263	4.880	4.870	4.875
9	800	55.158	5.600	5.600	5.600
10	900	62.053	6.280	6.260	6.270
11	1000	68.948	6.970	6.970	6.970
12	1100	75.845	7.620	7.890	7.755

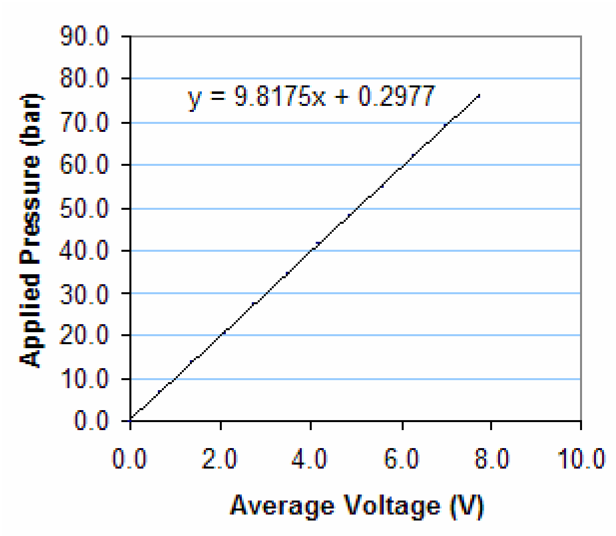

Figure A-7: Pressure Transducer Calibration Curve

B Appendix - Data Acquisition Procedure

B.1 Performance Data Set-up

The following procedure outlines the steps involved in setting up the directories to which the test data should be stored in the *Windows 95* software package such that they may be analysed further.

1. Once *Windows* has started up, point the cursor to the *Windows Taskbar*, click *Start*, move down the list and point to *Explorer,* displaying the installed files. Click on the *Data* file and then on *PH2W*.
2. Create a relevant folder into which the test data should be saved, e.g. c*:\PH2\Sept2005\25Nm.* The test data will be saved as a *.DAT* file.
3. In *Windows* double click on the *Engine Test* shortcut icon. This will open the *Engine Test* program.
4. In this window click on the *File* button on the menu bar and point the cursor to *Test Data Directory.* A window displaying the directory path is displayed. Select the appropriate data directory where the test data is to be saved. **NB: Always manually add a backslash after the path name since there is a fault in the program.**
5. In the *Engine Test* program window select the *Settings* button on the menu bar and toggle down to *Test Settings*. This will open the *Speedwave Channel Settings* window.
6. On the menu bar click on the *Open File* shortcut button. This will allow you to retrieve the relevant file for the various test rigs. For example to open the file for the Petter engine, *C:/Program Files/TLC/Engine Test/PH2.*
7. On the menu bar of the *Speedwave Channel Settings* window select the *Test Settings* label. The storage option should be set to M*ulti Event* and the saving method changed to *DOS Compatible*.
8. Enter the relevant path for the data to be captured and then click on the *Ok* button. The *Test Filename* is to be set as the *file location*, *fuel type, date and test number*. The codes for the fuel types are listed below.
9. Select the *Steady State Channels* and enter the applicable calibration constants into this window. Remember that for the *Calibration* value a value of *–c* has to be entered and for the *Conversion* value only *m* needs to be entered into the relevant column.
10. Similarly the *High Speed Channels* have to be set.
11. Save the changes in its directory.
12. Select the 'lightning bolt' icon to arm the *Speedwave Channel Settings* with changed parameters. The program is ready to acquire a set of tests.

Table B-1 - Fuel Type Coding Description

Fuel Type	Code
Diesel	di
Dimethyl Ether (DME)	dm
Methanol/DME	md
Ethanol/DME	ed
Motoring	mo

Once the data sets have been captured, the results are ready to be accessed and interpreted by the Heat and Combustion Analysis (HRCA) program. The following procedure is to be followed when opening a file in HRCA. [16]

1. Click on the *Open File* icon at the top of the screen in HRCA. This will open up a *Data Acquisition Wizard*.
2. Select the path and filename and press *Enter.*
3. Choose between *Motoring* and *Firing* modes for the test data. In all instances above, *Firing* was chosen as the option.
4. Select the type of fuel being used for the test. When DME is selected, the fuelflow reading and overflow reading must be entered.
5. Select the number of cycles over which the data must be averaged. The maximum number of cycles is nine with the default being one.
6. The *Data Summary* window should now be displayed.
7. Various graphs can be plotted automatically by choosing the Summary window and clicking on *Plots*. A number of options will appear which can then be selected.
8. The *Data Summary* can be exported to Microsoft Excel by clicking on the Excel icon that is visible at the top of the window. The results will then be saved as a comma separated variable file in Excel in the drive as selected by the user.

C Appendix – Low Pressure DME Rig Procedure

1. Ensure that the 12 VDC power cable for the Low Pressure DME Rig is connected to the engine battery.
2. Ensure that the control termination card is plugged into its corresponding card mounted in the Low Pressure DME Rig control computer.
3. Switch on the Low Pressure DME Rig control computer.
4. Open the file named *DME LP Fuel Sys.dgm* in the program called Visual Designer. The program flow code can be seen in Appendix D.
5. Ensure that the black control box is supplied with 12 VDC power from the 500 mA power supply. A yellow LED on the side of the box will indicate that the box is supplied with power.
6. Click the yellow arrow button in the Visual Designer program to run the control program.
7. Toggle the fan button on the screen and note whether the fan on the evaporator turns on. This is done to ensure communication between the equipment and the PC.
8. Turn on the DME supply cylinder.
9. Ensure that the pressure release valve is closed and set to release at approximately 15 bar.
10. Ensure that the pressure release overflow pipe is connected to the valve and the end is placed outside the window.
11. Ensure that the fuel supply pipe to the three-way valve is connected.
12. Ensure that the fuel outlet rotameter is closed.
13. Switch on the compressor
14. Turn on the power to engage the mechanical clutch on the compressor.
15. Trigger the *DME Supply* button on the PC screen to allow DME to enter the system.
16. Monitor the 'HP Pres' reading on the screen. When it reaches 7.5 bar, click the *DME Supply* button to turn off the DME Supply.
17. Monitor the 'HP Pres' reading on the screen. When it reaches approximately 10.5 bar or stabilises, click on the green *START* button on the screen. This will turn the system into automatic mode.
18. Slightly open the fuel outlet rotameter. When the ball inside the sight glass falls, the fuel line to the three-way valve is charged.
19. Monitor the graph on the screen and when all values have stabilised the system is ready to supply fuel to the engine.

D Appendix – Program Flow Diagram

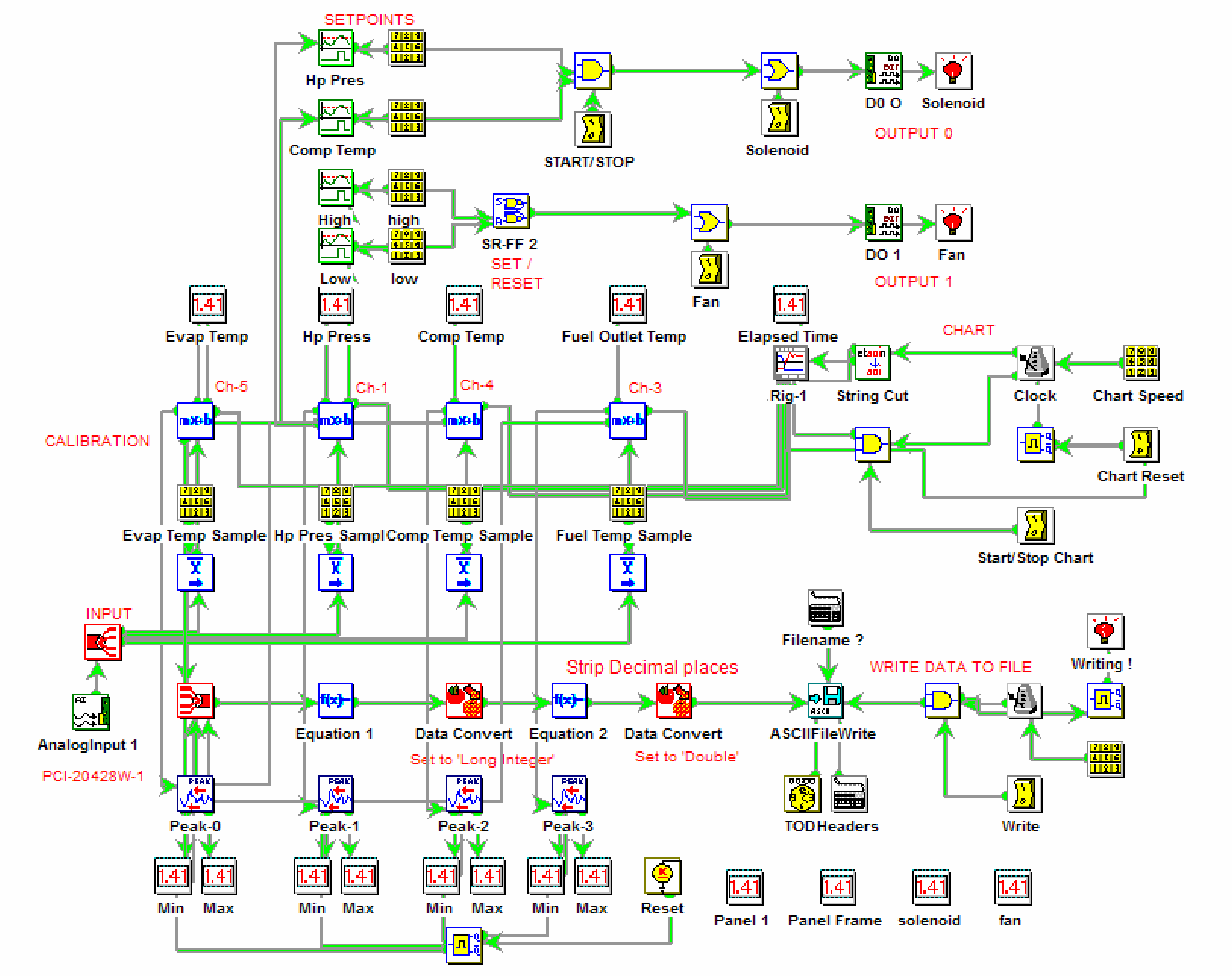

Figure D-1: Controller program flow diagram

E Appendix – Raw Data

E.1 Low Pressure DME

25 Nm LP DME		1100 rpm						1200 rpm					
File name		dm260901	dm260902	dm260903	dm260904	dm260905	**Average**	dm260906	dm260907	dm260908	dm260909	dm260910	**Average**
speed	**(rpm)**	1090.6	1095.4	1090.6	1090.6	1090.6	**1091.560**	1202.3	1202.3	1202.3	1202.3	1202.3	**1202.300**
Load	**(Nm)**	24.7	25.4	24.4	24.5	24.7	**24.740**	25.8	25.4	25.1	25.6	25.4	**25.460**
Brake Power	**(W)**	2818.1	2908.5	2787	2802.6	2818.1	**2826.860**	3243.7	3192.4	3158.2	3226.6	3192.4	**3202.660**
Ind. work per Cycle	**(J)**	475.1	514.8	422.7	453.9	441.4	**461.580**	413.9	443.1	428.4	438.7	438.9	**432.600**
Indicated Power	**(W)**	8635.8	9399.2	7683.1	8249.8	8023.4	**8398.260**	8294.7	8878.4	8585.2	8791.3	8795.1	**8668.940**
imep	**(kPa)**	714.5	774.2	635.7	682.5	663.8	**694.140**	622.5	666.3	644.3	659.7	660	**650.560**
bmep	**(kPa)**	233.1	239.6	230.6	231.9	233.1	**233.660**	243.4	239.6	237	242.1	239.6	**240.340**
Equivalence Ratio		0.347	0.347	0.353	0.346	0.349	**0.348**	0.36	0.367	0.365	0.366	0.366	**0.365**
Air/fuel ratio		29.01	28.89	28.67	28.89	28.82	**28.856**	27.74	27.59	27.46	27.54	27.75	**27.616**
Air Flow	**(g/s)**	11.275	11.229	11.142	11.227	11.199	**11.214**	11.994	11.93	11.875	11.911	12.001	**11.942**
Fuel Flow	**(g/s)**	0.39	0.39	0.39	0.39	0.39	**0.390**	0.43	0.43	0.43	0.43	0.43	**0.430**
Additive Flow	**(g/s)**	0	0	0	0	0	**0.000**	0	0	0	0	0	**0.000**
Percentage DME	**(%)**	0	0	0	0	0	**0.000**	0	0	0	0	0	**0.000**
Fuel Conv. Eff.	**(%)**	25.5	26.3	25.2	25.4	25.5	**25.580**	26.4	26	25.7	26.2	26	**26.060**
isfc	**(kg/J)**	4.50E-08	4.13E-08	5.06E-08	4.71E-08	4.84E-08	**4.65E-08**	5.21E-08	4.87E-08	5.04E-08	4.92E-08	4.92E-08	**4.99E-08**
bsfcf	**(kg/J)**	1.38E-07	1.34E-07	1.39E-07	1.39E-07	1.38E-07	**1.38E-07**	1.33E-07	1.35E-07	1.37E-07	1.34E-07	1.35E-07	**1.35E-07**
Injection	**(°CA)**	358.1	357.7	355.1	355.7	355.1	**356.340**	355.3	353.5	354.1	353.7	354.5	**354.220**
Ignition	**(°CA)**	359.9	358.5	355.9	357.3	356.1	**357.540**	355.7	355.1	354.7	355.3	357.9	**355.740**
Ignition delay	**(°CA)**	1.8	0.8	0.8	1.6	1	**1.200**	0.4	1.6	0.6	1.6	3.4	**1.520**
Patm	**(kPa)**	82.1	82.1	82.1	82.1	82.1	**82.100**	82.1	82.1	82.1	82.1	82.1	**82.100**
Exhaust Temperature	**(°C)**	344	383	380.6	373.3	378.2	**371.820**	403.7	400.3	415.2	415.2	417.6	**410.400**
Pmax	**(kPa)**	6020.8	6135.2	6171	6009.8	6107.5	**6088.860**	5975.6	6131.9	6097.7	6092.8	6102.6	**6080.120**
Position of Pmax	**(°CA)**	371.4	372.2	369.6	370.8	369.8	**370.760**	370.4	369	369.6	368.4	368.6	**369.200**
Tmax	**(K)**	1893	1984.2	1776.9	1836.5	1812.8	**1860.680**	1804.3	1876	1853.2	1854.4	1831	**1843.780**
Position of Tmax	**(°CA)**	379.4	380.2	377.4	378.6	377.6	**378.640**	377	378	376.6	377.8	377.2	**377.320**
Mech Efficiency	**(%)**	32.6	30.9	36.3	34	35.1	**33.780**	39.1	36	36.8	36.7	36.3	**36.980**
ITE	**(%)**	78.2	85.1	69.5	74.7	72.6	**76.020**	67.5	72.2	69.8	71.5	71.5	**70.500**
BTE	**(%)**	25.5	26.3	25.2	25.4	25.5	**25.580**	26.4	26	25.7	26.2	26	**26.060**
Volumetric Efficiency	**(%)**	93.3	92.5	92.2	92.9	92.7	**92.720**	90	89.5	89.1	89.4	90.1	**89.620**

25 Nm LP DME		1300 rpm						1400 rpm					
File name		dm260911	dm260912	dm260913	dm260914	dm260915	**Average**	dm260917	dm260918	dm260919	dm260920	dm260921	**Average**
speed	**(rpm)**	1304.4	1304.4	1304.4	1304.4	1304.4	**1304.400**	1401.5	1406.4	1401.5	1406.4	1406.4	**1404.440**
Load	**(Nm)**	24.9	25.2	25.5	24.9	25.4	**25.180**	24.9	25.1	24.7	24.8	24.5	**24.800**
Brake Power	**(W)**	3407.7	3444.8	3481.9	3407.7	3463.3	**3441.080**	3661.6	3694.3	3621.7	3654.3	3614.3	**3649.240**
Ind. work per Cycle	**(J)**	470.2	453	433	422.4	419	**439.520**	435.6	430.8	445.7	431.8	428.2	**434.420**
Indicated Power	**(W)**	10221.6	9847.9	9414.1	9183.5	9108.5	**9555.120**	10174.6	10098	10411.6	10122.1	10037.4	**10168.740**
imep	**(kPa)**	707	681.2	651.2	635.2	630.1	**660.940**	655	647.8	670.3	649.4	643.9	**653.280**
bmep	**(kPa)**	235.7	238.3	240.9	235.7	239.6	**238.040**	235.7	237	233.1	234.4	231.9	**234.420**
Equivalence Ratio		0.381	0.385	0.379	0.381	0.378	**0.381**	0.437	0.437	0.435	0.439	0.434	**0.436**
Air/fuel ratio		26.2	26.16	26.31	26.41	26.3	**26.276**	22.64	22.66	22.88	22.7	22.73	**22.722**
Air Flow	**(g/s)**	12.274	12.256	12.326	12.37	12.32	**12.309**	12.7	12.709	12.835	12.734	12.751	**12.746**
Fuel Flow	**(g/s)**	0.47	0.47	0.47	0.47	0.47	**0.470**	0.56	0.56	0.56	0.56	0.56	**0.560**
Additive Flow	**(g/s)**	0	0	0	0	0	**0.000**	0	0	0	0	0	**0.000**
Percentage DME	**(%)**	0	0	0	0	0	**0.000**	0	0	0	0	0	**0.000**
Fuel Conv. Eff.	**(%)**	25.6	25.9	26.1	25.6	26	**25.840**	23	23.2	22.7	22.9	22.7	**22.900**
isfc	**(kg/J)**	4.58E-08	4.76E-08	4.98E-08	5.10E-08	5.14E-08	**4.91E-08**	5.51E-08	5.55E-08	5.39E-08	5.54E-08	5.59E-08	**5.52E-08**
bsfcf	**(kg/J)**	1.37E-07	1.36E-07	1.35E-07	1.37E-07	1.35E-07	**1.36E-07**	1.53E-07	1.52E-07	1.55E-07	1.53E-07	1.55E-07	**1.54E-07**
Injection	**(°CA)**	354.1	354.5	354.5	354.1	355.1	**354.460**	355.7	354.9	355.1	355.7	355.3	**355.340**
Ignition	**(°CA)**	354.9	357.7	355.7	354.1	358.3	**356.140**	355.7	355.1	355.9	355.7	355.3	**355.540**
Ignition delay	**(°CA)**	0.8	3.2	1.2	0	3.2	**1.680**	0	0.2	0.8	0	0	**0.200**
Patm	**(kPa)**	82	82	82	82.1	82.1	**82.040**	82	82	82	82	82	**82.000**
Exhaust Temperature	**(°C)**	426.7	424.3	418.6	413.8	400.8	**416.840**	425.8	421	417.1	407	399.8	**414.140**
Pmax	**(kPa)**	6234.4	6151.4	6122.1	6073.3	6087.9	**6133.820**	6048.8	5970.7	6029.3	5995.1	6000	**6008.780**
Position of Pmax	**(°CA)**	369.6	370	369.8	369.4	369.6	**369.680**	368.4	369.8	370.6	370.4	369.4	**369.720**
Tmax	**(K)**	2000.2	2005.5	1972.3	1926.3	1930.8	**1967.020**	1994.7	2003	2001	2004	1987.7	**1998.080**
Position of Tmax	**(°CA)**	378.6	379.4	379.4	378.6	377.8	**378.760**	379.8	379.4	376.8	376.6	376.4	**377.800**
Mech Efficiency	**(%)**	33.3	35	37	37.1	38	**36.080**	36	36.6	34.8	36.1	36	**35.900**
ITE	**(%)**	76.8	73.9	70.7	69	68.4	**71.760**	63.8	63.3	65.3	63.5	62.9	**63.760**
BTE	**(%)**	25.6	25.9	26.1	25.6	26	**25.840**	23	23.2	22.7	22.9	22.7	**22.900**
Volumetric Efficiency	**(%)**	84.9	84.8	85.3	85.6	85.2	**85.160**	81.8	81.5	82.6	81.7	81.8	**81.880**

25 Nm LP DME		1500 rpm						1600 rpm					
File name		dm260923	dm260924	dm260925	dm260926	dm260927	**Average**	dm260929	dm260930	dm260931	dm260932	dm260933	**Average**
speed	**(rpm)**	1503.6	1503.6	1503.6	1503.6	1503.6	**1503.600**	1600.8	1600.8	1600.8	1600.8	1600.8	**1600.800**
Load	**(Nm)**	24.8	24.7	25.1	24.9	24.9	**24.880**	24.8	24.9	24.4	25.8	25.2	**25.020**
Brake Power	**(W)**	3906.8	3885.4	3949.6	3928.2	3928.2	**3919.640**	4159.3	4182.1	4091	4318.7	4227.6	**4195.740**
Ind. work per Cycle	**(J)**	442.9	408.2	421.8	433.6	423.2	**425.940**	439.3	447.9	419.1	454.6	432.2	**438.620**
Indicated Power	**(W)**	11099.3	10229.7	10570.2	10867.1	10604.2	**10674.100**	11720.4	11949.2	11182.6	12129.9	11530.8	**11702.580**
imep	**(kPa)**	666	613.9	634.3	652.1	636.3	**640.520**	660.6	673.5	630.3	683.7	649.9	**659.600**
bmep	**(kPa)**	234.4	233.1	237	235.7	235.7	**235.180**	234.4	235.7	230.6	243.4	238.3	**236.480**
Equivalence Ratio		0.444	0.441	0.443	0.44	0.445	**0.443**	0.427	0.099	0.426	0.427	0.424	**0.361**
Air/fuel ratio		22.44	22.45	22.25	22.44	22.43	**22.402**	23.23	23.27	23.41	23.37	23.34	**23.324**
Air Flow	**(g/s)**	13.664	13.667	13.548	13.664	13.657	**13.640**	15.614	15.641	15.736	15.71	15.689	**15.678**
Fuel Flow	**(g/s)**	0.61	0.61	0.61	0.61	0.61	**0.610**	0.67	0.67	0.67	0.67	0.67	**0.670**
Additive Flow	**(g/s)**	0	0	0	0	0	**0.000**	0	0	0	0	0	**0.000**
Percentage DME	**(%)**	0	0	0	0	0	**0.000**	0	0	0	0	0	**0.000**
Fuel Conv. Eff.	**(%)**	22.6	22.4	22.8	22.7	22.7	**22.640**	21.8	21.9	21.4	22.6	22.1	**21.960**
isfc	**(kg/J)**	5.49E-08	5.95E-08	5.76E-08	5.60E-08	5.74E-08	**5.71E-08**	5.74E-08	5.63E-08	6.01E-08	5.54E-08	5.83E-08	**5.75E-08**
bsfcf	**(kg/J)**	1.56E-07	1.57E-07	1.54E-07	1.55E-07	1.55E-07	**1.55E-07**	1.62E-07	1.61E-07	1.64E-07	1.56E-07	1.59E-07	**1.60E-07**
Injection	**(°CA)**	356.7	356.5	357.3	356.7	356.1	**356.660**	357.9		358.3	358.3	358.7	**358.300**
Ignition	**(°CA)**	356.9	356.5	357.3	356.7	356.3	**356.740**	357.9		360.9	358.3	358.7	**358.950**
Ignition delay	**(°CA)**	0.2	0	0	0	0.2	**0.080**	0	0	2.6	0	0	**0.520**
Patm	**(kPa)**	82	82	82	82	82	**82.000**	82	82	82	82	82	**82.000**
Exhaust Temperature	**(°C)**	425.3	426.3	430.1	426.3	425.3	**426.660**	469.1	464.7	439.7	472.4	471	**463.380**
Pmax	**(kPa)**	5877.9	5707	5741.2	5775.4	5799.8	**5780.260**	5609.4	5624	5506.8	5467.8	5453.1	**5532.220**
Position of Pmax	**(°CA)**	370.8	369.2	370.2	371	369.4	**370.120**	370.2	369.4	369.6	370	370.6	**369.960**
Tmax	**(K)**	1997.1	1916	1963.2	1954.7	1917.8	**1949.760**	1788.9	1923.8	1780.7	1804.9	1811.1	**1821.880**
Position of Tmax	**(°CA)**	380	375.4	376.8	377	379.6	**377.760**	379.4	381.2	380	381.2	380	**380.360**
Mech Efficiency	**(%)**	35.2	38	37.4	36.1	37	**36.740**	35.5	35	36.6	35.6	36.7	**35.880**
ITE	**(%)**	64.1	59.1	61.1	62.8	61.3	**61.680**	61.3	62.5	58.5	63.5	60.3	**61.220**
BTE	**(%)**	22.6	22.4	22.8	22.7	22.7	**22.640**	21.8	21.9	21.4	22.6	22.1	**21.960**
Volumetric Efficiency	**(%)**	82	82	81.3	82	81.9	**81.840**	88	88.2	88.7	88.5	88.4	**88.360**

25 Nm LP DME		1700 rpm						1800 rpm					
File name		dm260934	dm260935	dm260936	dm260937	dm260938	**Average**	dm260940	dm260941	dm260942	dm260943	dm260944	**Average**
speed	**(rpm)**	1702.8	1702.8	1702.8	1702.8	1698	**1701.840**	1804.9	1804.9	1804.9	1800	1800	**1802.940**
Load	**(Nm)**	25.2	25.1	24.7	25.2	24.5	**24.940**	24.5	25.1	24.9	25.5	24.8	**24.960**
Brake Power	**(W)**	4497.1	4472.9	4400.2	4497.1	4363.5	**4446.160**	4638.3	4741	4715.3	4805	4677	**4715.320**
Ind. work per Cycle	**(J)**	442	404	444.9	403.8	413.9	**421.720**	423.4	441.6	419.6	453	489.2	**445.360**
Indicated Power	**(W)**	12543.3	11465.4	12626.9	11459.8	11712.2	**11961.520**	12737.4	13284	12623.1	13590	14677.3	**13382.360**
imep	**(kPa)**	664.6	607.5	669	607.2	622.4	**634.140**	636.7	664.1	631	681.2	735.7	**669.740**
bmep	**(kPa)**	238.3	237	233.1	238.3	231.9	**235.720**	231.9	237	235.7	240.9	234.4	**235.980**
Equivalence Ratio		0.477	0.478	0.479	0.477	0.476	**0.477**	0.471	0.469	0.476	0.477	0.472	**0.473**
Air/fuel ratio		20.55	20.56	20.59	20.62	20.67	**20.598**	20.97	20.97	20.92	20.82	20.83	**20.902**
Air Flow	**(g/s)**	15.359	15.366	15.387	15.408	15.448	**15.394**	16.066	16.065	16.032	15.952	15.959	**16.015**
Fuel Flow	**(g/s)**	0.75	0.75	0.75	0.75	0.75	**0.750**	0.77	0.77	0.77	0.77	0.77	**0.770**
Additive Flow	**(g/s)**	0	0	0	0	0	**0.000**	0	0	0	0	0	**0.000**
Percentage DME	**(%)**	0	0	0	0	0	**0.000**	0	0	0	0	0	**0.000**
Fuel Conv. Eff.	**(%)**	21.2	21.1	20.7	21.2	20.5	**20.940**	21.3	21.8	21.6	22.1	21.5	**21.660**
isfc	**(kg/J)**	5.96E-08	6.52E-08	5.92E-08	6.52E-08	6.38E-08	**6.26E-08**	6.02E-08	5.77E-08	6.07E-08	5.64E-08	5.22E-08	**5.74E-08**
bsfcf	**(kg/J)**	1.66E-07	1.67E-07	1.70E-07	1.66E-07	1.71E-07	**1.68E-07**	1.65E-07	1.62E-07	1.62E-07	1.59E-07	1.64E-07	**1.63E-07**
Injection	**(°CA)**	357.9	357.5	358.3	358.1	358.3	**358.020**	359.5	359.3	359.3	359.5	359.3	**359.380**
Ignition	**(°CA)**	357.9	360.7	361.1	358.1	358.3	**359.220**	359.5	362.9	359.3	359.5	359.3	**360.100**
Ignition delay	**(°CA)**	0	3.2	2.8	0	0	**1.200**	0	3.6	0	0	0	**0.720**
Patm	**(kPa)**	82	82	82	82	82	**82.000**	82	82	82	82	82	**82.000**
Exhaust Temperature	**(°C)**	499.8	466.2	467.1	461.4	452.7	**469.440**	491.2	496	492.1	530.1	559	**513.680**
Pmax	**(kPa)**	5394.5	5370.1	5394.5	5423.8	5404.3	**5397.440**	5140.6	5189.4	5179.7	5233.4	5179.7	**5184.560**
Position of Pmax	**(°CA)**	371.4	370	370.4	370	370.2	**370.400**	370.2	370.6	372.4	370	372.8	**371.200**
Tmax	**(K)**	1948.1	1873.1	1948.3	1876.2	1898.3	**1908.800**	1903.5	1980.7	1912.7	1961.5	2028.8	**1957.440**
Position of Tmax	**(°CA)**	384	382.2	382.4	380.4	381	**382.000**	383	384.2	383.4	383.2	388.4	**384.440**
Mech Efficiency	**(%)**	35.9	39	34.8	39.2	37.3	**37.240**	36.4	35.7	37.4	35.4	31.9	**35.360**
ITE	**(%)**	59	54	59.4	53.9	55.1	**56.280**	58.5	61	57.9	62.4	67.4	**61.440**
BTE	**(%)**	21.2	21.1	20.7	21.2	20.5	**20.940**	21.3	21.8	21.6	22.1	21.5	**21.660**
Volumetric Efficiency	**(%)**	81.4	81.4	81.5	81.6	82.1	**81.600**	80.3	80.3	80.1	80	80	**80.140**

35 Nm LP DME		**1100 rpm**					**1200 rpm**			
File name		dm290900	dm290901	dm290902	dm290903	**Average**	dm290904	dm290905	dm290906	Average
speed	**(rpm)**	1100.3	1100.3	1095.4	1100.3	**1099.075**	1202.3	1202.3	1202.3	1202.300
Load	**(Nm)**	35.3	34.9	34.5	34.3	**34.750**	35.8	34.3	35.1	35.067
Brake Power	**(W)**	4064	4017	3952.5	3954.4	**3996.975**	4509.3	4321.2	4423.8	4418.100
Ind. work per Cycle	**(J)**	396.3	481.7	500.7	496.8	**468.875**	515.6	458.8	460.8	478.400
Indicated Power	**(W)**	7266.7	8833.6	9140.9	9110.4	**8587.900**	10332.6	9194.4	9234.4	9587.133
imep	**(kPa)**	595.9	724.4	752.9	747.1	**705.075**	775.4	690	693	719.467
bmep	**(kPa)**	333.3	329.4	325.6	324.3	**328.150**	338.4	324.3	332	331.567
Equivalence Ratio		0.645	0.647	0.652	0.65	**0.649**	0.657	0.657	0.656	0.657
Air/fuel ratio		14.8	14.76	14.63	14.7	**14.723**	14.5	14.52	14.52	14.513
Air Flow	**(g/s)**	11.558	11.529	11.423	11.481	**11.498**	11.927	11.945	11.945	11.939
Fuel Flow	**(g/s)**	0.78	0.78	0.78	0.78	**0.780**	0.82	0.82	0.82	0.820
Additive Flow	**(g/s)**	0	0	0	0	**0.000**	0	0	0	0.000
Percentage DME	**(%)**	0	0	0	0	**0.000**	0	0	0	0.000
Fuel Conv. Eff.	**(%)**	18.3	18.1	17.8	17.8	**18.000**	19.3	18.5	18.9	18.900
isfc	**(kg/J)**	1.07E-07	8.84E-08	8.54E-08	8.57E-08	**9.18E-08**	7.96E-08	8.95E-08	8.91E-08	8.60E-08
bsfcf	**(kg/J)**	1.92E-07	1.94E-07	1.98E-07	1.98E-07	**1.95E-07**	1.82E-07	1.90E-07	1.86E-07	1.86E-07
Injection	**(°CA)**	394.7	353.7	353.9	353.9	**364.050**	362.5	350.9	350.9	354.767
Ignition	**(°CA)**	394.7	360.1	359.5	355.7	**367.500**	362.5	356.7	357.9	359.033
Ignition delay	**(°CA)**	0	6.4	5.6	1.8	**3.450**	0	5.8	7	4.267
Patm	**(kPa)**	83.5	83.5	83.5	83.5	**83.500**	83.5	83.4	83.4	83.433
Exhaust Temperature	**(°C)**	380.1	393.5	390.2	403.7	**391.875**	430.1	408.9	410.4	416.467
Pmax	**(kPa)**	6255.3	6436	6455.5	6406.7	**6388.375**	6592.2	6645.9	6641.1	6626.400
Position of Pmax	**(°CA)**	368.2	368.4	370.2	369	**368.950**	367.6	367.4	367.2	367.400
Tmax	**(K)**	1790.9	1835	1889.7	1846.5	**1840.525**	2014.2	1898	1910.8	1941.000
Position of Tmax	**(°CA)**	374.6	375.6	377.4	378.2	**376.450**	376.8	373.6	374.4	374.933
Mech Efficiency	**(%)**	55.9	45.5	43.2	43.4	**47.000**	43.6	47	47.9	46.167
ITE	**(%)**	32.7	39.8	41.2	41	**38.675**	44.2	39.3	39.5	41.000
BTE	**(%)**	18.3	18.1	17.8	17.8	**18.000**	19.3	18.5	18.9	18.900
Volumetric Efficiency	**(%)**	94.8	94.5	94.1	94.1	**94.375**	89.5	89.6	89.6	89.567

35 Nm LP DME		1300 rpm				1400 rpm			
File name		dm290907	dm290908	dm290909	**Average**	dm290910	dm290911	dm290912	**Average**
speed	(rpm)	1304.4	1304.4	1304.4	**1304.400**	1401.5	1396.7	1401.5	**1399.900**
Load	(Nm)	35.1	35	35.4	**35.167**	34.3	34.6	34.6	**34.500**
Brake Power	(W)	4799.2	4780.7	4836.3	**4805.400**	5037.2	5059.5	5077.1	**5057.933**
Ind. work per Cycle	(J)	465	490.7	450.4	**468.700**	464.9	453.7	477.8	**465.467**
Indicated Power	(W)	10108.5	10666.9	9791.5	**10188.967**	10858.9	10560.5	11160	**10859.800**
imep	(kPa)	699.2	737.9	677.3	**704.800**	699	682.2	718.4	**699.867**
bmep	(kPa)	332	330.7	334.5	**332.400**	324.3	326.8	326.8	**325.967**
Equivalence Ratio		0.618	0.615	0.615	**0.616**	0.633	0.637	0.634	**0.635**
Air/fuel ratio		15.56	15.62	15.6	**15.593**	15.12	15.04	15.1	**15.087**
Air Flow	(g/s)	12.448	12.501	12.483	**12.477**	12.955	12.886	12.938	**12.926**
Fuel Flow	(g/s)	0.8	0.8	0.8	**0.800**	0.86	0.86	0.86	**0.860**
Additive Flow	(g/s)	0	0	0	**0.000**	0	0	0	**0.000**
Percentage DME	(%)	0	0	0	**0.000**	0	0	0	**0.000**
Fuel Conv. Eff.	(%)	21.1	21	21.3	**21.133**	20.7	20.8	20.8	**20.767**
isfc	(kg/J)	7.92E-08	7.50E-08	8.17E-08	**7.86E-08**	7.89E-08	8.12E-08	7.68E-08	**7.90E-08**
bsfcf	(kg/J)	1.67E-07	1.67E-07	1.65E-07	**1.67E-07**	1.70E-07	1.69E-07	1.69E-07	**1.69E-07**
Injection	(°CA)	352.5	354.1	353.1	**353.233**	354.9	353.9	353.9	**354.233**
Ignition	(°CA)	352.7	360.1	353.1	**355.300**	355.5	359.1	358.9	**357.833**
Ignition delay	(°CA)	0.2	6	0	**2.067**	0.6	5.2	5	**3.600**
Patm	(kPa)	83.5	83.5	83.5	**83.500**	83.4	83.4	83.4	**83.400**
Exhaust Temperature	(°C)	415.2	417.6	417.1	**416.633**	410.9	420	424.3	**418.400**
Pmax	(kPa)	6470.2	6372.5	6440.9	**6427.867**	6245.5	6309	6440.9	**6331.800**
Position of Pmax	(°CA)	368.6	369.8	368.8	**369.067**	370	369.6	368.8	**369.467**
Tmax	(K)	1955.7	1992.9	1928.8	**1959.133**	2016.9	2000	2061.6	**2026.167**
Position of Tmax	(°CA)	377	378.6	376.2	**377.267**	376.4	374.4	376.6	**375.800**
Mech Efficiency	(%)	47.5	44.8	49.4	**47.233**	46.4	47.9	45.5	**46.600**
ITE	(%)	44.4	46.9	43	**44.767**	44.6	43.3	45.8	**44.567**
BTE	(%)	21.1	21	21.3	**21.133**	20.7	20.8	20.8	**20.767**
Volumetric Efficiency	(%)	86.1	86.5	86.4	**86.333**	83.4	83.2	83.3	**83.300**

35 Nm LP DME		1500 rpm				1600 rpm				
File name		dm290913	dm290914	dm290915	**Average**	dm290916	dm290917	dm290918	dm290919	**Average**
speed	**(rpm)**	1503.6	1503.6	1508.5	**1505.233**	1605.6	1605.6	1605.6	1605.6	**1605.600**
Load	**(Nm)**	34.7	34	35	**34.567**	34.9	35.3	35.5	35.1	**35.200**
Brake Power	**(W)**	5468.1	5361.2	5528.7	**5452.667**	5862.1	5930.6	5976.3	5907.8	**5919.200**
Ind. work per Cycle	**(J)**	459.1	464.6	464.5	**462.733**	448.7	449.7	463.6	443.5	**451.375**
Indicated Power	**(W)**	11506.2	11642.8	11678.6	**11609.200**	12008.5	12035.3	12406.3	11869.2	**12079.825**
imep	**(kPa)**	690.4	698.6	698.5	**695.833**	674.8	676.3	697.1	667	**678.800**
bmep	**(kPa)**	328.1	321.7	330.7	**326.833**	329.4	333.3	335.8	332	**332.625**
Equivalence Ratio		0.628	0.625	0.624	**0.626**	0.622	0.62	0.626	0.62	**0.622**
Air/fuel ratio		15.37	15.32	15.36	**15.350**	15.47	15.48	15.5	15.47	**15.480**
Air Flow	**(g/s)**	14.284	14.238	14.268	**14.263**	16.043	16.049	16.077	16.043	**16.053**
Fuel Flow	**(g/s)**	0.93	0.93	0.93	**0.930**	1.04	1.04	1.04	1.04	**1.040**
Additive Flow	**(g/s)**	0	0	0	**0.000**	0	0	0	0	**0.000**
Percentage DME	**(%)**	0	0	0	**0.000**	0	0	0	0	**0.000**
Fuel Conv. Eff.	**(%)**	20.7	20.3	20.9	**20.633**	19.9	20.1	20.3	20	**20.075**
isfc	**(kg/J)**	8.07E-08	7.98E-08	7.96E-08	**8.00E-08**	8.64E-08	8.62E-08	8.36E-08	8.74E-08	**8.59E-08**
bsfcf	**(kg/J)**	1.70E-07	1.73E-07	1.68E-07	**1.70E-07**	1.77E-07	1.75E-07	1.74E-07	1.76E-07	**1.75E-07**
Injection	**(°CA)**	353.5	355.1	355.7	**354.767**	354.7	354.3	354.5	353.9	**354.350**
Ignition	**(°CA)**	354.3	355.1	360.1	**356.500**	355.1	358.1	354.7	363.5	**357.850**
Ignition delay	**(°CA)**	0.8	0	4.4	**1.733**	0.4	3.8	0.2	9.6	**3.500**
Patm	**(kPa)**	83.4	83.4	83.4	**83.400**	83.4	83.4	83.4	83.4	**83.400**
Exhaust Temperature	**(°C)**	431.1	433.5	429.6	**431.400**	452.7	451.3	458	455.1	**454.275**
Pmax	**(kPa)**	6284.6	6123.5	6230.9	**6213.000**	6182.1	6055.1	6138.1	6182.1	**6139.350**
Position of Pmax	**(°CA)**	369.4	369.8	369	**369.400**	369	368.8	368.8	369.6	**369.050**
Tmax	**(K)**	1908.8	1914.2	1997.4	**1940.133**	1813.3	1832.2	1851.4	1862.3	**1839.800**
Position of Tmax	**(°CA)**	379	380.6	375.2	**378.267**	375.6	376.8	375.6	378.2	**376.550**
Mech Efficiency	**(%)**	47.5	46	47.3	**46.933**	48.8	49.3	48.2	49.8	**49.025**
ITE	**(%)**	43.6	44.1	44.2	**43.967**	40.7	40.8	42.1	40.3	**40.975**
BTE	**(%)**	20.7	20.3	20.9	**20.633**	19.9	20.1	20.3	20	**20.075**
Volumetric Efficiency	**(%)**	85.7	85.4	85.3	**85.467**	90.2	90.2	90.3	90.2	**90.225**

35 Nm LP DME		1700 rpm					1800 rpm				
File name		dm290920	dm290921	dm290922	dm290923	**Average**	dm290924	dm290925	dm290926	dm290927	**Average**
speed	**(rpm)**	1707.7	1702.8	1702.8	1702.8	**1704.025**	1800	1804.9	1800	1804.9	**1802.450**
Load	**(Nm)**	35.1	35.3	34.9	34.7	**35.000**	35	35	34.7	34.6	**34.825**
Brake Power	**(W)**	6283.2	6289.6	6216.9	6192.7	**6245.600**	6597.3	6615.1	6546.1	6538.1	**6574.150**
Ind. work per Cycle	**(J)**	443.9	453.5	455.5	481.5	**458.600**	447.8	494.4	431.9	459.3	**458.350**
Indicated Power	**(W)**	12633.7	12871.9	12926.8	13666.5	**13024.725**	13435.4	14872	12956.8	13816.1	**13770.075**
imep	**(kPa)**	667.5	682	684.9	724.1	**689.625**	673.4	743.5	649.5	690.7	**689.275**
bmep	**(kPa)**	332	333.3	329.4	328.1	**330.700**	330.7	330.7	328.1	326.8	**329.075**
Equivalence Ratio		0.703	0.706	0.705	0.708	**0.706**	0.7	0.703	0.709	0.697	**0.702**
Air/fuel ratio		13.49	13.46	13.44	13.41	**13.450**	13.53	13.51	13.55	13.58	**13.543**
Air Flow	**(g/s)**	15.911	15.877	15.855	15.821	**15.866**	16.595	16.574	16.626	16.659	**16.614**
Fuel Flow	**(g/s)**	1.18	1.18	1.18	1.18	**1.180**	1.23	1.23	1.23	1.23	**1.230**
Additive Flow	**(g/s)**	0	0	0	0	**0.000**	0	0	0	0	**0.000**
Percentage DME	**(%)**	0	0	0	0	**0.000**	0	0	0	0	**0.000**
Fuel Conv. Eff.	**(%)**	18.7	18.8	18.5	18.5	**18.625**	18.9	19	18.8	18.7	**18.850**
isfc	**(kg/J)**	9.34E-08	9.17E-08	9.13E-08	8.63E-08	**9.07E-08**	9.13E-08	8.25E-08	9.47E-08	8.88E-08	**8.93E-08**
bsfcf	**(kg/J)**	1.88E-07	1.88E-07	1.90E-07	1.91E-07	**1.89E-07**	1.86E-07	1.85E-07	1.87E-07	1.88E-07	**1.87E-07**
Injection	**(°CA)**	356.7	356.9	357.5	357.5	**357.150**	358.7	358.5	357.5	357.3	**358.000**
Ignition	**(°CA)**	356.7	356.9	360.3	358.1	**358.000**	364.7	358.5	357.5	357.3	**359.500**
Ignition delay	**(°CA)**	0	0	2.8	0.6	**0.850**	6	0	0	0	**1.500**
Patm	**(kPa)**	83.4	83.4	83.4	83.4	**83.400**	83.4	83.4	83.4	83.4	**83.400**
Exhaust Temperature	**(°C)**	490.2	495.5	497.4	496	**494.775**	506.6	509.5	515.2	512.3	**510.900**
Pmax	**(kPa)**	5747.5	5786.6	5786.5	5742.6	**5765.800**	5703.6	5669.4	5630.3	5669.4	**5668.175**
Position of Pmax	**(°CA)**	369.2	370.6	369.4	371.8	**370.250**	368	371	370.2	370.8	**370.000**
Tmax	**(K)**	1905.5	1906.9	1910.7	1988.3	**1927.850**	1924.6	1996.8	1850.9	1900.4	**1918.175**
Position of Tmax	**(°CA)**	376.8	381	381	382	**380.200**	379.8	383.6	378.4	380.8	**380.650**
Mech Efficiency	**(%)**	49.7	48.9	48.1	45.3	**48.000**	49.1	44.5	50.5	47.3	**47.850**
ITE	**(%)**	37.7	38.4	38.5	40.7	**38.825**	38.5	42.6	37.2	39.6	**39.475**
BTE	**(%)**	18.7	18.8	18.5	18.5	**18.625**	18.9	19	18.8	18.7	**18.850**
Volumetric Efficiency	**(%)**	84.1	84.1	84	83.8	**84.000**	83.2	82.9	83.3	83.3	**83.175**

45 Nm DME LP		**1100 rpm**						**1200 rpm**					
File name		dm300938	dm300939	dm300940	dm300941	dm300942	**Average**	dm300900	dm300901	dm300902	dm300903	dm300904	**Average**
speed	**(rpm)**	1100.3	1100.3	1100.3	1105.1	1100.3	**1101.260**	1202.3	1202.3	1202.3	1202.3	1202.3	**1202.300**
Load	**(Nm)**	37.7	37	38.4	39.5	39.1	**38.340**	44.9	44.6	44.6	45.1	44.6	**44.760**
Brake Power	**(W)**	4345.7	4267.4	4423.9	4569.2	4502.2	**4421.680**	5655.2	5620.9	5620.9	5672.3	5620.9	**5638.040**
Ind. work per Cycle	**(J)**	476.2	498.6	481.6	509.1	514.3	**495.960**	548	561.8	533.3	525.5	553.1	**544.340**
Indicated Power	**(W)**	8731.8	9142.7	8831.4	9377.6	9430.6	**9102.820**	10982.1	11257.5	10686	10529.5	11083.2	**10907.660**
imep	**(kPa)**	716	749.7	724.2	765.6	773.3	**745.760**	824.1	844.8	801.9	790.2	831.7	**818.540**
bmep	**(kPa)**	356.4	349.9	362.8	373	369.2	**362.260**	424.4	421.8	421.8	425.7	421.8	**423.100**
Equivalence Ratio		0.706	0.704	0.704	0.7	0.69	**0.701**	0.79	0.79	0.789	0.794	0.794	**0.791**
Air/fuel ratio		13.42	13.43	13.47	13.54	13.76	**13.524**	11.82	11.81	11.82	11.76	11.75	**11.792**
Air Flow	**(g/s)**	11.252	11.263	11.291	11.35	11.532	**11.338**	11.756	11.746	11.755	11.69	11.689	**11.727**
Fuel Flow	**(g/s)**	0.84	0.84	0.84	0.84	0.84	**0.840**	0.99	0.99	0.99	0.99	0.99	**0.990**
Additive Flow	**(g/s)**	0	0	0	0	0	**0.000**	0	0	0	0	0	**0.000**
Percentage DME	**(%)**	0	0	0	0	0	**0.000**	0	0	0	0	0	**0.000**
Fuel Conv. Eff.	**(%)**	18.2	17.9	18.6	19.2	18.9	**18.560**	20	19.9	19.9	20.1	19.9	**19.960**
isfc	**(kg/J)**	9.60E-08	9.17E-08	9.49E-08	8.94E-08	8.89E-08	**9.22E-08**	9.05E-08	8.83E-08	9.31E-08	9.44E-08	8.97E-08	**9.12E-08**
bsfcf	**(kg/J)**	1.93E-07	1.96E-07	1.90E-07	1.83E-07	1.86E-07	**1.90E-07**	1.76E-07	1.77E-07	1.77E-07	1.75E-07	1.77E-07	**1.76E-07**
Injection	**(°CA)**	366.1	366.9	366.1	366.1	366.5	**366.340**	362.9	362.5	363.9	361.9	364.3	**363.100**
Ignition	**(°CA)**	366.9	368.1	366.1	366.9	366.5	**366.900**	362.9	363.7	363.9	361.9	364.9	**363.460**
Ignition delay	**(°CA)**	0.8	1.2	0	0.8	0	**0.560**	0	1.2	0	0	0.6	**0.360**
Patm	**(kPa)**	83.1	83.1	83.1	83.1	83.1	**83.100**	83.2	83.2	83.2	83.2	83.2	**83.200**
Exhaust Temperature	**(°C)**	460.9	461.4	453.2	457	459.4	**458.380**	458.5	461.4	459.9	460.9	468.1	**461.760**
Pmax	**(kPa)**	6020.6	6035.2	6064.5	6142.7	6142.7	**6081.140**	7026.5	6933.7	6816.6	6836.1	6767.7	**6876.120**
Position of Pmax	**(°CA)**	369.2	370.8	370.4	370.8	371.8	**370.600**	367	369.4	368.4	368	367.6	**368.080**
Tmax	**(K)**	1884.1	1922.3	1896.8	1939	1908.1	**1910.060**	2142	2164.3	2117.2	2102.5	2143.1	**2133.820**
Position of Tmax	**(°CA)**	379	380	379.8	380	378	**379.360**	376.8	378.4	377.2	376.8	379.4	**377.720**
Mech Efficiency	**(%)**	49.8	46.7	50.1	48.7	47.7	**48.600**	51.5	49.9	52.6	53.9	50.7	**51.720**
ITE	**(%)**	36.6	38.4	37.1	39.3	39.6	**38.200**	38.8	39.8	37.8	37.2	39.2	**38.560**
BTE	**(%)**	18.2	17.9	18.6	19.2	18.9	**18.560**	20	19.9	19.9	20.1	19.9	**19.960**
Volumetric Efficiency	**(%)**	92.3	92.4	92.6	92.7	94.6	**92.920**	88.2	88.1	88.2	87.7	87.7	**87.980**

45 Nm DME LP		1300 rpm						1400 rpm					
File name		dm300906	dm300907	dm300908	dm300909	dm300910	**Average**	dm300912	dm300913	dm300914	dm300915	dm300916	**Average**
speed	**(rpm)**	1304.4	1304.4	1304.4	1304.4	1304.4	**1304.400**	1406.4	1406.4	1406.4	1406.4	1406.4	**1406.400**
Load	**(Nm)**	44.8	45.3	44.5	44.6	44.5	**44.740**	45.3	45.3	45.1	45.5	45.1	**45.260**
Brake Power	**(W)**	6116.6	6190.8	6079.5	6098	6079.5	**6112.880**	6675.1	6675.1	6635.1	6695.1	6635.1	**6663.100**
Ind. work per Cycle	**(J)**	538.9	539.8	552	532.3	547.5	**542.100**	540.4	517.9	532.1	515.1	550.8	**531.260**
Indicated Power	**(W)**	11714.9	11734.7	12000.1	11571.1	11902.6	**11784.680**	12668.2	12139	12472.3	12073.4	12910.8	**12452.740**
imep	**(kPa)**	810.3	811.7	830.1	800.4	823.3	**815.160**	812.7	778.8	800.1	774.5	828.3	**798.880**
bmep	**(kPa)**	423.1	428.2	420.5	421.8	420.5	**422.820**	428.2	428.2	425.7	429.5	425.7	**427.460**
Equivalence Ratio		0.816	0.82	0.816	0.819	0.817	**0.818**	0.804	0.805	0.811	0.8	0.799	**0.804**
Air/fuel ratio		11.38	11.34	11.39	11.34	11.38	**11.366**	11.61	11.58	11.46	11.65	11.66	**11.592**
Air Flow	**(g/s)**	12.196	12.151	12.205	12.151	12.195	**12.180**	12.64	12.605	12.47	12.676	12.694	**12.617**
Fuel Flow	**(g/s)**	1.07	1.07	1.07	1.07	1.07	**1.070**	1.09	1.09	1.09	1.09	1.09	**1.090**
Additive Flow	**(g/s)**	0	0	0	0	0	**0.000**	0	0	0	0	0	**0.000**
Percentage DME	**(%)**	0	0	0	0	0	**0.000**	0	0	0	0	0	**0.000**
Fuel Conv. Eff.	**(%)**	20.1	20.3	20	20	20	**20.080**	21.6	21.6	21.4	21.6	21.4	**21.520**
isfc	**(kg/J)**	9.15E-08	9.13E-08	8.93E-08	9.26E-08	9.00E-08	**9.10E-08**	8.59E-08	8.96E-08	8.73E-08	9.01E-08	8.43E-08	**8.74E-08**
bsfcf	**(kg/J)**	1.75E-07	1.73E-07	1.76E-07	1.76E-07	1.76E-07	**1.75E-07**	1.63E-07	1.63E-07	1.64E-07	1.63E-07	1.64E-07	**1.63E-07**
Injection	**(°CA)**	364.7	365.1	363.9	363.9	364.7	**364.460**	365.5	364.9	365.5	364.9	365.1	**365.180**
Ignition	**(°CA)**	365.1	379.7	364.5	363.9	364.7	**367.580**	365.5	364.9	365.5	365.1	366.1	**365.420**
Ignition delay	**(°CA)**	0.4	14.6	0.6	0	0	**3.120**	0	0	0	0.2	1	**0.240**
Patm	**(kPa)**	83.2	83.2	83.2	83.2	83.1	**83.180**	83.1	83.1	83.1	83.1	83.1	**83.100**
Exhaust Temperature	**(°C)**	475.8	474.8	486.4	483	489.3	**481.860**	499.8	501.3	506.1	510.4	513.3	**506.180**
Pmax	**(kPa)**	6694.5	6758	6767.7	6733.5	6772.6	**6745.260**	6396.6	6445.4	6450.3	6401.5	6421	**6422.960**
Position of Pmax	**(°CA)**	368.6	369.4	368.4	368.4	368.4	**368.640**	368.6	369.2	368.2	367.8	368.6	**368.480**
Tmax	**(K)**	2179.5	2285.2	2218.9	2204	2221.7	**2221.860**	2224.2	2228.2	2257.3	2159.7	2260.5	**2225.980**
Position of Tmax	**(°CA)**	379.6	380.4	378.6	378	381	**379.520**	381.8	380.2	380.2	378	380	**380.040**
Mech Efficiency	**(%)**	52.2	52.8	50.7	52.7	51.1	**51.900**	52.7	55	53.2	55.5	51.4	**53.560**
ITE	**(%)**	38.4	38.5	39.4	38	39.1	**38.680**	40.9	39.2	40.3	39	41.7	**40.220**
BTE	**(%)**	20.1	20.3	20	20	20	**20.080**	21.6	21.6	21.4	21.6	21.4	**21.520**
Volumetric Efficiency	**(%)**	84.4	84.1	84.4	84.1	84.4	**84.280**	81.1	80.9	80	81.3	81.4	**80.940**

45 Nm DME LP		1500 rpm						1600 rpm					
File name		dm300918	dm300919	dm300920	dm300921	dm300922	**Average**	dm300923	dm300924	dm300925	dm300926	dm300927	**Average**
speed	**(rpm)**	1503.6	1503.6	1503.6	1503.6	1503.6	**1503.600**	1605.6	1605.6	1605.6	1605.6	1605.6	**1605.600**
Load	**(Nm)**	45.3	45.1	45.1	45.2	45.2	**45.180**	44.9	44.9	44.9	44.8	45.2	**44.940**
Brake Power	**(W)**	7136.4	7093.6	7093.6	7115	7115	**7110.720**	7552.2	7552.2	7552.2	7529.4	7597.9	**7556.780**
Ind. work per Cycle	**(J)**	545.7	531.9	553.9	533.4	538	**540.580**	534.6	544	570.9	530.1	529.3	**541.780**
Indicated Power	**(W)**	13675.4	13328.2	13879.5	13366.5	13481.6	**13546.240**	14306.5	14558.7	15279	14186.3	14163.9	**14498.880**
imep	**(kPa)**	820.6	799.8	832.9	802.1	809	**812.880**	803.9	818.1	858.6	797.2	795.9	**814.740**
bmep	**(kPa)**	428.2	425.7	425.7	426.9	426.9	**426.680**	424.4	424.4	424.4	423.1	426.9	**424.640**
Equivalence Ratio		0.775	0.776	0.777	0.78	0.776	**0.777**	0.743	0.748	0.745	0.744	0.749	**0.746**
Air/fuel ratio		12.11	12.09	12.07	12.05	12.06	**12.076**	12.67	12.64	12.65	12.65	12.65	**12.652**
Air Flow	**(g/s)**	13.871	13.839	13.822	13.799	13.815	**13.829**	15.667	15.632	15.652	15.647	15.647	**15.649**
Fuel Flow	**(g/s)**	1.15	1.15	1.15	1.15	1.15	**1.150**	1.24	1.24	1.24	1.24	1.24	**1.240**
Additive Flow	**(g/s)**	0	0	0	0	0	**0.000**	0	0	0	0	0	**0.000**
Percentage DME	**(%)**	0	0	0	0	0	**0.000**	0	0	0	0	0	**0.000**
Fuel Conv. Eff.	**(%)**	21.9	21.8	21.8	21.9	21.9	**21.860**	21.5	21.5	21.5	21.4	21.6	**21.500**
isfc	**(kg/J)**	8.37E-08	8.59E-08	8.25E-08	8.57E-08	8.49E-08	**8.45E-08**	8.65E-08	8.50E-08	8.10E-08	8.72E-08	8.73E-08	**8.54E-08**
bsfcf	**(kg/J)**	1.60E-07	1.61E-07	1.61E-07	1.61E-07	1.61E-07	**1.61E-07**	1.64E-07	1.64E-07	1.64E-07	1.64E-07	1.63E-07	**1.64E-07**
Injection	**(°CA)**		366.1	367.1	366.3	366.5	**366.500**	356.7	356.7	356.1	356.9		**356.600**
Ignition	**(°CA)**		366.9	367.3	368.5	366.9	**367.400**	356.7	356.7	356.1	356.9		**356.600**
Ignition delay	**(°CA)**	0	0.8	0.2	2.2	0.4	**0.720**	0	0	0	0	10.6	**2.120**
Patm	**(kPa)**	83.1	83.1	83.1	83.1	83.1	**83.100**	83.1	83.1	83.1	83.1	83.1	**83.100**
Exhaust Temperature	**(°C)**	524.4	528.2	533.5	531.6	531.1	**529.760**	557.6	563.8	558	560.9	560.4	**560.140**
Pmax	**(kPa)**	6230.6	6269.7	6377.1	6347.8	6328.3	**6310.700**	5898.6	5830.2	6054.8	6001.1	6025.5	**5962.040**
Position of Pmax	**(°CA)**	369.6	369.8	370.4	369	368.6	**369.480**	370.6	372.2	370.4	369.8	369.2	**370.440**
Tmax	**(K)**	2023.9	2155	2224.8	2178.5	2171.4	**2150.720**	1930.5	1912	2003.7	1945.6	1903.3	**1939.020**
Position of Tmax	**(°CA)**	383.6	382.4	381.4	379.6	382.6	**381.920**	383.8	385.8	383.4	385.8	386.2	**385.000**
Mech Efficiency	**(%)**	52.2	53.2	51.1	53.2	52.8	**52.500**	52.8	51.9	49.4	53.1	53.6	**52.160**
ITE	**(%)**	42	40.9	42.6	41.1	41.4	**41.600**	40.7	41.4	43.4	40.3	40.3	**41.220**
BTE	**(%)**	21.9	21.8	21.8	21.9	21.9	**21.860**	21.5	21.5	21.5	21.4	21.6	**21.500**
Volumetric Efficiency	**(%)**	83.2	83	82.9	82.8	82.9	**82.960**	88	87.8	88	87.9	87.9	**87.920**

45 Nm DME LP		1700 rpm						1800 rpm					
File name		dm300928	dm300929	dm300930	dm300931	dm300932	**Average**	dm300933	dm300934	dm300935	dm300936	dm300937	**Average**
speed	(rpm)	1702.8	1707.7	1707.7	1707.7	1707.7	**1706.720**	1809.7	1804.9	1809.7	1804.9	1804.9	**1806.820**
Load	(Nm)	44.2	45.2	44.8	45.2	44.8	**44.840**	44.9	45.2	44.8	44.6	44.1	**44.720**
Brake Power	(W)	7888.2	8080.8	8007.9	8080.8	8007.9	**8013.120**	8512.2	8540.7	8486.4	8438	8335.3	**8462.520**
Ind. work per Cycle	(J)	529.7	530.5	524.7	515.3	547.1	**529.460**	515.3	509.4	531.6	538.2	504.1	**519.720**
Indicated Power	(W)	15031.7	15098.3	14934.6	14666.5	15572	**15060.620**	15542	15324.8	16035.5	16189.7	15163.2	**15651.040**
imep	(kPa)	796.5	797.7	789.1	774.9	822.7	**796.180**	774.9	766.1	799.5	809.3	758	**781.560**
bmep	(kPa)	418	426.9	423.1	426.9	423.1	**423.600**	424.4	426.9	423.1	421.8	416.7	**422.580**
Equivalence Ratio		0.792	0.793	0.794	0.799	0.795	**0.795**	0.822	0.821	0.818	0.817	0.819	**0.819**
Air/fuel ratio		11.8	11.76	11.79	11.79	11.74	**11.776**	11.33	11.33	11.35	11.36	11.34	**11.342**
Air Flow	(g/s)	15.536	15.479	15.526	15.52	15.454	**15.503**	16.232	16.225	16.253	16.272	16.24	**16.244**
Fuel Flow	(g/s)	1.32	1.32	1.32	1.32	1.32	**1.320**	1.43	1.43	1.43	1.43	1.43	**1.430**
Additive Flow	(g/s)	0	0	0	0	0	**0.000**	0	0	0	0	0	**0.000**
Percentage DME	(%)	0	0	0	0	0	**0.000**	0	0	0	0	0	**0.000**
Fuel Conv. Eff.	(%)	21.1	21.6	21.4	21.6	21.4	**21.420**	20.9	21	20.8	20.7	20.5	**20.780**
isfc	(kg/J)	8.76E-08	8.72E-08	8.82E-08	8.98E-08	8.45E-08	**8.74E-08**	9.22E-08	9.35E-08	8.93E-08	8.85E-08	9.45E-08	**9.16E-08**
bsfcf	(kg/J)	1.67E-07	1.63E-07	1.64E-07	1.63E-07	1.64E-07	**1.64E-07**	1.68E-07	1.68E-07	1.69E-07	1.70E-07	1.72E-07	**1.69E-07**
Injection	(°CA)	358.1		358.3	358.3	358.5	**358.300**	358.7	361.1	358.7	359.1	358.9	**359.300**
Ignition	(°CA)	358.1		359.1	360.5	360.1	**359.450**	364.1	363.9	366.5	367.3	365.7	**365.500**
Ignition delay	(°CA)	0	2.6	0.8	2.2	1.6	**1.440**	5.4	2.8	7.8	8.2	6.8	**6.200**
Patm	(kPa)	83.1	83.1	83.1	83.1	83.1	**83.100**	83.1	83.1	83.1	83.1	83.1	**83.100**
Exhaust Temperature	(°C)	577.8	576.3	579.7	581.6	580.2	**579.120**	594.1	582.6	585.9	577.8	585.5	**585.180**
Pmax	(kPa)	5669.1	5659.3	5673.9	5752.1	5683.7	**5687.620**	5542.1	5498.2	5561.6	5600.7	5664.2	**5573.360**
Position of Pmax	(°CA)	369.4	372.6	371.4	371.8	371.8	**371.400**	368.6	370.6	368.2	371	371	**369.880**
Tmax	(K)	2066	2015.6	2045.4	2054.7	2091.7	**2054.680**	2031.5	2039.6	2105.9	2103.9	2075.5	**2071.280**
Position of Tmax	(°CA)	383.2	390.2	386	386.4	384.4	**386.040**	388.4	383.8	381.6	386.4	386.4	**385.320**
Mech Efficiency	(%)	52.5	53.5	53.6	55.1	51.4	**53.220**	54.8	55.7	52.9	52.1	55	**54.100**
ITE	(%)	40.2	40.3	39.9	39.2	41.6	**40.240**	38.2	37.6	39.4	39.8	37.2	**38.440**
BTE	(%)	21.1	21.6	21.4	21.6	21.4	**21.420**	20.9	21	20.8	20.7	20.5	**20.780**
Volumetric Efficiency	(%)	82.3	81.8	82	82	81.7	**81.960**	80.9	81.1	81	81.3	81.2	**81.100**

E.2 High Pressure DME

25 Nm HP DME		1100 rpm						1200 rpm					
File name		dm300704	dm300705	dm300706	dm300707	dm300708	**Average**	dm300709	dm300710	dm300711	dm300712	dm300713	**Average**
speed	**(rpm)**	1110	1105.1	1110	1100.3	1100.3	1105.140	1197.5	1202.3	1197.5	1197.5	1197.5	1198.460
Load	**(Nm)**	25.1	25.6	25.6	24.8	25.2	25.260	25.2	24.9	24.5	24.7	24.4	24.740
Brake Power	**(W)**	2915.7	2965.8	2978.8	2858.8	2905.8	2924.980	3162.5	3141.1	3077.3	3094.3	3060.3	3107.100
Ind. work per Cycle	**(J)**	384.1	377.4	364.7	379.3	375.7	376.240	437.7	373	375.9	366.1	354.9	381.520
Indicated Power	**(W)**	7106.3	6950.7	6746.7	6955.1	6890.1	6929.780	8734.9	7474.5	7502.6	7306.7	7082.8	7620.300
imep	**(kPa)**	577.6	567.5	548.4	570.3	565	565.760	658.2	560.9	565.3	550.5	533.7	573.720
bmep	**(kPa)**	237	242.1	242.1	234.4	238.3	238.780	238.3	235.7	231.9	233.1	230.6	233.920
Equivalence Ratio		0.478	0.481	0.478	0.482	0.481	0.480	0.474	0.475	0.475	0.474	0.474	0.474
Air/fuel ratio		20.53	20.38	20.48	20.31	20.37	20.414	20.69	20.68	20.68	20.72	20.67	20.688
Air Flow	**(g/s)**	11.508	11.421	11.479	11.382	11.42	11.442	11.822	11.821	11.821	11.84	11.812	11.823
Fuel Flow	**(g/s)**	0.56	0.56	0.56	0.56	0.56	0.560	0.57	0.57	0.57	0.57	0.57	0.570
Additive Flow	**(g/s)**	0	0	0	0	0	0.000	0	0	0	0	0	0.000
Percentage DME	**(%)**	0	0	0	0	0	0.000	0	0	0	0	0	0.000
Fuel Conv. Eff.	**(%)**	18.3	18.6	18.7	17.9	18.2	18.340	19.5	19.3	18.9	19	18.8	19.100
isfc	**(kg/J)**	7.89E-08	8.06E-08	8.31E-08	8.06E-08	8.14E-08	8.09E-08	6.54E-08	7.65E-08	7.62E-08	7.82E-08	8.07E-08	7.54E-08
bsfcf	**(kg/J)**	1.92E-07	1.89E-07	1.88E-07	1.96E-07	1.93E-07	1.92E-07	1.81E-07	1.82E-07	1.86E-07	1.85E-07	1.87E-07	1.84E-07
Injection	**(°CA)**	351.3	351.7	351.1	352.3	352.7	351.820	352.5		353.3	352.9	353.3	353.000
Ignition	**(°CA)**	352.9	352.9	352.7	353.1	354.7	353.260	353.5		353.9	353.9	353.5	353.700
Ignition delay	**(°CA)**	1.6	1.2	1.6	0.8	2	1.440	1	0.8	0.6	1	0.2	0.720
Patm	**(kPa)**	82.9	82.9	82.9	82.9	82.9	82.900	82.9	82.9	82.9	82.9	82.9	82.900
Exhaust Temperature	**(°C)**	335.4	340.6	335.8	332.5	334.9	335.840	347.9	333.4	334.9	329.1	328.6	334.780
Pmax	**(kPa)**	6845.6	6699.1	6660	6660	6533.1	6679.560	6787	6537.9	6415.9	6498.9	6523.3	6552.600
Position of Pmax	**(°CA)**	365.4	366.4	365.2	366	366.8	365.960	367.8	367	367.4	365.8	366.6	366.920
Tmax	**(K)**	1774.2	1751.5	1726.4	1753.7	1735.5	1748.260	1897.5	1801.7	1794.2	1793.7	1787	1814.820
Position of Tmax	**(°CA)**	370.6	372	370.8	372	373	371.680	374.8	372	371.6	370.6	371	372.000
Mech Efficiency	**(%)**	41	42.7	44.2	41.1	42.2	42.240	36.2	42	41	42.3	43.2	40.940
ITE	**(%)**	44.6	43.6	42.3	43.6	43.2	43.460	53.8	46	46.2	45	43.6	46.920
BTE	**(%)**	18.3	18.6	18.7	17.9	18.2	18.340	19.5	19.3	18.9	19	18.8	19.100
Volumetric Efficiency	**(%)**	93.5	93.2	93.3	93.3	93.6	93.380	89.1	88.7	89.1	89.2	89	89.020

25 Nm HP DME		1300 rpm						1400 rpm					
File name		dm300714	dm300715	dm300716	dm300717	dm300718	**Average**	dm300719	dm300720	dm300721	dm300722	dm300723	**Average**
speed	**(rpm)**	1304.4	1304.4	1299.5	1299.5	1299.5	**1301.460**	1401.5	1401.5	1396.7	1401.5	1396.7	**1399.580**
Load	**(Nm)**	25.8	25.1	25.9	24.9	24.7	**25.280**	25.2	25.2	25.1	25.5	24.8	**25.160**
Brake Power	**(W)**	3519	3426.2	3524.4	3395	3358	**3444.520**	3701.5	3701.5	3668.8	3741.3	3629	**3688.420**
Ind. work per Cycle	**(J)**	370.2	377.9	373.7	386.5	381.3	**377.920**	380.5	358.4	385.1	370.8	380.2	**375.000**
Indicated Power	**(W)**	8047	8214.8	8094.1	8372	8258.9	**8197.360**	8888	8372	8964.8	8661.5	8850.4	**8747.340**
imep	**(kPa)**	556.6	568.2	562	581.3	573.4	**568.300**	572.2	539	579.1	557.6	571.7	**563.920**
bmep	**(kPa)**	243.4	237	244.7	235.7	233.1	**238.780**	238.3	238.3	237	240.9	234.4	**237.780**
Equivalence Ratio		0.475	0.479	0.474	0.475	0.476	**0.476**	0.464	0.463	0.47	0.464	0.465	**0.465**
Air/fuel ratio		20.73	20.65	20.67	20.65	20.63	**20.666**	21.22	21.25	21.08	21.24	21.27	**21.212**
Air Flow	**(g/s)**	12.3	12.255	12.264	12.254	12.245	**12.264**	12.741	12.758	12.654	12.75	12.768	**12.734**
Fuel Flow	**(g/s)**	0.59	0.59	0.59	0.59	0.59	**0.590**	0.6	0.6	0.6	0.6	0.6	**0.600**
Additive Flow	**(g/s)**	0	0	0	0	0	**0.000**	0	0	0	0	0	**0.000**
Percentage DME	**(%)**	0	0	0	0	0	**0.000**	0	0	0	0	0	**0.000**
Fuel Conv. Eff.	**(%)**	20.9	20.3	20.9	20.1	19.9	**20.420**	21.7	21.7	21.5	21.9	21.3	**21.620**
isfc	**(kg/J)**	7.37E-08	7.22E-08	7.33E-08	7.09E-08	7.19E-08	**7.24E-08**	6.76E-08	7.17E-08	6.70E-08	6.93E-08	6.78E-08	**6.87E-08**
bsfcf	**(kg/J)**	1.69E-07	1.73E-07	1.68E-07	1.75E-07	1.77E-07	**1.72E-07**	1.62E-07	1.62E-07	1.64E-07	1.60E-07	1.65E-07	**1.63E-07**
Injection	**(°CA)**	352.9	353.1	353.1	353.7	353.5	**353.260**	354.1	354.1	355.1	354.3	354.9	**354.500**
Ignition	**(°CA)**	356.5	354.7	354.5	354.3	355.1	**355.020**	355.1	355.5	356.1	356.3	355.1	**355.620**
Ignition delay	**(°CA)**	3.6	1.6	1.4	0.6	1.6	**1.760**	1	1.4	1	2	0.2	**1.120**
Patm	**(kPa)**	82.9	82.9	82.9	82.9	82.9	**82.900**	82.9	82.9	82.9	82.9	82.9	**82.900**
Exhaust Temperature	**(°C)**	332.9	334.4	334.9	336.8	337.3	**335.260**	345.9	345.5	343.5	340.2	344	**343.820**
Pmax	**(kPa)**	6406.1	6376.8	6396.3	6430.5	6245	**6370.940**	6083.8	6103.4	6132.7	6035	6059.4	**6082.860**
Position of Pmax	**(°CA)**	366.8	367.4	367	367.4	367.8	**367.280**	368.2	368	368.2	368.2	369.2	**368.360**
Tmax	**(K)**	1883.7	1872.9	1872	1895.7	1876.1	**1880.080**	1907.1	1871.3	1931.1	1899	1894.4	**1900.580**
Position of Tmax	**(°CA)**	372.8	373.6	372.6	371.4	373.6	**372.800**	375.4	373.4	375.4	375	375.4	**374.920**
Mech Efficiency	**(%)**	43.7	41.7	43.5	40.6	40.7	**42.040**	41.6	44.2	40.9	43.2	41	**42.180**
ITE	**(%)**	47.7	48.7	48	49.6	49	**48.600**	52.1	49	52.5	50.7	51.8	**51.220**
BTE	**(%)**	20.9	20.3	20.9	20.1	19.9	**20.420**	21.7	21.7	21.5	21.9	21.3	**21.620**
Volumetric Efficiency	**(%)**	85.1	84.8	85.2	85.1	85	**85.040**	82	82.1	81.7	82.1	82.5	**82.080**

25 Nm HP DME		1500 rpm					1600 rpm					
File name		dm300725	dm300726	dm300727	dm300728	**Average**	dm300729	dm300730	dm300731	dm300732	dm300733	**Average**
speed	**(rpm)**	1503.6	1498.7	1498.7	1498.7	**1499.925**	1595.9	1595.9	1600.8	1600.8	1600.8	**1598.840**
Load	**(Nm)**	24.9	25.1	25.4	25.4	**25.200**	25.1	25.5	24.8	25.4	25.1	**25.180**
Brake Power	**(W)**	3928.2	3936.8	3979.4	3979.4	**3955.950**	4192.1	4260.2	4159.3	4250.4	4204.9	**4213.380**
Ind. work per Cycle	**(J)**	410.6	397.2	395.9	399.6	**400.825**	404.5	394.5	389.5	411.9	389.7	**398.020**
Indicated Power	**(W)**	10290.6	9922.8	9888.9	9981.1	**10020.850**	10758.2	10492.6	10392.5	10989	10398	**10606.060**
imep	**(kPa)**	617.5	597.4	595.3	600.9	**602.775**	608.2	593.2	585.8	619.4	586.1	**598.540**
bmep	**(kPa)**	235.7	237	239.6	239.6	**237.975**	237	240.9	234.4	239.6	237	**237.780**
Equivalence Ratio		0.473	0.476	0.476	0.481	**0.477**	0.44	0.442	0.437	0.436	0.437	**0.438**
Air/fuel ratio		20.73	20.73	20.71	20.72	**20.723**	22.56	22.55	22.57	22.59	22.64	**22.582**
Air Flow	**(g/s)**	14.051	14.051	14.035	14.043	**14.045**	15.875	15.868	15.881	15.894	15.93	**15.890**
Fuel Flow	**(g/s)**	0.68	0.68	0.68	0.68	**0.680**	0.7	0.7	0.7	0.7	0.7	**0.700**
Additive Flow	**(g/s)**	0	0	0	0	**0.000**	0	0	0	0	0	**0.000**
Percentage DME	**(%)**	0	0	0	0	**0.000**	0	0	0	0	0	**0.000**
Fuel Conv. Eff.	**(%)**	20.4	20.4	20.7	20.7	**20.550**	21	21.3	20.8	21.2	21	**21.060**
isfc	**(kg/J)**	6.59E-08	6.83E-08	6.85E-08	6.79E-08	**6.77E-08**	6.54E-08	6.71E-08	6.77E-08	6.40E-08	6.77E-08	**6.64E-08**
bsfcf	**(kg/J)**	1.73E-07	1.72E-07	1.70E-07	1.70E-07	**1.71E-07**	1.68E-07	1.65E-07	1.69E-07	1.66E-07	1.67E-07	**1.67E-07**
Injection	**(°CA)**	355.3	354.9	355.5	354.9	**355.150**	356.7	355.7	354.7	354.5	355.3	**355.380**
Ignition	**(°CA)**	356.5	355.1	355.5	361.7	**357.200**	356.7	356.5	358.1	357.7	358.7	**357.540**
Ignition delay	**(°CA)**	1.2	0.2	0	6.8	**2.050**	0	0.8	3.4	3.2	3.4	**2.160**
Patm	**(kPa)**	82.8	82.8	82.8	82.8	**82.800**	82.8	82.8	82.8	82.8	82.8	**82.800**
Exhaust Temperature	**(°C)**	349.3	352.2	352.7	349.8	**351.000**	366.6	355.1	352.2	353.1	349.8	**355.360**
Pmax	**(kPa)**	5888.5	6054.5	6122.9	6020.3	**6021.550**	5912.9	5864.1	5727.4	5854.3	5536.9	**5779.120**
Position of Pmax	**(°CA)**	368.8	368	368.8	370	**368.900**	370.2	369.2	370	369.8	370.8	**370.000**
Tmax	**(K)**	1885.9	1878.8	1895.9	1884	**1886.150**	1786.3	1772.6	1759.7	1818.3	1749.2	**1777.220**
Position of Tmax	**(°CA)**	376.6	376.2	375.2	376.2	**376.050**	377.4	378	377.2	379	380	**378.320**
Mech Efficiency	**(%)**	38.2	39.7	40.2	39.9	**39.500**	39	40.6	40	38.7	40.4	**39.740**
ITE	**(%)**	53.4	51.5	51.3	51.8	**52.000**	53.8	52.4	51.9	54.9	52	**53.000**
BTE	**(%)**	20.4	20.4	20.7	20.7	**20.550**	21	21.3	20.8	21.2	21	**21.060**
Volumetric Efficiency	**(%)**	84.3	84.6	84.5	84.5	**84.475**	89.7	89.7	89.5	89.6	89.8	**89.660**

25 Nm HP DME		1700 rpm						1800 rpm					
File name		dm300734	dm300735	dm300736	dm300737	dm300738	**Average**	dm300739	dm300740	dm300742	dm300743	dm300744	**Average**
speed	**(rpm)**	1702.8	1702.8	1702.8	1702.8	1702.8	**1702.800**	1800	1800	1804.9	1804.9	1804.9	**1802.940**
Load	**(Nm)**	25.1	25.1	24.8	24.5	24	**24.700**	24.4	24.7	24.4	24.7	25.4	**24.720**
Brake Power	**(W)**	4472.9	4472.9	4424.5	4376	4279.1	**4405.080**	4600.2	4651.4	4612.6	4663.9	4792.3	**4664.080**
Ind. work per Cycle	**(J)**	386.8	398.7	400.4	406	332.6	**384.900**	380.8	384	357.4	374.5	384.7	**376.280**
Indicated Power	**(W)**	10978.2	11315.9	11364.4	11523.7	9439.6	**10924.360**	11424.6	11519.8	10752.2	11266.9	11571.1	**11306.920**
imep	**(kPa)**	581.7	599.6	602.2	610.6	500.2	**578.860**	572.7	577.4	537.5	563.2	578.4	**565.840**
bmep	**(kPa)**	237	237	234.4	231.9	226.7	**233.400**	230.6	233.1	230.6	233.1	239.6	**233.400**
Equivalence Ratio		0.477	0.47	0.471	0.469	0.479	**0.473**	0.451	0.449	0.449	0.452	0.446	**0.449**
Air/fuel ratio		20.93	20.99	20.92	20.92	20.84	**20.920**	21.94	22.14	22.21	22.22	22.1	**22.122**
Air Flow	**(g/s)**	15.811	15.853	15.803	15.802	15.74	**15.802**	16.572	16.552	16.61	16.616	16.524	**16.575**
Fuel Flow	**(g/s)**	0.76	0.76	0.76	0.76	0.76	**0.760**	0.76	0.75	0.75	0.75	0.75	**0.752**
Additive Flow	**(g/s)**	0	0	0	0	0	**0.000**	0	0	0	0	0	**0.000**
Percentage DME	**(%)**	0	0	0	0	0	**0.000**	0	0	0	0	0	**0.000**
Fuel Conv. Eff.	**(%)**	20.8	20.8	20.6	20.4	19.9	**20.500**	21.4	21.9	21.7	21.9	22.5	**21.880**
isfc	**(kg/J)**	6.88E-08	6.68E-08	6.65E-08	6.55E-08	8.00E-08	**6.95E-08**	6.61E-08	6.49E-08	6.95E-08	6.64E-08	6.46E-08	**6.63E-08**
bsfcf	**(kg/J)**	1.69E-07	1.69E-07	1.71E-07	1.73E-07	1.77E-07	**1.72E-07**	1.64E-07	1.61E-07	1.62E-07	1.60E-07	1.56E-07	**1.61E-07**
Injection	**(°CA)**	356.5	355.3	354.3	354.9	353.9	**354.980**	356.1	356.5	355.3	356.7	356.5	**356.220**
Ignition	**(°CA)**	357.5	361.1	358.7	358.7	358.9	**358.980**	358.3	359.5	360.1	358.5	358.5	**358.980**
Ignition delay	**(°CA)**	1	5.8	4.4	3.8	5	**4.000**	2.2	3	4.8	1.8	2	**2.760**
Patm	**(kPa)**	82.8	82.8	82.8	82.8	82.8	**82.800**	82.8	82.8	82.8	82.8	82.8	**82.800**
Exhaust Temperature	**(°C)**	355.6	350.7	349.8	348.3	347.4	**350.360**	372.4	374.8	363.7	371.4	375.8	**371.620**
Pmax	**(kPa)**	5781.1	5663.9	5522.3	5629.7	5200	**5559.400**	5405.1	5410	5346.5	5409.9	5463.7	**5407.040**
Position of Pmax	**(°CA)**	370.4	370.8	369.4	371.4	371	**370.600**	371	370.8	370.8	370.8	370.2	**370.720**
Tmax	**(K)**	1862.5	1861.1	1871.1	1877.8	1759.5	**1846.400**	1868.9	1868.3	1811.9	1873.8	1897.1	**1864.000**
Position of Tmax	**(°CA)**	377.4	377.8	379	378	380.8	**378.600**	380.4	378.4	381	378.2	380.4	**379.680**
Mech Efficiency	**(%)**	40.7	39.5	38.9	38	45.3	**40.480**	40.3	40.4	42.9	41.4	41.4	**41.280**
ITE	**(%)**	51.1	52.7	52.9	53.7	44	**50.880**	53.2	54.2	50.6	53	54.4	**53.080**
BTE	**(%)**	20.8	20.8	20.6	20.4	19.9	**20.500**	21.4	21.9	21.7	21.9	22.5	**21.880**
Volumetric Efficiency	**(%)**	83.8	84	83.7	83.7	83.4	**83.720**	83.1	83	83	83.1	82.6	**82.960**

35 Nm DME HP		1100 rpm						1200 rpm					
File name		dm280701	dm280702	dm270703	dm280704	dm280705	**Average**	dm280706	dm280707	dm280708	dm280709	dm280710	**Average**
speed	**(rpm)**	1100.3	1100.3	1105.1	1105.1	1105.1	**1103.180**	1202.3	1202.3	1202.3	1202.3	1202.3	**1202.300**
Load	**(Nm)**	35.8	35.8	35.7	35.8	35.3	**35.680**	35	34.9	35.4	35	34.9	**35.040**
Brake Power	**(W)**	4126.6	4126.6	4129.1	4144.8	4081.9	**4121.800**	4406.7	4389.6	4458	4406.7	4389.6	**4410.120**
Ind. work per Cycle	**(J)**	433.4	424.2	413.9	422.3	400.8	**418.920**	414.1	378.7	414.1	416.2	424.3	**409.480**
Indicated Power	**(W)**	7948.4	7778.6	7623.8	7778.8	7382.8	**7702.480**	8298.9	7588.6	8297.3	8339.6	8502.7	**8205.420**
imep	**(kPa)**	651.8	637.9	622.4	635.1	602.7	**629.980**	622.8	569.5	622.7	625.8	638.1	**615.780**
bmep	**(kPa)**	338.4	338.4	337.1	338.4	333.3	**337.120**	330.7	329.4	334.5	330.7	329.4	**330.940**
Equivalence Ratio		0.601	0.608	0.606	0.608	0.61	**0.607**	0.532	0.533	0.534	0.534	0.536	**0.534**
Air/fuel ratio		16.01	15.79	15.88	15.79	15.8	**15.854**	18.26	18.23	18.17	18.2	18.16	**18.204**
Air Flow	**(g/s)**	11.443	11.283	11.354	11.284	11.294	**11.332**	11.685	11.665	11.627	11.646	11.617	**11.648**
Fuel Flow	**(g/s)**	0.71	0.71	0.71	0.71	0.71	**0.710**	0.64	0.64	0.64	0.64	0.64	**0.640**
Additive Flow	**(g/s)**	0	0	0	0	0	**0.000**	0	0	0	0	0	**0.000**
Percentage DME	**(%)**	0	0	0	0	0	**0.000**	0	0	0	0	0	**0.000**
Fuel Conv. Eff.	**(%)**	20.3	20.3	20.3	20.4	20.1	**20.280**	24.2	24.1	24.5	24.2	24.1	**24.220**
isfc	**(kg/J)**	8.99E-08	9.19E-08	9.38E-08	9.19E-08	9.68E-08	**9.29E-08**	7.71E-08	8.43E-08	7.71E-08	7.67E-08	7.52E-08	**7.81E-08**
bsfcf	**(kg/J)**	1.73E-07	1.73E-07	1.73E-07	1.72E-07	1.75E-07	**1.73E-07**	1.45E-07	1.46E-07	1.44E-07	1.45E-07	1.46E-07	**1.45E-07**
Injection	**(°CA)**	354.1	355.5	355.1	353.5	353.1	**354.260**	354.3	354.9	354.1	353.1	352.7	**353.820**
Ignition	**(°CA)**	354.7	355.9	355.1	353.9	353.3	**354.580**	354.3	354.9	354.3	353.1	353.3	**353.980**
Ignition delay	**(°CA)**	0.6	0.4	0	0.4	0.2	**0.320**	0	0	0.2	0	0.6	**0.160**
Patm	**(kPa)**	83.3	83.3	83.3	83.3	83.3	**83.300**	83.3	83.3	83.3	83.3	83.3	**83.300**
Exhaust Temperature	**(°C)**	398.8	412.3	423.9	422.4	432	**417.880**	445	437.3	438.3	428.2	427.7	**435.300**
Pmax	**(kPa)**	6592.1	6489.6	6387.1	6543.3	6601.9	**6522.800**	6362.6	6343.1	6348	6557.9	6538.4	**6430.000**
Position of Pmax	**(°CA)**	368.2	368.8	367	368.4	366	**367.680**	366.6	367.6	368.4	366.8	366.8	**367.240**
Tmax	**(K)**	1779.5	1798.1	1761.6	1809.4	1767	**1783.120**	1843.8	1805.4	1864.1	1855.5	1876.5	**1849.060**
Position of Tmax	**(°CA)**	374.8	373	374.2	373.2	373.2	**373.680**	373.2	374.2	374.4	373.2	373	**373.600**
Mech Efficiency	**(%)**	51.9	53.1	54.2	53.3	55.3	**53.560**	53.1	57.8	53.7	52.8	51.6	**53.800**
ITE	**(%)**	39.1	38.3	37.5	38.3	36.3	**37.900**	45.6	41.7	45.6	45.8	46.7	**45.080**
BTE	**(%)**	20.3	20.3	20.3	20.4	20.1	**20.280**	24.2	24.1	24.5	24.2	24.1	**24.220**
Volumetric Efficiency	**(%)**	93.8	92.5	92.7	92.1	92.2	**92.660**	87.7	87.5	87.2	87.4	87.2	**87.400**

35 Nm DME HP		1300 rpm						1400 rpm					
File name		dm280711	dm280712	dm280713	dm280714	dm280716	**Average**	dm280717	dm280718	dm280719	dm280720	dm280721	**Average**
speed	**(rpm)**	1299.5	1299.5	1299.5	1299.5	1299.5	**1299.500**	1396.7	1396.7	1396.7	1396.7	1396.7	**1396.700**
Load	**(Nm)**	35.7	36.1	35.5	35	34.3	**35.320**	38	37.3	37.3	37.2	35.1	**36.980**
Brake Power	**(W)**	4855.3	4910.8	4836.8	4762.9	4670.5	**4807.260**	5556.2	5456.8	5456.8	5437	5138.9	**5409.140**
Ind. work per Cycle	**(J)**	436.8	440.4	406.3	432.7	421.6	**427.560**	469.2	431.1	426.4	422.4	387.6	**427.340**
Indicated Power	**(W)**	9461	9539.4	8799.7	9370.9	9131.3	**9260.460**	10922.3	10035.3	9926.9	9832.1	9022	**9947.720**
imep	**(kPa)**	656.9	662.3	611	650.6	634	**642.960**	705.6	648.3	641.3	635.2	582.8	**642.640**
bmep	**(kPa)**	337.1	341	335.8	330.7	324.3	**333.780**	358.9	352.5	352.5	351.2	332	**349.420**
Equivalence Ratio		0.562	0.561	0.559	0.56	0.559	**0.560**	0.579	0.577	0.578	0.579	0.579	**0.578**
Air/fuel ratio		17.25	17.23	17.31	17.29	17.31	**17.278**	16.69	16.75	16.73	16.73	19.73	**17.326**
Air Flow	**(g/s)**	11.998	11.979	12.035	12.026	12.036	**12.015**	12.538	12.585	12.567	12.567	12.566	**12.565**
Fuel Flow	**(g/s)**	0.7	0.7	0.7	0.7	0.7	**0.700**	0.75	0.75	0.75	0.75	0.75	**0.750**
Additive Flow	**(g/s)**	0	0	0	0	0	**0.000**	0	0	0	0	0	**0.000**
Percentage DME	**(%)**	0	0	0	0	0	**0.000**	0	0	0	0		**0.000**
Fuel Conv. Eff.	**(%)**	24.6	24.8	24.5	24.1	23.6	**24.320**	26	25.6	25.6	25.5	24.1	**25.360**
isfc	**(kg/J)**	7.35E-08	7.29E-08	7.90E-08	7.42E-08	7.62E-08	**7.52E-08**	6.88E-08	7.49E-08	7.57E-08	7.64E-08	8.33E-08	**7.58E-08**
bsfcf	**(kg/J)**	1.43E-07	1.42E-07	1.44E-07	1.46E-07	1.49E-07	**1.45E-07**	1.35E-07	1.38E-07	1.38E-07	1.38E-07	1.46E-07	**1.39E-07**
Injection	**(°CA)**	353.3	353.9	352.7	353.7	354.3	**353.580**	354.3	355.1	355.7	355.7	356.7	**355.500**
Ignition	**(°CA)**	353.5	353.9	352.7	353.7	354.3	**353.620**	354.3	355.1	355.7	355.7	359.1	**355.980**
Ignition delay	**(°CA)**	0.2	0	0	0	0	**0.040**	0	0	0	0	2.4	**0.480**
Patm	**(kPa)**	83.3	83.3	83.3	83.3	83.3	**83.300**	83.3	83.3	83.3	83.3	83.3	**83.300**
Exhaust Temperature	**(°C)**	444.1	440.7	433	428.2	431.5	**435.500**	457.5	453.7	449.8	448.4	423.4	**446.560**
Pmax	**(kPa)**	6548.2	6533.5	6435.9	6499.3	6426.1	**6488.600**	6489.6	6196.6	6206.4	6269.9	5986.6	**6229.820**
Position of Pmax	**(°CA)**	366.6	367	366.6	366.8	367.2	**366.840**	368.4	367.8	368.8	368.4	368.4	**368.360**
Tmax	**(K)**	1988	1989.7	1945.1	1966.1	1948.4	**1967.460**	2066.2	1994	1972.3	2005.8	1945.7	**1996.800**
Position of Tmax	**(°CA)**	374.2	373	373.6	375.4	374	**374.040**	375.6	377.2	373.2	376.2	374.6	**375.360**
Mech Efficiency	**(%)**	51.3	51.5	55	50.8	51.1	**51.940**	50.9	54.4	55	55.3	57	**54.520**
ITE	**(%)**	47.9	48.3	44.5	47.4	46.2	**46.860**	51.1	47	46.5	46	42.2	**46.560**
BTE	**(%)**	24.6	24.8	24.5	24.1	23.6	**24.320**	26	25.6	25.6	25.5	24.1	**25.360**
Volumetric Efficiency	**(%)**	83.3	83.2	83.6	83.5	83.6	**83.440**	81	81.3	81.2	81.2	81.2	**81.180**

35 Nm DME HP		1500 rpm					1600 rpm					
File name		dm280722	dm280724	dm280726	dm280727	**Average**	dm280728	dm280729	dm280730	dm280731	dm280732	Average
speed	**(rpm)**	1503.6	1503.6	1503.6	1503.6	**1503.600**	1600.8	1600.8	1600.8	1600.8	1600.8	1600.800
Load	**(Nm)**	34.6	35.7	34.7	34.5	**34.875**	35.1	34.7	34.6	34.9	34.9	34.840
Brake Power	**(W)**	5446.7	5617.8	5468.1	5425.3	**5489.475**	5889.9	5821.6	5798.8	5844.3	5844.3	5839.780
Ind. work per Cycle	**(J)**	395.2	436.3	399	421.6	**413.025**	448.3	436.4	442	414.2	422.1	432.600
Indicated Power	**(W)**	9902.9	10933.6	9998.9	10565.4	**10350.200**	11961	11642.6	11792.3	11049.9	11261.3	11541.420
imep	**(kPa)**	594.2	656.1	600	634	**621.075**	674.2	656.2	664.7	622.8	634.7	650.520
bmep	**(kPa)**	326.8	337.1	328.1	325.6	**329.400**	332	328.1	326.8	329.4	329.4	329.140
Equivalence Ratio		0.595	0.591	0.592	0.593	**0.593**	0.572	0.575	0.576	0.573	0.574	0.574
Air/fuel ratio		16.29	16.3	16.27	16.26	**16.280**	16.91	16.89	16.85	16.86	16.81	16.864
Air Flow	**(g/s)**	14.066	14.078	14.054	14.046	**14.061**	15.559	15.537	15.508	15.516	15.471	15.518
Fuel Flow	**(g/s)**	0.86	0.86	0.86	0.86	**0.860**	0.92	0.92	0.92	0.92	0.92	0.920
Additive Flow	**(g/s)**	0	0	0	0	**0.000**	0	0	0	0	0	0.000
Percentage DME	**(%)**	0	0	0	0	**0.000**	0	0	0	0	0	0.000
Fuel Conv. Eff.	**(%)**	22.2	22.9	22.3	22.1	**22.375**	22.5	22.3	22.2	22.3	22.3	22.320
isfc	**(kg/J)**	8.72E-08	7.90E-08	8.64E-08	8.17E-08	**8.36E-08**	7.69E-08	7.90E-08	7.80E-08	8.33E-08	8.17E-08	7.98E-08
bsfcf	**(kg/J)**	1.59E-07	1.54E-07	1.58E-07	1.59E-07	**1.57E-07**	1.56E-07	1.58E-07	1.59E-07	1.57E-07	1.57E-07	1.58E-07
Injection	**(°CA)**	355.9	355.3	357.1	355.1	**355.850**	356.3	357.5	356.3	356.5	357.1	356.740
Ignition	**(°CA)**	356.9	355.3	357.1	355.1	**356.100**	357.3	357.7	358.3	356.5	357.1	357.380
Ignition delay	**(°CA)**	1	0	0	0	**0.250**	1	0.2	2	0	0	0.640
Patm	**(kPa)**	83.3	83.3	83.3	83.3	**83.300**	83.3	83.3	83.3	83.3	83.3	83.300
Exhaust Temperature	**(°C)**	433	440.7	428.7	424.8	**431.800**	448.4	452.2	453.2	439.2	431.5	444.900
Pmax	**(kPa)**	5703.4	6108.7	5913.4	6284.5	**6002.500**	5893.9	5864.6	5937.8	5947.6	5913.4	5911.460
Position of Pmax	**(°CA)**	369.8	368.6	369	368.6	**369.000**	370.8	369.4	369.8	370.2	370	370.040
Tmax	**(K)**	1829.5	1930	1872	1942.1	**1893.400**	1856.5	1844.1	1852.6	1813.1	1829.2	1839.100
Position of Tmax	**(°CA)**	376.6	374.6	375.4	375.4	**375.500**	377.6	378.4	376.8	376.2	375.4	376.880
Mech Efficiency	**(%)**	55	51.4	54.7	51.4	**53.125**	49.2	50	48.2	52.9	51.9	50.440
ITE	**(%)**	40.3	44.5	40.7	43	**42.125**	45.7	44.5	45.1	42.2	43	44.100
BTE	**(%)**	22.2	22.9	22.3	22.1	**22.375**	22.5	22.3	22.2	22.3	22.3	22.320
Volumetric Efficiency	**(%)**	84.4	84.5	74.3	84.3	**81.875**	87.7	87.6	87.4	87.5	87.2	87.480

35 Nm DME HP		1700 rpm					1800 rpm					
File name		dm280734	dm280735	dm280736	dm280738	**Average**	dm280742	dm280743	dm280744	dm280745	dm280746	**Average**
speed	**(rpm)**	1698	1702.8	1702.8	1702.8	**1701.600**	1804.9	1804.9	1800	1804.9	1804.9	**1803.920**
Load	**(Nm)**	35.3	34.7	35.4	35.1	**35.125**	34.5	34.6	35	35.1	35	**34.840**
Brake Power	**(W)**	6271.6	6192.7	6313.8	6265.3	**6260.850**	6512.4	6538.1	6597.3	6640.8	6615.1	**6580.740**
Ind. work per Cycle	**(J)**	443.9	416.7	451.7	443.4	**438.925**	398.9	442.1	425.4	405.1	433.1	**420.920**
Indicated Power	**(W)**	12562.1	11827.3	12818.2	12583.8	**12447.850**	11998.9	13299.4	12761.9	12185.5	13026.7	**12654.480**
imep	**(kPa)**	667.5	626.7	679.2	666.8	**660.050**	599.8	664.8	639.7	609.2	651.2	**632.940**
bmep	**(kPa)**	333.3	328.1	334.5	332	**331.975**	325.6	326.8	330.7	332	330.7	**329.160**
Equivalence Ratio		0.591	0.594	0.592	0.587	**0.591**	0.625	0.624	0.622	0.622	0.626	**0.624**
Air/fuel ratio		16.48	16.44	16.46	16.44	**16.455**	15.39	15.39	15.41	15.41	15.36	**15.392**
Air Flow	**(g/s)**	15.609	15.565	15.587	15.572	**15.583**	16.332	16.332	16.351	16.351	16.303	**16.334**
Fuel Flow	**(g/s)**	0.95	0.95	0.95	0.95	**0.950**	1.06	1.06	1.06	1.06	1.06	**1.060**
Additive Flow	**(g/s)**	0	0	0	0	**0.000**	0	0	0	0	0	**0.000**
Percentage DME	**(%)**	0	0	0	0	**0.000**	0	0	0	0	0	**0.000**
Fuel Conv. Eff.	**(%)**	23.3	23	23.5	23.3	**23.275**	21.6	21.7	21.9	22	21.9	**21.820**
isfc	**(kg/J)**	7.54E-08	8.01E-08	7.39E-08	7.53E-08	**7.61E-08**	8.85E-08	7.98E-08	8.32E-08	8.71E-08	8.15E-08	**8.40E-08**
bsfcf	**(kg/J)**	1.51E-07	1.53E-07	1.50E-07	1.51E-07	**1.51E-07**	1.63E-07	1.62E-07	1.61E-07	1.60E-07	1.60E-07	**1.61E-07**
Injection	**(°CA)**	358.5	357.3	358.1		**357.967**	357.3	356.9	357.3	356.7	357.5	**357.140**
Ignition	**(°CA)**	358.5	357.3	358.5		**358.100**	357.9	358.7	361.5	361.1	359.1	**359.660**
Ignition delay	**(°CA)**	0	0	0.4	8.2	**2.150**	0.6	1.8	4.2	4.4	1.6	**2.520**
Patm	**(kPa)**	83.3	83.3	83.3	83.3	**83.300**	83.3	83.3	83.3	83.3	83.3	**83.300**
Exhaust Temperature	**(°C)**	466.7	461.4	468.1	469.1	**466.325**	480.1	484	485.4	478.2	472.4	**480.020**
Pmax	**(kPa)**	5659.5	5605.8	5679	5806	**5687.575**	5444.6	5615.5	5654.6	5473.9	5508.1	**5539.340**
Position of Pmax	**(°CA)**	370.4	369.6	370.4	370	**370.100**	370	371.2	370.8	370.8	371.8	**370.920**
Tmax	**(K)**	1881.1	1822.1	1908.2	1921.5	**1883.225**	1860.8	1934.2	1918.7	1907.8	1938.1	**1911.920**
Position of Tmax	**(°CA)**	381.4	379.6	378.4	380.4	**379.950**	378.6	381.8	379.6	378.6	377.6	**379.240**
Mech Efficiency	**(%)**	49.9	52.4	49.3	49.8	**50.350**	54.3	49.2	51.7	54.5	50.8	**52.100**
ITE	**(%)**	46.7	43.9	47.6	46.7	**46.225**	39.8	44.1	42.3	40.4	43.2	**41.960**
BTE	**(%)**	23.3	23	23.5	23.3	**23.275**	21.6	21.7	21.9	22	21.9	**21.820**
Volumetric Efficiency	**(%)**	82.9	82.5	82.6	82.5	**82.625**	81.6	81.6	82	81.7	81.5	**81.680**

45 Nm DME HP		1100 rpm						1200 rpm					
File name		dm290702	dm290703	dm290704	dm290705	dm290706	**Average**	dm290707	dm290708	dm290709	dm290710	dm290711	**Average**
speed	**(rpm)**	1105.1	1105.1	1105.1	1100.3	1105.1	**1104.140**	1202.3	1202.3	1197.5	1202.3	1197.5	**1200.380**
Load	**(Nm)**	44.1	54.6	44.8	45.1	44.2	**46.560**	45.5	45.7	44.6	44.5	45.3	**45.120**
Brake Power	**(W)**	5103.7	5276.6	5182.3	5190.8	5119.4	**5174.560**	5723.6	5757.8	5598.2	5603.8	5683.4	**5673.360**
Ind. work per Cycle	**(J)**	457.3	434.7	448.3	450.6	454.2	**449.020**	468.9	464.4	457.2	466.6	467.4	**464.900**
Indicated Power	**(W)**	8422	8005.8	8256.8	8262.2	8365.5	**8262.460**	9396.5	9305.9	9124.1	9349.7	9328.9	**9301.020**
imep	**(kPa)**	687.6	653.6	674.1	677.5	683	**675.160**	705.1	698.3	687.5	701.6	702.9	**699.080**
bmep	**(kPa)**	416.7	430.8	423.1	425.7	418	**422.860**	429.5	432.1	421.8	420.5	428.2	**426.420**
Equivalence Ratio		0.564	0.564	0.567	0.572	0.567	**0.567**	0.61	0.611	0.609	0.611	0.611	**0.610**
Air/fuel ratio		17.15	17.13	17.05	16.94	17.03	**17.060**	15.75	15.71	15.76	15.73	15.73	**15.736**
Air Flow	**(g/s)**	10.97	10.96	10.908	10.836	10.898	**10.914**	11.303	11.272	11.313	11.292	11.292	**11.294**
Fuel Flow	**(g/s)**	0.64	0.64	0.64	0.64	0.64	**0.640**	0.72	0.72	0.72	0.72	0.72	**0.720**
Additive Flow	**(g/s)**	0	0	0	0	0	**0.000**	0	0	0	0	0	**0.000**
Percentage DME	**(%)**	0	0	0	0	0	**0.000**	0	0	0	0	0	**0.000**
Fuel Conv. Eff.	**(%)**	28.1	29	28.5	28.5	28.1	**28.440**	28.1	28.2	27.4	27.5	27.9	**27.820**
isfc	**(kg/J)**	7.60E-08	7.88E-08	7.75E-08	7.74E-08	7.65E-08	**7.72E-08**	7.64E-08	7.71E-08	7.87E-08	7.68E-08	7.69E-08	**7.72E-08**
bsfcf	**(kg/J)**	1.25E-07	1.21E-07	1.23E-07	1.23E-07	1.25E-07	**1.24E-07**	1.25E-07	1.25E-07	1.28E-07	1.28E-07	1.26E-07	**1.27E-07**
Injection	**(°CA)**	351.9	350.5	351.7	351.9	351.9	**351.580**	352.1	351.9	351.1	352.3	351.5	**351.780**
Ignition	**(°CA)**	352.1	351.3	351.7	352.1	351.9	**351.820**	352.1	351.9	351.1	352.3	351.5	**351.780**
Ignition delay	**(°CA)**	0.2	0.8	0	0.2	0	**0.240**	0	0	0	0	0	**0.000**
Patm	**(kPa)**	83.2	83.2	83.2	83.2	83.2	**83.200**	83.2	83.2	83.2	83.2	83.2	**83.200**
Exhaust Temperature	**(°C)**	478.2	484.9	497	491.7	507.5	**491.860**	522.5	521	509.5	517.2	510.4	**516.120**
Pmax	**(kPa)**	6718.9	6821.5	6826.3	6748.2	6777.5	**6778.480**	6797.1	6762.9	6865.4	6684.7	6758	**6773.620**
Position of Pmax	**(°CA)**	367.2	365.6	366.4	367	366.8	**366.600**	367.6	367.8	366	366.4	366.6	**366.880**
Tmax	**(K)**	1870.5	1868.1	1897.3	1910.1	1921.4	**1893.480**	2017.4	2008.9	1989.4	2003.1	1985.5	**2000.860**
Position of Tmax	**(°CA)**	371.8	373	372.6	373.2	374.2	**372.960**	372.6	372.6	373.2	374	373.8	**373.240**
Mech Efficiency	**(%)**	60.6	65.9	62.8	62.8	61.2	**62.660**	60.9	61.9	61.4	59.9	60.9	**61.000**
ITE	**(%)**	46.3	44	45.4	45.4	46	**45.420**	46.1	45.6	44.7	45.8	45.7	**45.580**
BTE	**(%)**	28.1	29	28.5	28.5	28.1	**28.440**	28.1	28.2	27.4	27.5	27.9	**27.820**
Volumetric Efficiency	**(%)**	89.6	89.5	89.1	88.9	89	**89.220**	84.8	84.6	85.2	84.7	85.1	**84.880**

45 Nm DME HP		1300 rpm						1400 rpm					
File name		dm290712	dm290713	dm290714	dm290715	dm290716	**Average**	dm290717	dm290718	dm290719	dm290720	dm290721	**Average**
speed	**(rpm)**	1299.5	1299.5	1299.5	1299.5	1299.5	**1299.500**	1401.5	1396.7	1396.7	1401.5	1401.5	**1399.580**
Load	**(Nm)**	45.2	45.5	44.9	44.9	45.6	**45.220**	45.3	45.2	45.5	45.1	45.1	**45.240**
Brake Power	**(W)**	6149.2	6186.2	6112.3	6112.3	6204.7	**6152.940**	6652.1	6606.1	6648.9	6612.2	6612.2	**6626.300**
Ind. work per Cycle	**(J)**	469.6	472.2	464.9	454.1	478.5	**467.860**	499.8	480.1	458.5	491.9	490.5	**484.160**
Indicated Power	**(W)**	10171.8	10228	10068.9	9834.2	10364	**10133.380**	11675.6	11176	10672	11490.7	11457.7	**11294.400**
imep	**(kPa)**	706.2	710.1	699.1	682.8	719.6	**703.560**	751.6	722	689.4	739.7	737.6	**728.060**
bmep	**(kPa)**	426.9	429.5	424.4	424.4	430.8	**427.200**	428.2	426.9	429.5	425.7	425.7	**427.200**
Equivalence Ratio		0.591	0.59	0.593	0.59	0.588	**0.590**	0.612	0.611	0.61	0.609	0.609	**0.610**
Air/fuel ratio		16.3	16.37	16.28	16.3	16.43	**16.336**	15.73	15.72	15.77	15.78	15.78	**15.756**
Air Flow	**(g/s)**	11.577	11.625	11.556	11.577	11.662	**11.599**	12.227	12.218	12.255	12.263	12.264	**12.245**
Fuel Flow	**(g/s)**	0.71	0.71	0.71	0.71	0.71	**0.710**	0.78	0.78	0.78	0.78	0.78	**0.780**
Additive Flow	**(g/s)**	0	0	0	0	0	**0.000**	0	0	0	0	0	**0.000**
Percentage DME	**(%)**	0	0	0	0	0	**0.000**	0	0	0	0	0	**0.000**
Fuel Conv. Eff.	**(%)**	30.5	30.6	30.3	30.3	30.7	**30.480**	30.1	29.9	30.1	29.9	29.9	**29.980**
isfc	**(kg/J)**	6.98E-08	6.94E-08	7.05E-08	7.22E-08	6.85E-08	**7.01E-08**	6.66E-08	6.95E-08	7.28E-08	6.76E-08	6.78E-08	**6.89E-08**
bsfcf	**(kg/J)**	1.15E-07	1.15E-07	1.16E-07	1.16E-07	1.14E-07	**1.15E-07**	1.17E-07	1.18E-07	1.17E-07	1.18E-07	1.18E-07	**1.17E-07**
Injection	**(°CA)**	352.5	354.9	353.5	354.7	353.9	**353.900**	354.5	354.1	355.1	354.3	354.7	**354.540**
Ignition	**(°CA)**	354.5	354.9	353.5	354.7	357.3	**354.980**	354.5	355.1	356.3	355.3	355.1	**355.260**
Ignition delay	**(°CA)**	2	0	0	0	3.4	**1.080**	0	1	1.2	1	0.4	**0.720**
Patm	**(kPa)**	83.2	83.2	83.2	83.2	83.1	**83.180**	83.2	83.2	83.2	83.2	83.2	**83.200**
Exhaust Temperature	**(°C)**	534	535.4	525.3	530.1	526.3	**530.220**	538.8	531.6	535.9	541.7	536.9	**536.980**
Pmax	**(kPa)**	6577.3	6460.1	6513.8	6347.8	6450.3	**6469.860**	6362.5	6455.2	6303.9	6342.9	6382	**6369.300**
Position of Pmax	**(°CA)**	366.8	367.6	366.4	367.8	368	**367.320**	369	366.4	367.8	367.2	366.6	**367.400**
Tmax	**(K)**	2091	2081.7	2074.2	2057	2089.2	**2078.620**	2133.4	2112.4	2085.2	2096.9	2098.4	**2105.260**
Position of Tmax	**(°CA)**	374.4	376	374	376	374.2	**374.920**	376.2	376	376	377	376.6	**376.360**
Mech Efficiency	**(%)**	60.5	60.5	60.7	62.2	59.9	**60.760**	57	59.1	62.3	57.5	57.7	**58.720**
ITE	**(%)**	50.4	50.7	49.9	48.7	51.3	**50.200**	52.8	50.6	48.3	52	51.8	**51.100**
BTE	**(%)**	30.5	30.6	30.3	30.3	30.7	**30.480**	30.1	29.9	30.1	29.9	29.9	**29.980**
Volumetric Efficiency	**(%)**	80.4	80.7	80.2	80.4	81	**80.540**	78.7	78.9	79.2	78.9	79	**78.940**

45 Nm DME HP		1500 rpm						1600 rpm					
File name		dm290723	dm290724	dm290725	dm290726	**dm290727**	**Average**	dm290728	dm290730	dm290731	dm290733	dm290734	**Average**
speed	**(rpm)**	1503.6	1503.6	1503.6	1503.6	1498.7	**1502.620**	1600.8	1600.8	1600.8	1600.8	1600.8	**1600.800**
Load	**(Nm)**	45.6	45.1	45.2	45.6	45.1	**45.320**	45.3	44.9	45.2	44.9	44.8	**45.020**
Brake Power	**(W)**	7179.2	7093.6	7115	7179.2	7070.7	**7127.540**	7579.7	7529.4	7574.9	7529.4	7506.6	**7544.000**
Ind. work per Cycle	**(J)**	486.5	518	475.6	503.5	517.3	**500.180**	490	475.8	520.2	490.2	517.1	**498.660**
Indicated Power	**(W)**	12191.8	12982.1	11919	12617.1	12921.5	**12526.300**	13072.8	12694.6	13877.8	13078.8	13796.5	**13304.100**
imep	**(kPa)**	731.6	779	715.2	757.1	777.9	**752.160**	736.8	715.5	782.2	737.2	777.6	**749.860**
bmep	**(kPa)**	430.8	425.7	426.9	430.8	425.7	**427.980**	428.2	424.4	426.9	424.4	423.1	**425.400**
Equivalence Ratio		0.599	0.6	0.599	0.598	0.599	**0.599**	0.538	0.548	0.553	0.547	0.55	**0.547**
Air/fuel ratio		16.06	16.07	16.05	16.07	16.05	**16.060**	18.03	17.68	17.68	17.74	17.68	**17.762**
Air Flow	**(g/s)**	13.506	13.514	13.497	13.513	13.497	**13.505**	15.168	15.141	15.141	15.191	15.141	**15.156**
Fuel Flow	**(g/s)**	0.84	0.84	0.84	0.84	0.84	**0.840**	0.84	0.86	0.86	0.86	0.86	**0.856**
Additive Flow	**(g/s)**	0	0	0	0	0	**0.000**	0	0	0	0	0	**0.000**
Percentage DME	**(%)**	0	0	0	0	0	**0.000**	0	0	0	0	0	**0.000**
Fuel Conv. Eff.	**(%)**	30	29.7	29.8	30	29.6	**29.820**	31.8	30.9	31.1	30.9	30.8	**31.100**
isfc	**(kg/J)**	6.90E-08	6.48E-08	7.06E-08	6.67E-08	6.51E-08	**6.72E-08**	6.43E-08	6.74E-08	6.17E-08	6.55E-08	6.21E-08	**6.42E-08**
bsfcf	**(kg/J)**	1.17E-07	1.19E-07	1.18E-07	1.17E-07	1.19E-07	**1.18E-07**	1.11E-07	1.14E-07	1.13E-07	1.14E-07	1.14E-07	**1.13E-07**
Injection	**(°CA)**	356.5	356.5	357.7	357.5	356.1	**356.860**	357.9	358.3	357.9	358.9	358.5	**358.300**
Ignition	**(°CA)**	360.3	358.9	357.7	358.5	357.1	**358.500**	359.3	358.9	358.9	365.1	359.9	**360.420**
Ignition delay	**(°CA)**	3.8	2.4	0	1	1	**1.640**	1.4	0.6	1	6.2	1.4	**2.120**
Patm	**(kPa)**	83.1	83.1	83.1	83.1	83.1	**83.100**	83.1	83.1	83.1	83.1	83.1	**83.100**
Exhaust Temperature	**(°C)**	555.6	555.2	555.6	560.4	555.2	**556.400**	550.8	547.9	539.3	548.4	554.7	**548.220**
Pmax	**(kPa)**	5976.7	6020.6	5942.5	5923	6064.6	**5985.480**	5747.2	5703.2	5791.1	5649.5	5659.2	**5710.040**
Position of Pmax	**(°CA)**	369.2	369.8	368.8	369.6	369.4	**369.360**	371.4	370	370.2	370.6	371.4	**370.720**
Tmax	**(K)**	2071.3	2091.2	1974.5	2035.8	2031.8	**2040.920**	1912.6	1881.5	1946.4	1927.2	1937.9	**1921.120**
Position of Tmax	**(°CA)**	380.6	380	377.2	380.4	380	**379.640**	381.4	381.8	382	380.4	382.2	**381.560**
Mech Efficiency	**(%)**	58.9	54.6	59.7	56.9	54.7	**56.960**	58.1	59.3	54.6	57.3	54.4	**56.740**
ITE	**(%)**	51	54.3	49.8	52.8	54	**52.380**	54.7	52.2	57	53.7	56.7	**54.860**
BTE	**(%)**	30	29.7	29.8	30	29.6	**29.820**	31.8	30.9	31.1	30.9	30.8	**31.100**
Volumetric Efficiency	**(%)**	81	81.1	81	81.1	81.3	**81.100**	85.5	85.3	85.3	85.6	85.3	**85.400**

45 Nm DME HP		1700 rpm					1800 rpm					
File name		dm290735	dm290736	dm290738	dm290740	**Average**	dm290741	dm290742	dm290743	dm290744	dm290745	**Average**
speed	**(rpm)**	1702.8	1702.8	1707.7	1707.7	**1705.250**	1800	1800	1800	1800	1800	**1800.000**
Load	**(Nm)**	44.1	44.5	44	44.9	**44.375**	44.4	45.9	46.1	45.3	45.2	**45.380**
Brake Power	**(W)**	7864	7936.7	7862.1	8032.2	**7923.750**	8364	8645.7	8696.9	8543.3	8517.7	**8553.520**
Ind. work per Cycle	**(J)**	501.2	474.8	472.4	489.8	**484.550**	479.8	507.3	496.1	442.8	508.9	**486.980**
Indicated Power	**(W)**	14223.9	13474.3	13444.3	13941.4	**13770.975**	14393	15218.1	14882.3	13283.5	15266.1	**14608.600**
imep	**(kPa)**	753.7	713.9	710.3	736.6	**728.625**	721.4	762.8	746	665.8	765.2	**732.240**
bmep	**(kPa)**	416.7	420.5	415.4	424.4	**419.250**	419.2	433.4	435.9	428.2	426.9	**428.720**
Equivalence Ratio		0.567	0.569	0.57	0.0568	**0.441**	0.567	0.57	0.571	0.572	0.578	**0.572**
Air/fuel ratio		17.06	17.05	17.09	17.05	**17.063**	17.04	17.01	17.01	16.99	17.03	**17.016**
Air Flow	**(g/s)**	15.19	15.177	15.213	15.177	**15.189**	16.072	16.044	16.044	16.029	16.064	**16.051**
Fuel Flow	**(g/s)**	0.89	0.89	0.89	0.89	**0.890**	0.94	0.94	0.94	0.94	0.94	**0.940**
Additive Flow	**(g/s)**	0	0	0	0	**0.000**	0	0	0	0	0	**0.000**
Percentage DME	**(%)**	0	0	0	0	**0.000**	0	0	0	0	0	**0.000**
Fuel Conv. Eff.	**(%)**	31.1	31.4	31.1	31.7	**31.325**	31.2	32.2	32.4	31.9	31.8	**31.900**
isfc	**(kg/J)**	6.26E-08	6.61E-08	6.62E-08	6.39E-08	**6.47E-08**	6.55E-08	6.20E-08	6.34E-08	7.10E-08	6.18E-08	**6.47E-08**
bsfcf	**(kg/J)**	1.13E-07	1.12E-07	1.13E-07	1.11E-06	**3.62E-07**	1.13E-07	1.09E-07	1.08E-07	1.10E-07	1.11E-07	**1.10E-07**
Injection	**(°CA)**	359.1	357.7	359.1	357.5	**358.350**	360.1	361.3	360.5	361.1	360.1	**360.620**
Ignition	**(°CA)**	359.5	357.7	360.7	357.5	**358.850**	362.3	361.3	365.9	361.1	360.1	**362.140**
Ignition delay	**(°CA)**	0.4	0	1.6	0	**0.500**	2.2	0	5.4	0	0	**1.520**
Patm	**(kPa)**	83.1	83.1	83	83.1	**83.075**	83	83	83	83	83	**83.000**
Exhaust Temperature	**(°C)**	562.4	567.7	564.8	559	**563.475**	598.9	598	603.7	599.4	599.4	**599.880**
Pmax	**(kPa)**	5590.9	5522.5	5366.2	5600.6	**5520.050**	5297.9	5166	5258.8	5253.9	5390.6	**5273.440**
Position of Pmax	**(°CA)**	369.4	369.8	371.8	371.2	**370.550**	372.2	373.8	369.2	370.8	372.2	**371.640**
Tmax	**(K)**	2042.2	1951.6	1988	1993.9	**1993.925**	1999.5	2027.1	1992.7	1935.4	2009.8	**1992.900**
Position of Tmax	**(°CA)**	383.4	381.4	382.4	383.9	**382.775**	384	387.4	385.6	386.2	388.2	**386.280**
Mech Efficiency	**(%)**	55.3	58.9	58.5	57.6	**57.575**	58.1	56.8	58.4	64.3	55.8	**58.680**
ITE	**(%)**	56.2	53.2	53.1	55.1	**54.400**	53.7	56.7	55.5	49.5	56.9	**54.460**
BTE	**(%)**	31.1	31.4	31.1	31.7	**31.325**	31.2	32.2	32.4	31.9	31.8	**31.900**
Volumetric Efficiency	**(%)**	80.5	80.4	80.4	80.2	**80.375**	80.6	80.4	80.4	80.3	80.5	**80.440**

E.3 Diesel

25 Nm Diesel		1100 rpm						1200 rpm					
File name		di260711	di260712	di260713	di260714	di260715	**Average**	di260706	di260707	di260708	di260709	di260710	**Average**
speed	**(rpm)**	1100.3	1100.3	1100.3	1100.3	1100.3	**1100.300**	1212	1197.5	1197.5	1197.5	1197.5	**1200.400**
Load	**(Nm)**	25.8	24.4	24.8	25.2	25.5	**25.140**	24.8	24.4	24.4	24.8	24.7	**24.620**
Brake Power	**(W)**	2968.4	2811.9	2858.8	2905.8	2937.1	**2896.400**	3149.2	3060.3	3060.3	3111.4	2094.3	**2895.100**
Ind. work per Cycle	**(J)**	324.7	316.6	295.7	279.1	282.4	**299.700**	334.8	346.6	346	346.7	334.5	**341.720**
Indicated Power	**(W)**	5954.6	5805.3	542.4	5118.5	5178.3	**4519.820**	6763.6	6917.6	6905.8	6920.3	6675.6	**6836.580**
imep	**(kPa)**	488.3	476.1	444.6	419.7	424.6	**450.660**	503.5	521.2	520.3	521.4	503	**513.880**
bmep	**(kPa)**	243.4	230.6	234.4	238.3	240.9	**237.520**	234.4	230.6	230.6	234.4	233.1	**232.620**
Equivalence Ratio		0.776	0.739	0.733	0.724	0.73	**0.740**	0.607	0.699	0.628	0.651	0.648	**0.647**
Air/fuel ratio		19.24	20.2	20.41	20.63	20.49	**20.194**	24.66	21.49	23.86	22.94	23.08	**23.206**
Air Flow	**(g/s)**	10.992	10.963	10.982	11.004	11.024	**10.993**	11.63	11.562	11.592	11.582	11.544	**11.582**
Fuel Flow	**(g/s)**	0.57	0.54	0.54	0.53	0.54	**0.544**	0.47	0.54	0.49	0.5	0.5	**0.500**
Additive Flow	**(g/s)**	0	0	0	0	0	**0.000**	0	0	0	0	0	**0.000**
Percentage DME	**(%)**	0	0	0	0	0	**0.000**	0	0	0	0	0	**0.000**
Fuel Conv. Eff.	**(%)**	11.9	11.9	12.2	12.5	12.5	**12.200**	15.3	13	14.4	14.1	14.2	**14.200**
isfc	**(kg/J)**	9.59E-08	9.35E-08	9.92E-08	1.04E-07	1.04E-07	**9.93E-08**	6.97E-08	7.78E-08	7.04E-08	7.29E-08	7.49E-08	**7.31E-08**
bsfcf	**(kg/J)**	1.92E-07	1.93E-07	1.88E-07	1.84E-07	1.83E-07	**1.88E-07**	1.50E-07	1.76E-07	1.59E-07	1.62E-07	1.62E-07	**1.62E-07**
Injection	**(°CA)**	345.5	352.1	352.3	351.5	352.7	**350.820**	346.5	345.7	346.5	345.9	347.7	**346.460**
Ignition	**(°CA)**	353.9	352.1	352.3	352.9	352.7	**352.780**	352.1	351.7	352.1	351.3	352.1	**351.860**
Ignition delay	**(°CA)**	8.4	0	0	1.4	0	**1.960**	5.6	6	5.6	5.4	4.4	**5.400**
Patm	**(kPa)**	82.5	82.6	82.6	82.6	82.6	**82.580**	82.6	82.5	82.6	82.5	82.6	**82.560**
Exhaust Temperature	**(°C)**	380.1	366.6	366.6	362.8	367.6	**368.740**	398.8	397.9	392.6	389.7	388.7	**393.540**
Pmax	**(kPa)**	7035.7	7265.2	7309.1	7270.1	7333.5	**7242.720**	6967.3	7123.6	7016.2	7011.3	6982	**7020.080**
Position of Pmax	**(°CA)**	365	364.4	363.6	363.2	363.4	**363.920**	365	365.4	364.6	365.2	364.6	**364.960**
Tmax	**(K)**	1871.4	1911.2	1909.6	1901.2	1927.1	**1904.100**	1910.8	1967.9	1930.5	1932.9	1935.9	**1935.600**
Position of Tmax	**(°CA)**	368.4	367.4	365.8	365	366.6	**366.640**	367.4	367.8	368.2	368.4	368.2	**368.000**
Mech Efficiency	**(%)**	49.9	48.4	52.7	56.8	56.7	**52.900**	46.6	44.2	44.3	45	46.4	**45.300**
ITE	**(%)**	23.9	24.5	23.1	22	22.1	**23.120**	32.9	29.5	32.6	31.4	30.6	**31.400**
BTE	**(%)**	11.9	11.9	12.2	12.5	12.5	**12.200**	15.3	13	14.4	14.1	14.2	**14.200**
Volumetric Efficiency	**(%)**	90.1	89.9	90.1	90.2	90.4	**90.140**	86.6	87.1	87.3	87.3	87	**87.060**

25 Nm Diesel		1300 rpm						1400 rpm					
File name		di260701	di260702	di060700	di260704	di260705	Average	di210715	di210716	di210717	di210718	di210719	Average
speed	(rpm)	1309.2	1304.4	1304.4	1304.4	1304.4	1305.360	1401.5	1401.5	1396.7	1396.7	1401.5	1399.580
Load	(Nm)	25.4	24.7	24.9	25.8	24.4	25.040	24.5	24.4	24.9	24.7	24.9	24.680
Brake Power	(W)	3476.3	3370.6	3407.7	3519	3333.5	3421.420	3601.8	3581.8	3648.9	3609.2	3661.6	3620.660
Ind. work per Cycle	(J)	376	376.1	359.4	354.3	355.6	364.280	318.8	332.8	352.6	334.8	328.3	333.460
Indicated Power	(W)	8203.8	8176.9	7812.7	7702	7730.8	7925.240	7446.4	7774	8207.8	7793.3	7668.9	7778.080
imep	(kPa)	565.4	565.6	540.4	532.8	534.8	547.800	479.4	500.5	530.2	503.4	493.7	501.440
bmep	(kPa)	239.6	233.1	235.7	243.4	230.6	236.480	231.9	230.6	235.7	233.1	235.7	233.400
Equivalence Ratio		0.669	0.67	0.676	0.667	0.664	0.669	0.631	0.616	0.614	0.608	0.621	0.618
Air/fuel ratio		22.33	22.32	22.1	22.38	22.55	22.336	23.69	24.3	24.37	24.6	24.15	24.222
Air Flow	(g/s)	12.016	12.007	11.997	12.043	12.024	12.017	12.631	12.615	12.65	12.65	12.647	12.639
Fuel Flow	(g/s)	0.54	0.54	0.54	0.54	0.53	0.538	0.53	0.52	0.52	0.51	0.52	0.520
Additive Flow	(g/s)	0	0	0	0	0	0.000	0	0	0	0	0	0.000
Percentage DME	(%)	0	0	0	0	0	0.000	0	0	0	0	0	0.000
Fuel Conv. Eff.	(%)	14.8	14.4	14.4	15	14.3	14.580	15.5	15.8	16.1	16.1	16.1	15.920
isfc	(kg/J)	6.56E-08	6.58E-08	6.95E-08	6.99E-08	6.90E-08	6.79E-08	7.16E-08	6.68E-08	6.32E-08	6.60E-08	4.83E-08	6.32E-08
bsfcf	(kg/J)	1.55E-07	1.60E-07	1.59E-07	1.53E-07	1.60E-07	1.57E-07	1.48E-07	1.45E-07	1.42E-07	1.43E-07	1.43E-07	1.44E-07
Injection	(°CA)	348.1	345.9	347.1	345.3	346.1	346.500	348.1	344.5	346.9	347.7	346.9	346.820
Ignition	(°CA)	352.5	355.3	351.9	353.5	354.5	353.540	352.5	351.3	355.3	352.7	355.7	353.500
Ignition delay	(°CA)	4.4	9.4	4.8	8.2	8.4	7.040	4.4	6.8	8.4	5	8.8	6.680
Patm	(kPa)	82.6	82.6	82.6	82.6	82.6	82.600	83.1	83.1	83.1	83.1	83.1	83.100
Exhaust Temperature	(°C)	421.4	416.6	417.1	412.8	410.4	415.660	421.4	421	421.4	419.5	425.3	421.720
Pmax	(kPa)	6855	7006.4	6816	7006.4	7069.9	6950.740	6977.6	7387.8	7177.8	7114.4	7368.2	7205.160
Position of Pmax	(°CA)	365.2	365.2	365.8	365.4	365	365.320	364.4	363.8	364.6	364.2	364.6	364.320
Tmax	(K)	2012.9	2066.4	1979.7	2036	2051.8	2029.360	2041.7	2129.5	2127.8	2077.6	2163.4	2108.000
Position of Tmax	(°CA)	369.4	368.6	369.6	368.2	368.4	368.840	367.2	366	369.8	368.6	366.6	367.640
Mech Efficiency	(%)	42.4	41.2	43.6	45.7	43.1	43.200	48.4	46.1	44.5	46.3	47.7	46.600
ITE	(%)	35	34.9	33	32.8	33.2	33.780	32	34.4	36.3	34.8	33.6	34.220
BTE	(%)	14.8	14.4	14.4	15	14.3	14.580	15.5	15.8	16.1	16.1	16	15.900
Volumetric Efficiency	(%)	82.8	83.1	83	83.3	83.2	83.080	81.3	81.2	81.7	81.7	81.4	81.460

25 Nm Diesel		1500 rpm						1600 rpm					
File name		di210720	di210721	di210722	di210723	di210724	Average	di210726	di210727	di210728	di210729	di210730	Average
speed	(rpm)	1503.6	1503.6	1503.6	1503.6	1503.6	1503.600	1600.8	1600.8	1600.8	1600.8	1600.8	1600.800
Load	(Nm)	24.8	25.1	25.2	25.1	24.9	25.020	24.3	25.8	25.9	25.2	24.7	25.180
Brake Power	(W)	3906.8	3949.6	3971	3949.6	3928.2	3941.040	4068.2	4318.7	4341.5	4227.6	4136.5	4218.500
Ind. work per Cycle	(J)	336.7	310.3	307.2	299.6	314.7	313.700	225.7	282.4	259.4	244	243.8	251.060
Indicated Power	(W)	8437.8	7776.7	7697.8	7508.5	7886	7861.360	6022.5	7535.3	6921.2	6509.6	6504.6	6698.640
imep	(kPa)	506.3	466.7	461.9	450.6	473.2	471.740	339.4	424.7	390.1	366.9	366.6	377.540
bmep	(kPa)	234.4	237	238.3	237	235.7	236.480	229.3	243.4	244.7	238.3	233.1	237.760
Equivalence Ratio		0.608	0.612	0.614	0.611	0.611	0.611	0.626	0.628	0.626	0.627	0.621	0.626
Air/fuel ratio		24.63	24.9	24.33	24.47	24.48	24.562	23.85	23.83	23.91	23.88	24.09	23.912
Air Flow	(g/s)	14.068	14.108	14.131	14.091	14.099	14.099	15.43	15.423	15.473	15.452	15.473	15.450
Fuel Flow	(g/s)	0.57	0.57	0.58	0.58	0.58	0.576	0.65	0.65	0.65	0.65	0.64	0.648
Additive Flow	(g/s)	0	0	0	0	0	0.000	0	0	0	0	0	0.000
Percentage DME	(%)	0	0	0	0	0	0.000	0	0	0	0	0	0.000
Fuel Conv. Eff.	(%)	15.7	16	15.7	15.7	15.6	15.740	14.4	15.3	15.4	15	14.8	14.980
isfc	(kg/J)	6.77E-08	7.28E-08	7.54E-08	7.67E-08	7.30E-08	7.31E-08	1.07E-07	8.59E-08	9.35E-08	9.94E-08	9.87E-08	9.70E-08
bsfcf	(kg/J)	1.46E-07	1.43E-07	1.46E-07	1.46E-07	1.47E-07	1.46E-07	1.59E-07	1.50E-07	1.49E-07	1.53E-07	1.55E-07	1.53E-07
Injection	(°CA)	346.7	346.1	347.5	346.5	348.7	347.100	346.1	346.7	346.7	346.3	346.5	346.460
Ignition	(°CA)	355.3	351.3	352.1	355.5	352.9	353.420	350.9	352.5	352.5	351.5	351.3	351.740
Ignition delay	(°CA)	8.6	5.2	4.6	9	4.2	6.320	4.8	5.8	5.8	5.2	4.8	5.280
Patm	(kPa)	83.1	83.1	83.1	83.1	83.1	83.100	83	83	83	83	83	83.000
Exhaust Temperature	(°C)	433.5	432.5	431.1	431.5	433	432.320	436.8	437.8	438.8	441.6	438.3	438.660
Pmax	(kPa)	7588	7724.7	7495.2	7490.3	7334.1	7526.460	7558.6	7710	7597.7	7622.1	7812.5	7660.180
Position of Pmax	(°CA)	364.6	364.2	364	364	366.6	364.680	362.6	363.8	363.8	364	364	363.640
Tmax	(K)	2155.4	2116.9	2083.1	2133.3	2109.6	2119.660	2005.7	2076.8	2047.7	2043.2	2091.1	2052.900
Position of Tmax	(°CA)	368.2	367	366.8	367.8	369.2	367.800	364.8	368.2	366.6	367.6	365.6	366.560
Mech Efficiency	(%)	46.3	50.8	51.6	52.6	49.8	50.220	67.6	57.3	62.7	64.9	63.6	63.220
ITE	(%)	33.9	31.5	30.4	29.9	31.4	31.420	21.3	26.7	24.5	23.1	23.2	23.760
BTE	(%)	15.7	16	15.7	15.7	15.6	15.740	14.4	15.3	15.4	15	14.8	14.980
Volumetric Efficiency	(%)	84.4	84.7	84.8	84.6	84.6	84.620	87	86.9	87.2	87.1	87.2	87.080

25 Nm Diesel		**1700 rpm**						**1800 rpm**					
File name		di210731	di210732	di210733	di210734	di210735	**Average**	di210736	di210737	di210738	di210739	di210740	**Average**
speed	**(rpm)**	1698	1702.8	1702.8	1702.8	1702.8	**1701.840**	1800	1800	1800	1800	1800	**1800.000**
Load	**(Nm)**	24.7	24.7	25.1	24.7	25.5	**24.940**	24.9	24.4	25.6	24.3	24.8	**24.800**
Brake Power	**(W)**	4387.7	4400.2	4472.9	4400.2	4545.6	**4441.320**	4702.6	4600.2	4830.6	4574.6	4677	**4677.000**
Ind. work per Cycle	**(J)**	255.2	268.5	272.1	209.2	242.6	**249.520**	213.4	229.8	258.8	258.2	217.1	**235.460**
Indicated Power	**(W)**	7221	7621.5	7722.3	5937.6	6886	**7077.680**	6402.1	6894.4	7763.6	7745.9	6513	**7063.800**
imep	**(kPa)**	383.7	403.8	409.2	314.6	364.9	**375.240**	320.9	345.6	389.1	388.3	326.5	**354.080**
bmep	**(kPa)**	233.1	233.1	237	233.1	240.9	**235.440**	325.7	230.6	242.1	229.3	234.4	**252.420**
Equivalence Ratio		0.655	0.62	0.622	0.628	0.669	**0.639**	0.609	0.593	0.6	0.631	0.604	**0.607**
Air/fuel ratio		22.87	24.11	24.08	23.8	22.31	**23.434**	24.52	25.28	24.9	23.81	24.87	**24.676**
Air Flow	**(g/s)**	15.559	15.602	15.695	15.516	15.493	**15.573**	16.33	16.357	16.35	16.309	16.33	**16.335**
Fuel Flow	**(g/s)**	0.68	0.65	0.65	0.65	0.69	**0.664**	0.67	0.65	0.66	0.68	0.66	**0.664**
Additive Flow	**(g/s)**	0	0	0	0	0	**0.000**	0	0	0	0	0	**0.000**
Percentage DME	**(%)**	0	0	0	0	0	**0.000**	0	0	0	0	0	**0.000**
Fuel Conv. Eff.	**(%)**	14.8	15.6	15.7	15.5	15	**15.320**	16.2	16.3	16.9	15.3	16.3	**16.200**
isfc	**(kg/J)**	9.42E-08	8.49E-08	8.44E-08	1.10E-07	1.01E-07	**9.48E-08**	1.04E-07	9.39E-08	8.46E-08	8.84E-08	1.01E-07	**9.43E-08**
bsfcf	**(kg/J)**	1.55E-07	1.47E-07	1.46E-07	1.48E-07	1.53E-07	**1.50E-07**	1.42E-07	1.41E-07	1.36E-07	1.50E-07	1.40E-07	**1.42E-07**
Injection	**(°CA)**	347.5	348.1	347.5	346.7	347.1	**347.380**	347.5	348.3	347.7	347.5	347.9	**347.780**
Ignition	**(°CA)**	352.7	356.9	352.1	350.9	352.3	**352.980**	357.7	351.5	353.3	352.9	351.5	**353.380**
Ignition delay	**(°CA)**	5.2	8.8	4.6	4.2	5.2	**5.600**	10.2	3.2	5.6	5.4	3.6	**5.600**
Patm	**(kPa)**	83	83	83	83	83	**83.000**	83	83	83	83	83	**83.000**
Exhaust Temperature	**(°C)**	457.5	450.3	450.3	454.2	450.8	**452.620**	470.5	471.9	469.5	465.2	464.7	**468.360**
Pmax	**(kPa)**	7739.3	7944.3	8281.3	8247.1	8012.7	**8044.940**	7924.8	7924.8	7880.9	7924.8	7973.6	**7925.780**
Position of Pmax	**(°CA)**	365.4	365	365.4	363.6	364.8	**364.840**	365.8	364.8	365	365.4	363.8	**364.960**
Tmax	**(K)**	2210.3	2312	2332.6	2309.6	2311.7	**2295.240**	2337.6	2288.2	2308.7	2309.6	2275.3	**2303.880**
Position of Tmax	**(°CA)**	366.6	367.4	367.8	366	368.2	**367.200**	368.4	369	369.2	367.8	366.2	**368.120**
Mech Efficiency	**(%)**	60.8	57.7	57.9	74.1	66	**63.300**	73.5	66.7	62.2	59.1	71.8	**66.660**
ITE	**(%)**	24.3	27	27.2	20.9	22.7	**24.420**	22	24.4	27.1	25.9	22.8	**24.440**
BTE	**(%)**	14.8	15.6	15.7	15.5	15	**15.320**	16.2	16.3	16.9	15.3	16.3	**16.200**
Volumetric Efficiency	**(%)**	82.7	82.7	83.2	82.2	82.1	**82.580**	81.9	82	82	81.7	81.9	**81.900**

35 Nm Diesel		1100 rpm						1200 rpm					
File name		di260702	di260703	di260704	di260705	di260706	**Average**	di260708	di260709	di260710	di260711	di260712	**Average**
speed	**(rpm)**	1105.1	1105.1	1100.3	1105.1	1105.1	**1104.140**	1202.3	1197.5	1202.3	1202.3	1202.3	**1201.340**
Load	**(Nm)**	34	33.6	36.8	34.5	35.4	**34.860**	35.7	34.6	34.9	34.6	34.3	**34.820**
Brake Power	**(W)**	3940.4	3893.3	4236.1	3987.6	4097.6	**4031.000**	4492.2	4337.8	4389.6	4355.4	4321.2	**4379.240**
Ind. work per Cycle	**(J)**	361.6	377	379.5	358	356.7	**366.560**	349.3	373.3	354.7	372.3	331.4	**356.200**
Indicated Power	**(W)**	6660.2	6943.4	6958.6	6594.4	6569.4	**6745.200**	7000	7451.1	7106.8	7460.9	6641.7	**7132.100**
imep	**(kPa)**	543.8	566.9	570.6	538.4	536.3	**551.200**	525.3	561.4	533.3	559.9	498.4	**535.660**
bmep	**(kPa)**	321.7	317.9	347.4	325.6	334.5	**329.420**	337.1	326.8	329.4	326.8	324.3	**328.880**
Equivalence Ratio		0.917	0.94	1.016	0.936	0.941	**0.950**	0.923	0.858	0.833	0.838	0.85	**0.860**
Air/fuel ratio		16.3	15.87	14.69	15.97	15.87	**15.740**	16.19	17.45	17.95	17.82	17.85	**17.452**
Air Flow	**(g/s)**	11.394	11.324	11.246	11.246	11.246	**11.291**	11.625	11.625	11.702	11.615	11.625	**11.638**
Fuel Flow	**(g/s)**	0.7	0.71	0.77	0.7	0.71	**0.718**	0.72	0.67	0.65	0.65	0.66	**0.670**
Additive Flow	**(g/s)**	0	0	0	0	0	**0.000**	0	0	0	0	0	**0.000**
Percentage DME	**(%)**	0	0	0	0	0	**0.000**	0	0	0	0	0	**0.000**
Fuel Conv. Eff.	**(%)**	12.9	12.5	12.7	13	13.3	**12.880**	14.3	14.9	15.4	15.3	15	**14.980**
isfc	**(kg/J)**	1.05E-07	1.03E-07	1.10E-07	1.07E-07	1.08E-07	**1.06E-07**	1.03E-07	8.94E-08	9.17E-08	8.74E-08	9.96E-08	**9.41E-08**
bsfcf	**(kg/J)**	1.77E-07	8.33E-06	8.07E-07	1.77E-07	1.73E-07	**1.93E-06**	5.99E-07	1.54E-07	1.48E-07	1.50E-07	1.53E-07	**2.41E-07**
Injection	**(°CA)**	350.5	351.5	350.7	351.5	351.5	**351.140**	352.9	353.9	293.3	352.7	352.1	**340.980**
Ignition	**(°CA)**	350.5	351.7	350.7	351.5	351.5	**351.180**	352.9	353.9	297.1	352.4	352.1	**341.680**
Ignition delay	**(°CA)**	0	0.2	0	0	0	**0.040**	0	0	3.8	0	0	**0.760**
Patm	**(kPa)**	82.6	82.6	82.6	82.6	82.6	**82.600**	82.6	82.6	82.6	82.6	82.6	**82.600**
Exhaust Temperature	**(°C)**	375.8	376.7	401.7	387.3	387.3	**385.760**	406.1	398.8	404.1	399.8	404.6	**402.680**
Pmax	**(kPa)**	7441	7475.2	7450.8	7289.7	7260.4	**7383.420**	7255.5	7387.3	7499.6	7509.4	7826.8	**7495.720**
Position of Pmax	**(°CA)**	363.4	363.4	364.4	363.6	364	**363.760**	363.8	363.6	363.6	363.6	361.6	**363.240**
Tmax	**(K)**	1853	1903.2	1897.3	1863.9	1863.9	**1876.260**	1961.8	2016	1951.2	2016.4	2037.9	**1996.660**
Position of Tmax	**(°CA)**	367	369.4	366.8	368.2	370.6	**368.400**	368.2	370.4	366	367.2	363	**366.960**
Mech Efficiency	**(%)**	59.2	56.1	60.9	60.5	62.4	**59.820**	64.2	58.2	61.8	58.4	65.1	**61.540**
ITE	**(%)**	21.8	22.3	20.8	21.5	12.3	**19.740**	22.4	25.7	25	26.3	23	**24.480**
BTE	**(%)**	12.9	12.5	12.7	13	13.3	**12.880**	14.3	14.9	15.41	**15.3**	15	**14.982**
Volumetric Efficiency	**(%)**	93	92.5	92.2	91.8	91.8	**92.260**	87.2	87.6	87.8	87.2	87.2	**87.400**

35 Nm Diesel		1300 rpm						1400 rpm					
File name		di260720	di260721	di260722	di260723		**Average**	di260724	di260725	di260726	di260727	di260728	**Average**
speed	**(rpm)**	1304.4	1304.4	1304.4	1304.4		**1304.400**	1401.5		1401.5	1401.5	1401.5	**1401.500**
Load	**(Nm)**	34.6	35.5	34.3	34.6		**34.750**	35.3		34.9	34.9	34.9	**35.000**
Brake Power	**(W)**	4725	4854.9	4687.9	4725		**4748.200**	5176.8		5117	5117	5117	**5131.950**
Ind. work per Cycle	**(J)**	428.8	418.9	443	416.5		**426.800**	444.4		425	411.3	399.4	**420.025**
Indicated Power	**(W)**	9322.3	9107.1	9631.1	9054.3		**9278.700**	10379.7		9927.7	9607.6	9330.6	**9811.400**
imep	**(kPa)**	644.8	630	666.2	626.3		**641.825**	668.2		639.1	618.5	600.7	**631.625**
bmep	**(kPa)**	326.8	335.8	324.3	326.8		**328.425**	333.3		329.4	329.4	329.4	**330.375**
Equivalence Ratio		0.825	0.813	0.8	0.762		**0.800**	0.842		0.823	0.797	0.799	**0.815**
Air/fuel ratio		18.15	18.56	19.04	19.67		**18.855**	17.76		18.4	18.79	18.7	**18.413**
Air Flow	**(g/s)**	12.263	12.272	12.228	12.264		**12.257**	12.585		12.602	12.513	12.54	**12.560**
Fuel Flow	**(g/s)**	0.68	0.66	0.64	0.62		**0.650**	0.71		0.68	0.67	0.67	**0.683**
Additive Flow	**(g/s)**	0	0	0	0		**0.000**	0		0	0	0	**0.000**
Percentage DME	**(%)**	0	0	0	0		**0.000**	0		0	0	0	**0.000**
Fuel Conv. Eff.	**(%)**	16	16.8	16.7	17.4		**16.725**	16.8		17.1	17.6	17.5	**17.250**
isfc	**(kg/J)**	7.25E-08	7.26E-08	6.67E-08	6.88E-08		**7.02E-08**	6.83E-08		6.90E-07	6.93E-08	7.19E-08	**2.25E-07**
bsfcf	**(kg/J)**	1.43E-07	1.36E-06	1.37E-07	1.32E-07		**4.44E-07**	1.37E-07		1.34E-07	1.30E-07	1.31E-07	**1.33E-07**
Injection	**(°CA)**	345.1	344.7	346.1	345.5		**345.350**	347.5		348.5	346.9	345.7	**347.150**
Ignition	**(°CA)**	352.9	352.3	352.1	352.3		**352.400**	356.5		353.7	353.3	351.3	**353.700**
Ignition delay	**(°CA)**	7.6	7.6	6	6.8		**7.000**	9		5.2	6.4	5.6	**6.550**
Patm	**(kPa)**	82.6	82.6	82.6	82.6		**82.600**	82.6		82.6	82.6	82.6	**82.600**
Exhaust Temperature	**(°C)**	408.5	409.9	417.6	419		**413.750**	432.5		436.4	438.3	436.4	**435.900**
Pmax	**(kPa)**	7196.8	7108.9	7138.3	7201.7		**7161.425**	7079.6		7079.6	7074.7	7333.5	**7141.850**
Position of Pmax	**(°CA)**	365.4	364.8	366	365		**365.300**	366.4		365.4	366.2	364.8	**365.700**
Tmax	**(K)**	2071.5	2027.8	2085.9	2049.3		**2058.625**	2175.6		2125.2	2135.4	2165.4	**2150.400**
Position of Tmax	**(°CA)**	371.6	370.4	370.6	369.6		**370.550**	372.6		371	369.8	369	**370.600**
Mech Efficiency	**(%)**	50.7	53.3	48.7	52.2		**51.225**	49.9		51.5	53.3	54.8	**52.375**
ITE	**(%)**	31.7	31.6	34.4	33.3		**32.750**	33.6		33.2	33.1	31.9	**32.950**
BTE	**(%)**	16	16.8	16.7	17.4		**16.725**	16.8		17.1	**17.6**	17.5	**17.250**
Volumetric Efficiency	**(%)**	84.8	84.9	84.6	84.8		**84.775**	81		81.1	80.6	80.7	**80.850**

35 Nm Diesel		1500 rpm						1600 rpm					
File name		di260729	di260730	di260731	di260732	di260733	Average	di230700	di230701	di230702	di230703		Average
speed	(rpm)	1498.7	1493.9	1498.7	1498.7	1498.7	1497.740	1600.8	1600.8	1600.8	1600.8		1600.800
Load	(Nm)	35.4	34.5	34.5	33.9	34.6	34.580	36.2	34.7	35.4	34.6		35.225
Brake Power	(W)	5557	5390.3	5407.8	5322.5	5429.1	5421.340	6072	5821.6	5935.4	5798.8		5906.950
Ind. work per Cycle	(J)	417.5	414.2	390.8	360.1	402	396.920	506.2	525.6	507.9	489.9		507.400
Indicated Power	(W)	10428.8	10313.4	9760.9	9743.7	10042.7	10057.900	13505.9	14023.1	13551.7	13071.4		13538.025
imep	(kPa)	627.8	622.9	587.6	586.6	604.6	605.900	761.2	790.4	763.8	736.7		763.025
bmep	(kPa)	334.5	325.6	325.6	320.4	326.8	326.580	342.2	328.1	334.5	326.8		332.900
Equivalence Ratio		0.848	0.819	0.812	0.813	0.81	0.820	0.784	0.741	0.772	0.8		0.774
Air/fuel ratio		17.74	18.25	18.39	18.38	18.59	18.270	19.07	20.19	19.38	18.7		19.335
Air Flow	(g/s)	13.748	13.715	13.731	13.722	13.707	13.725	15.776	15.647	15.662	15.555		15.660
Fuel Flow	(g/s)	0.78	0.75	0.75	0.75	0.74	0.754	0.83	0.78	0.81	0.83		0.813
Additive Flow	(g/s)	0	0	0	0	0	0.000	0	0	0	0		0.000
Percentage DME	(%)	0	0	0	0	0	0.000	0	0	0	0		0.000
Fuel Conv. Eff.	(%)	16.4	16.5	16.6	16.4	16.9	16.560	16.8	17.2	16.8	16		16.700
isfc	(kg/J)	7.43E-08	7.29E-08	7.65E-08	7.66E-08	7.34E-08	7.47E-08	6.12E-08	5.53E-08	5.96E-08	6.36E-08		6.00E-08
bsfcf	(kg/J)	1.39E-07	1.39E-07	1.38E-07	1.40E-07	1.36E-07	1.39E-07	1.36E-07	1.33E-07	1.36E-07	1.43E-07		1.37E-07
Injection	(°CA)	354.5	347.1	346.1	347.1	345.3	348.020	345.7	346.1	346.1	346.5		346.100
Ignition	(°CA)	354.7	352.7	352.5	352.3	351.1	352.660	353.5	352.9	353.9	352.9		353.300
Ignition delay	(°CA)	0.2	5.6	6.4	5.2	5.8	4.640	7.9	6.8	7.8	6.4		7.225
Patm	(kPa)	82.6	82.6	82.6	82.6	82.6	82.600	83	83	83	83		83.000
Exhaust Temperature	(°C)	459.4	454.2	453.7	454.6	454.2	455.220	454.2	448.9	459.9	478.2		460.300
Pmax	(kPa)	7431.2	7240.8	7445.9	7201.7	7445.9	7353.100	7304.7	7382.8	7314.5	7309.6		7327.900
Position of Pmax	(°CA)	365	365.4	365	365	364.6	365.000	366.8	367	366.8	366		366.650
Tmax	(K)	2192.5	2132.9	2166	2096.1	2170.5	2151.600	2040.2	2123.2	2120.2	2083.1		2091.675
Position of Tmax	(°CA)	371	369.6	367.8	370.8	370.4	369.920	373.4	374.4	375.6	375.6		374.750
Mech Efficiency	(%)	53.3	52.3	55.4	54.6	54.1	53.940	45	41.5	43.8	44.4		43.675
ITE	(%)	30.9	31.5	30	29.9	31.2	30.700	37.4	41.5	38.5	36		38.350
BTE	(%)	16.4	16.5	16.6	16.4	16.9	16.560	16.8	17.2	16.8	16		16.700
Volumetric Efficiency	(%)	82.8	82.8	82.7	82.6	82.5	82.680	88.9	88.2	88.3	87.7		88.275

35 Nm Diesel		1700 rpm						1800 rpm					
File name		di230704	di230705	di230706	di230707	di230708	**Average**	di230710	di320711	di230712	di230713	di230715	**Average**
speed	**(rpm)**	1698	1698	1698	1702.8	1698	**1698.960**	1800	1800	1800	1800	1800	**1800.000**
Load	**(Nm)**	34.9	34.6	34	35.4	35	**34.780**	34.9	35	35	35.5	34.9	**35.060**
Brake Power	**(W)**	6199.2	6150.8	6054.2	6313.8	6223.3	**6188.260**	6571.7	6597.3	6597.3	6699.7	6571.7	**6607.540**
Ind. work per Cycle	**(J)**	479.3	505	507.3	478	505.2	**494.960**	525.6	502.5	492.8	473.2	478.2	**494.460**
Indicated Power	**(W)**	13564.4	14291.5	14355.8	13566	14296.5	**14014.840**	15767	15074	14783	14195.8	14345.9	**14833.140**
imep	**(kPa)**	720.8	759.4	762.8	718.8	759.7	**744.300**	790.3	755.6	741	711.6	719.1	**743.520**
bmep	**(kPa)**	329.4	326.8	321.7	334.5	330.7	**328.620**	329.4	330.7	330.7	335.8	329.4	**331.200**
Equivalence Ratio		0.809	0.724	0.711	0.747	0.754	**0.749**	0.729	0.749	0.751	0.747	0.739	**0.743**
Air/fuel ratio		18.48	20.65	21.06	19.99	19.83	**20.002**	20.5	19.93	19.93	20.08	20.21	**20.130**
Air Flow	**(g/s)**	15.634	15.713	15.627	15.591	15.648	**15.643**	16.469	16.395	16.395	16.42	16.332	**16.402**
Fuel Flow	**(g/s)**	0.85	0.76	0.74	0.78	0.79	**0.784**	0.8	0.82	0.82	0.82	0.81	**0.814**
Additive Flow	**(g/s)**	0	0	0	0	0	**0.000**	0	0	0	0	0	**0.000**
Percentage DME	**(%)**	0	0	0	0	0	**0.000**	0	0	0	0	0	**0.000**
Fuel Conv. Eff.	**(%)**	16.8	18.5	18.7	18.6	18.1	**18.140**	18.8	18.4	18.4	18.8	18.6	**18.600**
isfc	**(kg/J)**	6.24E-08	5.32E-08	5.17E-08	5.75E-08	5.52E-08	**5.60E-08**	5.10E-08	5.46E-08	5.56E-08	5.76E-08	5.63E-08	**5.50E-08**
bsfcf	**(kg/J)**	1.37E-07	1.24E-07	1.23E-07	1.24E-07	1.27E-07	**1.27E-07**	1.22E-07	1.25E-07	1.25E-07	1.22E-07	1.23E-07	**1.23E-07**
Injection	**(°CA)**	345.7	346.7	346.5	346.7	346.5	**346.420**	346.9	347.5	347.5	347.1	348.5	**347.500**
Ignition	**(°CA)**	352.5	352.9	352.9	351.7	351.9	**352.380**	353.5	356.1	357.1	352.7	357.9	**355.460**
Ignition delay	**(°CA)**	6.8	6.2	6.4	5	5.4	**5.960**	6.6	8.6	9.6	5.6	9.4	**7.960**
Patm	**(kPa)**	83	83	83	83	83	**83.000**	83	83	83	83.1	83.1	**83.040**
Exhaust Temperature	**(°C)**	485.9	476.8	479.2	474.4	474.4	**478.140**	490.7	492.1	500.3	498.4	501.3	**496.560**
Pmax	**(kPa)**	7334	7270.5	7251	7163.1	7124.1	**7228.540**	7207.1	7124.1	7172.9	7104.6	7055.7	**7132.880**
Position of Pmax	**(°CA)**	365	365.5	366.8	367	367.6	**366.380**	367.4	366.4	367.2	367.8	366.4	**367.040**
Tmax	**(K)**	2185.2	2181.3	2204.3	2166.4	2186.8	**2184.800**	2251.3	2204.5	2262	2169	2222.2	**2221.800**
Position of Tmax	**(°CA)**	371.4	375.6	375.4	374.2	375.6	**374.440**	376.4	372.2	375.8	375.4	374.6	**374.880**
Mech Efficiency	**(%)**	45.7	43	42.2	45.6	43.5	**44.000**	41.7	43.8	44.6	47.2	45.8	**44.620**
ITE	**(%)**	36.8	43.1	44.4	39.9	41.5	**41.140**	45	42	41.2	39.8	40.7	**41.740**
BTE	**(%)**	16.8	18.5	**18.7**	**18.6**	18.1	**18.140**	18.8	18.4	**18.4**	**18.8**	18.6	**18.600**
Volumetric Efficiency	**(%)**	83.1	83.5	83	82.6	83.2	**83.080**	82.6	82.2	82.2	82.3	81.9	**82.240**

45Nm Diesel		1100 rpm						1200 rpm					
File name		dm060801	dm060802	dm060803	dm060804	dm060805	**Average**	dm060807	dm060808	dm060809	dm060810	dm060811	**Average**
speed	**(rpm)**	1100.3	1105.1	1105.1	1105.1	1105.1	**1104.140**	1202.3	1202.3	1202.3	1202.3	1202.3	**1202.300**
Load	**(Nm)**	47	45.5	46.1	46.5	46	**46.220**	45.9	44.8	46	46	45.5	**45.640**
Brake Power	**(W)**	5409.9	5260.9	5339.5	5386.7	5323.8	**5344.160**	5774.9	5638.1	5792	5792	5723.6	**5744.120**
Ind. work per Cycle	**(J)**	430.5	451.3	438.3	446.4	469.8	**447.260**	399.6	413.2	430.6	435.1	455.4	**426.780**
Indicated Power	**(W)**	7895.2	8313.1	8072.9	8221.3	8653.8	**8231.260**	8008.1	8279.8	8628.2	8719.8	9126.2	**8552.420**
imep	**(kPa)**	647.4	678.7	659.1	671.2	706.5	**672.580**	601	621.3	647.5	654.4	684.9	**641.820**
bmep	**(kPa)**	443.6	429.5	435.9	439.8	434.6	**436.680**	433.4	423.1	434.6	434.6	429.5	**431.040**
Equivalence Ratio		1.005	0.966	0.966	0.953	0.955	**0.969**	1.129	1.147	1.01	1.015	1.012	**1.063**
Air/fuel ratio		14.86	15.45	15.48	15.66	15.68	**15.426**	13.27	13.01	14.79	14.75	14.79	**14.122**
Air Flow	**(g/s)**	11.164	11.094	11.114	11.174	11.184	**11.146**	11.421	11.44	11.46	11.43	11.392	**11.429**
Fuel Flow	**(g/s)**	0.75	0.72	0.72	0.71	0.71	**0.722**	0.86	0.88	0.78	0.78	0.77	**0.814**
Additive Flow	**(g/s)**	0	0	0	0	0	**0.000**	0	0	0	0	0	**0.000**
Percentage DME	**(%)**	0	0	0	0	0	**0.000**	0	0	0	0	0	**0.000**
Fuel Conv. Eff.	**(%)**	16.5	16.8	17.1	17.3	17.1	**16.960**	15.4	14.7	17.1	17.1	17	**16.260**
isfc	**(kg/J)**	9.52E-08	8.64E-08	8.90E-08	8.68E-08	8.24E-08	**8.80E-08**	1.07E-07	1.06E-07	8.98E-08	8.89E-08	8.44E-08	**9.52E-08**
bsfcf	**(kg/J)**	1.39E-07	1.37E-07	1.35E-07	1.32E-07	1.34E-07	**1.35E-07**	1.49E-07	1.56E-07	1.34E-07	1.34E-07	1.35E-07	**1.42E-07**
Injection	**(°CA)**	351.3	351.1	351.5	351.1	350.9	**351.180**	352.1	351.1	352.1	351.9	351.7	**351.780**
Ignition	**(°CA)**	351.3	351.1	351.5	351.1	351.3	**351.260**	352.1	351.3	352.1	351.9	351.7	**351.820**
Ignition delay	**(°CA)**	0	0	0	0	0.4	**0.080**	0	0.2	0	0	0	**0.040**
Patm	**(kPa)**	83.2	83.2	83.2	83.2	83.2	**83.200**	83.2	83.2	83.2	83.2	83.2	**83.200**
Exhaust Temperature	**(°C)**	431.5	449.8	446	446.9	452.2	**445.280**	451.7	481.6	469.1	466.7	466.2	**467.060**
Pmax	**(kPa)**	7592.9	7690.6	7578.3	7588	7632	**7616.360**	7441.6	7422	7343.9	7402.5	7392.7	**7400.540**
Position of Pmax	**(°CA)**	364	364.2	364	364	364.6	**364.160**	363.8	364.4	364	364.2	364.6	**364.200**
Tmax	**(K)**	1969.5	2041.9	1966.7	1988.6	2033.9	**2000.120**	2026.5	2065	2034.3	2086.3	2095	**2061.420**
Position of Tmax	**(°CA)**	368.6	371.8	370	371	373.6	**371.000**	368.6	370.4	369.4	369.8	371.2	**369.880**
Mech Efficiency	**(%)**	68.5	63.3	66.1	65.5	61.5	**64.980**	72.1	68.1	67.1	66.4	62.7	**67.280**
ITE	**(%)**	24.1	26.5	25.8	26.4	27.8	**26.120**	21.3	21.6	25.5	25.8	27.2	**24.280**
BTE	**(%)**	16.5	16.8	17.1	17.3	17.1	**16.960**	15.4	14.7	17.1	**17.1**	17	**16.260**
Volumetric Efficiency	**(%)**	91.5	90.6	90.7	91.2	91.3	**91.060**	85.7	85.9	86	85.8	85.5	**85.780**

45Nm Diesel		**1300 rpm**						**1400 rpm**					
File name		dm060812	dm060813	dm060814	dm060815	dm060816	**Average**	dm060817	dm060818	dm060819	dm060820	dm060821	**Average**
speed	**(rpm)**	1299.5	1299.5	1299.5	1299.5	1299.5	**1299.500**	1411.3	1396.7	1401.5	1396.7	1396.7	**1400.580**
Load	**(Nm)**	44.5	44.2	44.5	44.6	44.6	**44.480**	45.2	44.6	46.1	45.9	45.2	**45.400**
Brake Power	**(W)**	6056.8	6019.9	6056.8	6075.3	6075.3	**6056.820**	6678.1	6529.7	6771.7	6708.5	6609.1	**6659.420**
Ind. work per Cycle	**(J)**	456.4	467.9	495.8	466.8	458.2	**469.020**	461.4	453.7	471.5	493.9	480.3	**472.160**
Indicated Power	**(W)**	9885.4	10134.8	10737.5	10109.2	9923.4	**10158.060**	10852.5	10561.7	11014.1	11496.2	11181.4	**11021.180**
imep	**(kPa)**	686.4	703.7	745.5	701.9	689	**705.300**	693.8	682.3	709	742.6	722.3	**710.000**
bmep	**(kPa)**	420.5	418	420.5	421.8	421.8	**420.520**	426.9	421.8	435.9	433.4	426.9	**428.980**
Equivalence Ratio		0.941	0.895	0.883	0.872	0.872	**0.893**	0.899	0.984	0.977	0.942	0.929	**0.946**
Air/fuel ratio		15.89	16.69	16.9	17.17	17.21	**16.772**	16.64	15.21	15.33	15.86	16.08	**15.824**
Air Flow	**(g/s)**	11.861	11.908	11.898	11.926	11.954	**11.909**	12.427	12.366	12.465	12.445	12.462	**12.433**
Fuel Flow	**(g/s)**	0.75	0.71	0.7	0.69	0.69	**0.708**	0.75	0.81	0.81	0.78	0.78	**0.786**
Additive Flow	**(g/s)**	0	0	0	0	0	**0.000**	0	0	0	0	0	**0.000**
Percentage DME	**(%)**	0	0	0	0	0	**0.000**	0	0	0	0	0	**0.000**
Fuel Conv. Eff.	**(%)**	18.6	19.4	19.7	20.1	20.1	**19.580**	20.5	18.4	19.1	19.6	19.6	**19.440**
isfc	**(kg/J)**	7.55E-08	7.04E-08	6.56E-08	6.87E-08	7.00E-08	**7.00E-08**	6.88E-08	7.70E-08	7.38E-08	6.82E-08	6.93E-08	**7.14E-08**
bsfcf	**(kg/J)**	1.23E-07	1.19E-07	1.16E-07	1.14E-07	1.14E-07	**1.17E-07**	1.12E-07	1.25E-07	1.20E-07	1.17E-07	1.17E-07	**1.18E-07**
Injection	**(°CA)**	351.7	344.3	344.1	343.7	343.7	**345.500**	343.7	353.3	353.7	344.5	344.1	**347.860**
Ignition	**(°CA)**	354.1	351.3	351.7	355.3	350.5	**352.580**	350.5	353.3	356.1	352.3	350.9	**352.620**
Ignition delay	**(°CA)**	2.4	7	7.6	11.6	6.8	**7.080**	6.8	0	2.4	7.8	6.8	**4.760**
Patm	**(kPa)**	83.2	83.2	83.1	83.1	83.1	**83.140**	83.1	83.1	83.1	83.1	83.1	**83.100**
Exhaust Temperature	**(°C)**	471.9	482.5	473.4	475.3	477.2	**476.060**	466.2	474.4	478.7	472.9	471.5	**472.740**
Pmax	**(kPa)**	7524.6	7368.3	7485.5	7529.4	7461.1	**7473.780**	7368.3	7422	7500.1	7514.8	7490.4	**7459.120**
Position of Pmax	**(°CA)**	364.2	365	365.4	364.8	364.6	**364.800**	365.4	365.6	365	366.2	364.8	**365.400**
Tmax	**(K)**	2239.7	2157.8	2241.1	2227.2	2161.4	**2205.440**	2247.2	2253.5	2298.7	2316.1	2264.8	**2276.060**
Position of Tmax	**(°CA)**	369.2	372.8	373.2	371.6	371.4	**371.640**	372.4	370.8	371.2	372.8	373.6	**372.160**
Mech Efficiency	**(%)**	61.3	59.4	56.4	60.1	61.2	**59.680**	61.5	61.8	61.5	58.4	59.1	**60.460**
ITE	**(%)**	30.4	32.6	35	33.4	32.8	**32.840**	33.3	29.8	31.1	33.6	33.1	**32.180**
BTE	**(%)**	18.6	19.4	19.7	20.1	20.1	**19.580**	20.5	18.4	19.1	**19.6**	19.6	**19.440**
Volumetric Efficiency	**(%)**	82.4	82.7	82.6	82.8	83	**82.700**	79.5	79.9	80.2	80.4	80.5	**80.100**

45Nm Diesel		**1500 rpm**						**1600 rpm**					
File name		dm060822	dm060823	dm060824	dm060825	dm060826	**Average**	dm060827	dm060828	dm060829	dm060830	dm060831	**Average**
speed	**(rpm)**	1503.6	1503.6	1503.6	1503.6	1503.6	**1503.600**	1600.8	1600.8	1605.6	1600.8	1605.6	**1602.720**
Load	**(Nm)**	44.1	44.4	44.9	45.1	45.2	**44.740**	43.8	45.6	44.6	44.4	45.6	**44.800**
Brake Power	**(W)**	6943.9	6986.7	7072.2	7093.6	7115	**7042.280**	7347.2	7643.2	7506.5	7438.3	7666.4	**7520.320**
Ind. work per Cycle	**(J)**	435.7	433.9	427	426.1	436	**431.740**	417.2	422.8	412.5	423.7	433.5	**421.940**
Indicated Power	**(W)**	10918	10874.4	10701.2	10679.2	10925.1	**10819.580**	11130.7	11280.4	11039.4	11305.4	11601.9	**11271.560**
imep	**(kPa)**	655.2	652.5	642.1	640.8	655.6	**649.240**	627.4	635.8	620.3	637.2	651.9	**634.520**
bmep	**(kPa)**	416.7	419.2	424.4	425.7	426.9	**422.580**	414.1	430.8	421.8	419.2	430.8	**423.340**
Equivalence Ratio		0.881	0.891	0.878	0.905	0.901	**0.891**	0.828	0.873	0.862	0.854	0.824	**0.848**
Air/fuel ratio		16.94	16.75	17.05	16.5	16.6	**16.768**	18.07	17.12	17.33	17.48	18.13	**17.626**
Air Flow	**(g/s)**	13.532	13.54	13.622	13.573	13.573	**13.568**	15.121	15.135	15.156	15.208	15.172	**15.158**
Fuel Flow	**(g/s)**	0.8	0.81	0.8	0.82	0.82	**0.810**	0.84	0.88	0.87	0.87	0.84	**0.860**
Additive Flow	**(g/s)**	0	0	0	0	0	**0.000**	0	0	0	0	0	**0.000**
Percentage DME	**(%)**	0	0	0	0	0	**0.000**	0	0	0	0	0	**0.000**
Fuel Conv. Eff.	**(%)**	19.9	19.8	20.3	19.8	20	**19.960**	20.1	19.8	19.7	19.6	21	**20.040**
isfc	**(kg/J)**	7.32E-08	7.43E-08	7.46E-08	7.70E-08	7.49E-08	**7.48E-08**	7.52E-08	7.84E-08	7.92E-08	7.69E-08	7.21E-08	**7.64E-08**
bsfcf	**(kg/J)**	1.15E-07	1.16E-07	1.13E-07	1.16E-07	1.15E-07	**1.15E-07**	1.14E-07	1.16E-07	1.17E-07	1.17E-07	1.09E-07	**1.14E-07**
Injection	**(°CA)**	346.3	346.1	346.3	345.7	345.3	**345.940**	346.1	345.7	346.1	346.7	346.3	**346.180**
Ignition	**(°CA)**	354.7	351.9	352.1	351.9	352.1	**352.540**	356.1	351.9	351.5	351.5	351.3	**352.460**
Ignition delay	**(°CA)**	8.4	5.8	5.8	6.2	6.8	**6.600**	10	6.2	5.4	4.8	5	**6.280**
Patm	**(kPa)**	83.1	83.1	83.1	83.1	83.1	**83.100**	83.1	83.1	83.1	83.1	83.1	**83.100**
Exhaust Temperature	**(°C)**	490.7	484	486.4	485.9	483.5	**486.100**	485.9	490.2	496.5	491.7	491.2	**491.100**
Pmax	**(kPa)**	7260.9	7163.2	7236.5	7099.7	7050.9	**7162.240**	7290.2	7392.7	7392.7	7251.1	7085.1	**7282.360**
Position of Pmax	**(°CA)**	365.6	365.4	365.6	364.8	366.6	**365.600**	366	363.8	363.4	364.6	364.8	**364.520**
Tmax	**(K)**	2201.6	2146.1	2158.5	2131.1	2122	**2151.860**	2088.9	2069.5	2065.8	2049.2	2066.9	**2068.060**
Position of Tmax	**(°CA)**	372	373.4	371.8	372.6	373	**372.560**	370.4	372.6	371.6	373.2	372.8	**372.120**
Mech Efficiency	**(%)**	63.6	64.2	66.1	66.4	65.1	**65.080**	66	67.8	68	65.8	66.1	**66.740**
ITE	**(%)**	31.3	30.9	30.7	29.8	30.6	**30.660**	30.5	29.3	28.9	29.8	31.8	**30.060**
BTE	**(%)**	19.9	19.8	**20.3**	**19.8**	20	**19.960**	20.1	19.8	19.7	19.6	21	**20.040**
Volumetric Efficiency	**(%)**	81.2	81.2	81.7	81.4	81.4	**81.380**	85.2	85.3	85.2	85.7	85.3	**85.340**

45Nm Diesel		1700 rpm						1800 rpm					
File name		dm060832	dm060833	dm060834	dm060835	dm060836	**Average**	dm060837	dm060838	dm060839	dm060840	dm060841	**Average**
speed	**(rpm)**	1702.8	1702.8	1702.8	1702.8	1702.8	**1702.800**	1804.9	1800	1800	1800	1800	**1800.980**
Load	**(Nm)**	44.6	45.9	45.6	44.9	45.2	**45.240**	45.6	45.5	44.4	44.2	43.8	**44.700**
Brake Power	**(W)**	7960.9	8178.9	8130.4	8009.3	8057.8	**8067.460**	8617.7	8568.9	8364	8338.4	8261.6	**8430.120**
Ind. work per Cycle	**(J)**	429	423.9	408.9	387.7	397.8	**409.460**	333.2	368.6	372.7	322.6	331.2	**345.660**
Indicated Power	**(W)**	12175	12029.7	11604.6	11002.4	11288.6	**11620.060**	10024.2	11056.9	11179.7	9677.1	9936.1	**10374.800**
imep	**(kPa)**	645.1	637.4	614.9	583	598.1	**615.700**	501.1	554.2	560.4	485.1	498	**519.760**
bmep	**(kPa)**	421.8	433.4	430.8	424.4	426.9	**427.460**	430.8	429.5	419.2	418	414.1	**422.320**
Equivalence Ratio		0.922	0.962	0.967	0.952	0.96	**0.953**	0.949	0.983	0.974	0.976	0.971	**0.971**
Air/fuel ratio		16.19	15.59	15.47	15.71	15.56	**15.704**	15.73	15.18	15.37	15.31	15.41	**15.400**
Air Flow	**(g/s)**	15.009	15.039	15.076	15.083	15.082	**15.058**	15.996	16.083	15.994	15.931	15.958	**15.992**
Fuel Flow	**(g/s)**	0.93	0.96	0.97	0.96	0.97	**0.958**	1.02	1.06	1.04	1.04	1.04	**1.040**
Additive Flow	**(g/s)**	0	0	0	0	0	**0.000**	0	0	0	0	0	**0.000**
Percentage DME	**(%)**	0	0	0	0	0	**0.000**	0	0	0	0	0	**0.000**
Fuel Conv. Eff.	**(%)**	19.7	19.4	19.1	19.1	19.1	**19.280**	19.4	18.5	18.4	18.4	18.3	**18.600**
isfc	**(kg/J)**	7.61E-08	8.02E-08	8.40E-08	8.73E-08	8.59E-08	**8.27E-08**	1.01E-07	9.58E-08	9.31E-08	1.08E-07	1.04E-07	**1.00E-07**
bsfcf	**(kg/J)**	1.16E-07	1.18E-07	1.20E-07	1.20E-07	1.20E-07	**1.19E-07**	1.18E-07	1.24E-07	1.24E-07	1.25E-07	1.25E-07	**1.23E-07**
Injection	**(°CA)**	346.9	345.9	346.5	345.9	347.3	**346.500**	346.5	346.5	346.9	347.3	347.5	**346.940**
Ignition	**(°CA)**	352.3	353.3	351.7	352.3	352.1	**352.340**	352.1	358.9	353.1	351.7	353.1	**353.780**
Ignition delay	**(°CA)**	5.4	7.4	5.2	6.4	4.8	**5.840**	5.6	12.4	6.2	4.4	5.6	**6.840**
Patm	**(kPa)**	83.1	83.1	83.1	83.1	83.1	**83.100**	83.1	83.1	83.1	83.1	83.1	**83.100**
Exhaust Temperature	**(°C)**	497.4	518.6	517.2	520	525.3	**515.700**	511.4	503.2	499.4	496.5	496	**501.300**
Pmax	**(kPa)**	7295	7387.8	7461	7387.8	7685.6	**7443.440**	7861.4	8169	8115.3	8105.5	8237.4	**8097.720**
Position of Pmax	**(°CA)**	365.6	365	365	364.6	363	**364.640**	363.2	364.6	363.6	362.6	364	**363.600**
Tmax	**(K)**	2229.1	2253.3	2192.4	2170.1	2232	**2215.380**	2290.4	2414	2389.4	2331	2360.1	**2356.980**
Position of Tmax	**(°CA)**	374.6	374.2	373.8	369	369.4	**372.200**	366.6	366.8	368	365	366.2	**366.520**
Mech Efficiency	**(%)**	65.4	68	70.1	72.8	71.4	**69.540**	86	77.5	74.8	86.2	83.1	**81.520**
ITE	**(%)**	30.1	28.6	27.3	26.3	26.7	**27.800**	22.6	23.9	24.6	21.3	22	**22.880**
BTE	**(%)**	19.7	19.4	**19.1**	**19.1**	19.1	**19.280**	19.4	18.5	**18.4**	**18.4**	18.3	**18.600**
Volumetric Efficiency	**(%)**	79.5	79.7	79.9	79.9	79.9	**79.780**	80	80.6	80.2	79.9	80	**80.140**