University of Southern Queensland

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Testing Australian commercially available biodiesel properties, combustion, performance and emission characteristics

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Table of Contents

List of Figures

List of Tables

Abstract

Diesel engines have a wide range of applications in transportation and energy sectors. Diesel fuel is depleting every year and energy demands of the world are increasing drastically due to growth in population. The exhaust emissions of the diesel engine have been declared as harmful emissions and they have negative impact on the health and environment. With this background, researchers are trying to find the alternative fuel of diesel. The aim of this research work is to investigate the performance, combustion and emission characteristics of diesel engine fueled with the different blends of biodiesel with the diesel fuel. Different biodiesel blends B20, B50 and B100 were prepared and tested in the diesel to compare their performance, combustion and exhaust emission characteristics with the that of diesel fuel. Engine brake power and torque for biodiesel blends are found to be almost similar to that of diesel fuel. Fuel consumption and brake specific fuel consumption of biodiesel blends are found to be higher for biodiesel blends as compared to that of diesel fuel. Exhaust temperatures of biodiesel blends are recorded lower values. Regarding exhaust emissions, significant reduced emissions have been found in biodiesel blends as compared to that of diesel fuel. Carbon monoxide, carbon dioxide, unburnt hydrocarbons nitrogen oxides are found to be reduced in biodiesel blends as compared to diesel fuel. Oxygen emissions are found to be higher in biodiesel blends. In combustion analysis, biodiesel blends follow the similar trend of in-cylinder pressure profile but their timing is different to that of diesel fuel. It is concluded that the biodiesel blends are the potential candidates in diesel engine which can serve the purpose of reduced exhaust emissions.

1 INTRODUCTION

In the present age, the need of fossil fuel has been increased due to increased population, industry sectors and transportation needs. Diesel engines are used in the wide range of applications ranging from powering electrical generators to transportation. The emissions produced by the diesel engine are degrading the quality of natural environment and have negative impact on it. There is a worldwide trend to find out alternative fuels which will have reduced emissions and be environmentally friendly. The petroleum reserves are depleting with the passage of time and also their prices are increasingly day by day. A report suggests that global energy consumption is expected to rise by 37% by 2040, whereas fossil fuel consumption is expected to increase by almost 15% a day (BP Group, 2014).

Diesel engine is considered as one of the main contributors to air pollution. They are many advantages of diesel such as better torque characteristics, lower carbon monoxide emissions, lower fuel consumption and higher reliability. Based on these characteristics they are suitable to be used in many applications. In contrast, due to presence of high temperature and pressures in the combustion process, diesel engine produces nitrogen oxides (NO_x) and particulate matters. Because of these emissions, they are considered as the main contributors to air pollution.

Various studies have been performed by different authors which claim that these emissions are reduced to maximum extent when the diesel engines are fueled with the biodiesel blends. Besides this aspect, the emissions of diesel engine especially particular matters have the negative impact on the environment and the human health. Most of the air pollution problems are caused significantly by the diesel engines. Pollutants emitted by the diesel engine constitute almost less than 1% of exhaust emissions. Among all the exhaust emissions, nitrogen oxides (NO_x) has the maximum percentage of emissions which is about 50%. Nitrogen oxides (NO_x) are produced due to incomplete combustion of fuel in the diesel engine. After (NO_x), particulate matters have the greatest percentage. They are also produced due to incomplete combustion. Percentage of carbon monoxide and carbon dioxide in exhaust emissions is less due to less amount of oxygen consumed by diesel fuel. Some percentage of emissions also constitute sulfur dioxide which are produced to presence of sulfate in the fuel (Reşitoğlu et al., 2015).

Particulate matters severely affect the human health and environment. They are deposited in the human respiratory tract during the inhaling process. The size of particulate matter decides where it will be deposited in tract. It is reported that particulate matter of size less than 10 μm can enter the human lungs and cause various diseases like bronchitis, coughing, asthma attacks, higher blood pressure and even heart attack. Particulate matters having the size less than 2.5 μm tend to penetrate the lungs, causing coughing, damage to sensitive alveoli tissues and several other respiratory problems. Human vital organs such as the brain are affected by the particulate matters of size less than 10 nm (Peng et al., 2008). Many epidemiological and toxicological studies have reported the adverse effects of particulate matters of various sizes on the human health (Burtscher, 2005). Based on the given disadvantages of particulate matters, it is now a major concern of researchers to reduce PM emissions in diesel engines. Many studies reported that the concentration of PM depends upon the fuel oxygen content.

According to National Biodiesel Board (NBB), biodiesel is the only fuel which satisfies the requirements of Clean Air Act (Board., 2009). Biodiesel is found to be the fuel which produces reduced emissions. There are many advantages and disadvantages of using biodiesel in the unmodified diesel engines. Biodiesel fuel is nontoxic and biodegradable and it yields reduced harmful exhaust emissions. Almost complete absence of soot and sulfur oxide emission can be obtained by using biodiesel fuels. Regarding disadvantages, it produces high levels of nitrogen oxides emission which are undesirable. Biodiesel has high viscosity and it is low energy content fuel.

The objective of this project is to investigate experimentally the performance, combustion and emissions characteristics of diesel engine fueled with different blends of commercially available biodiesel blends with diesel fuel. Biodiesel blends will be prepared in different proportions (w.r.t volume) with the diesel fuel and experiments will be performed on the engine test bed. The performance, combustion and emission characteristics of different biodiesel blends will be measured and compared with the standard diesel fuel.

2 BACKGROUND AND LITERATURE REVIEW

2.1 Biodiesel

Biodiesel is the fuel usually obtained from waste cooking oils, animals fats or vegetables oils. Palm oil, sunflower oil, rapeseed oil and cottonseed oil are the major feedstocks to produce biodiesel. Biodiesel is produced from these oils by using a chemical process known as transesterification. There are many advantages of biodiesel which make it useful to be used as alternative of diesel fuel in diesel engine. It is biodegradable, non-toxic and produces no petroleum-based products. It is safe to use because it has high flash point temperature as compared to diesel fuel. It can also be treated as clean fuel because it produces no sulfur, contains no aromatics and has excessive oxygen contents in it which make it suitable to be used in combustion process. Transesterification process can be categorized into acid catalyzed and base catalyzed transesterification process. Based catalyzed transesterification process is the process which yields almost 98% required products and can be performed at low temperature and pressure.

2.2 Transesterification

Transesterification is the reaction in which a molecule of glyceride is reacted with one molecule of alcohol in the present of catalyst to produce the three molecules of esters and one molecule of glycerol as shown in figure 2.1. A molecule of glyceride consists of a glycerine molecule in its base which is attached to three long chain of fatty acids. The characteristics of the fat and hence that of biodiesel are based on these long chains of fatty acids. In the reaction, triglyceride reacts with the alcohol in the presence of a catalyst which can be sodium hydroxide or potassium hydroxide to form mono-alkyl ester, which is the required biodiesel. The alcohol usually used is the methanol or ethanol. Methanol produces the methyl esters while the ethanol produces the ethyl

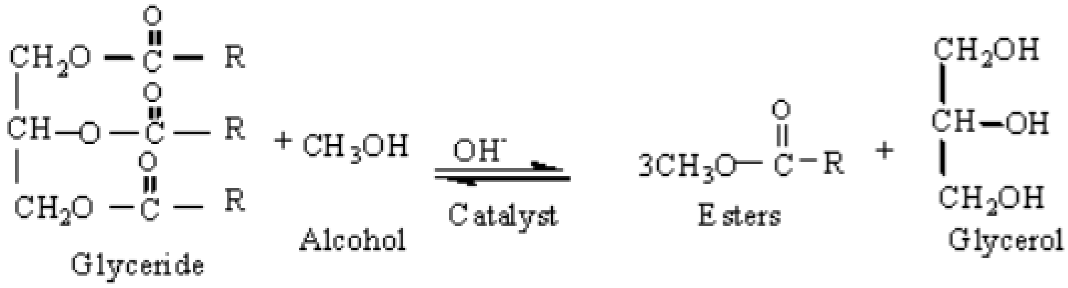

Figure 2.1: Transesterification reaction

esters. Transesterification reaction is a reversible reaction so alcohol is used in the excess quantity to ensure the complete conversion and shift the reaction to right side.

The products of transesterification reaction are glycerol and esters which are separated out after the reaction time. Glycerol is denser than esters and hence it settles out in the bottom and that can be separated. It is further processed and used in pharmaceutical and cosmetic industry.

The vegetable oil can directly be used as the substitute fuel in engine but due to its high viscosity it causes many severe problems in the engine like poor atomization, incomplete combustion, ring carbonization, coking of fuel injectors and fuel accumulation in lubricating oil. The best method to get rid of these problems is the transesterification process.

2.3 Production process of biodiesel

The production process of biodiesel is shown in figure 2.2. It basically consists of following main processes:

i. Mixing of catalyst and alcohol
ii. Transesterification
iii. Separation of products
iv. Removal of alcohol
v. Neutralization of glycerine
vi. Purifying biodiesel

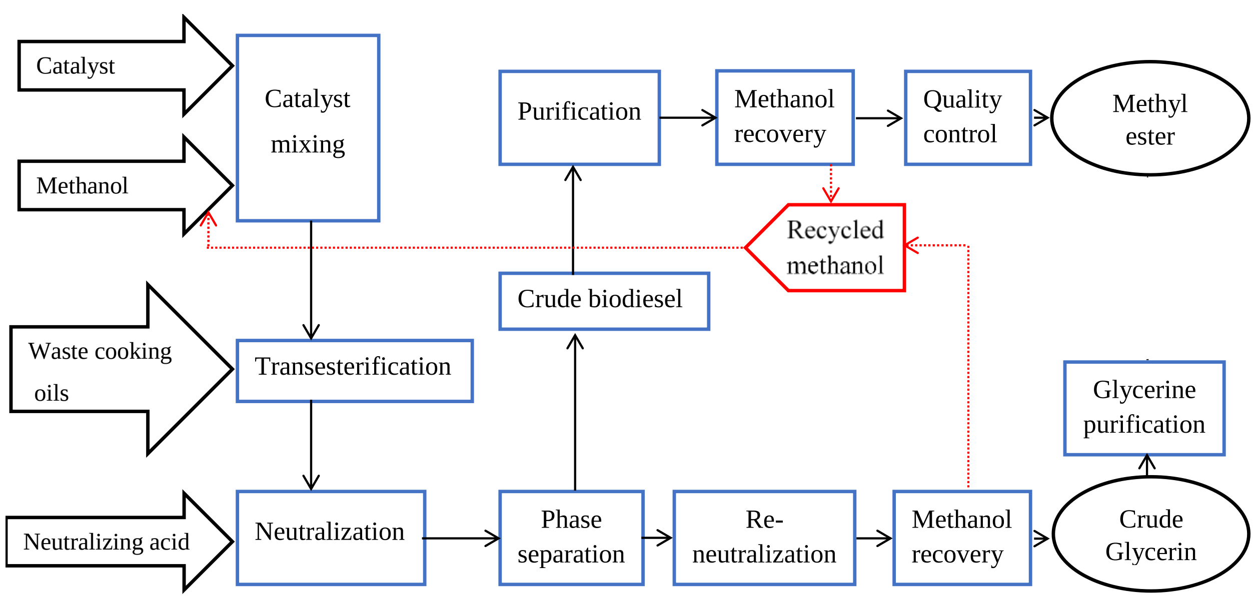

Figure 2.2: Biodiesel production process

i. **Mixing of catalyst and alcohol**

In the first step the catalyst which is usually potassium hydroxide or sodium hydroxide is mixed with the alcohol in a closed vessel (Gad et al., 2018). This mixture is then used in the transesterification.

ii. **Transesterification**

The mixture of catalyst and alcohol along with the vegetable oil, animal fats or waster cooking oils is charged into a closed vessel where they are allowed to react in a proper time. The mixture is almost heated to the temperature of 71^{o}C. The reaction time of transesterification varies from to 1 to 8 hours at room temperature. Excess amount of alcohol is used to shift the reaction to the right side and complete conversion of oils to biodiesel (esters).

iii. **Separation of products**

The products of the transesterification reaction are glycerine and biodiesel both of which have excess amount of alcohol in it. The density of glycerine is higher than biodiesel and it settles out in the bottom of vessel where it is separated out. To separate the products, centrifuge is also used in some cases.

iv. **Removal of alcohol**

After separating both the products, next step is to remove the excess quantity of alcohol from them. It is done by distillation or flash evaporation process. The recovered excess alcohol can be re-used in the system.

v. **Neutralization of glycerine**

The glycerine which is produced as a by-product contains excess amount of unused catalyst in it which is removed by neutralizing it with an acid. As a result of neutralization salt and water is produced which are further removed to obtain almost 80-88% of pure glycerine which can be used as crude glycerine.

vi. **Purifying biodiesel**

Once being separated from the glycerine, the biodiesel is purified by washing it gently with warm water to remove the residual soap contents or catalyst. The final product is an amber-yellow liquid which can now be used as fuel in engine.

2.4 Literature Review

2.4.1 Reported studies about diesel engine performance, emission and combustion properties

Several studies have been collected after the detail literature review, regarding the engine performance, emission and combustion properties of the diesel engine fueled with the biodiesel blends. There details are summarized as:

(Lapuerta et al., 2008) investigated the exhaust emissions characteristics of the diesel engine fueled with four types of biodiesel obtained from waste cooking oil, algae oil, palm oil and Jatropha oil. These alternatives were prepared in the proportions of B10 (blend of 10% biodiesel oil and 90% diesel fuel) and B20 (blend of 20% biodiesel oil and 80% diesel fuel). The effect of these blends was studied on the engine emissions of carbon monoxide, carbon dioxide, nitrogen oxides, hydrocarbons and smoke. These emissions were compared with the emissions of standard diesel fuel using the single cylinder diesel engine. In the results, the exhaust emissions of carbon dioxide, carbon monoxide and hydrocarbons were found to be lower for blends of vegetable oils B10 and B20 (palm, algae and Jatropha) as compared to that of standard diesel fuel. Exhaust emissions of carbon dioxide obtained from the waste cooking oil blends B10 and B20 were found to be higher when compared with standard diesel fuel. Emissions of nitrogen oxides were found to be higher in all four biodiesel blends of B10 and B20 as compared to diesel fuel.

(Abed et al., 2018) studied the performance and exhaust emissions of diesel engine by using blends of waste cooking oils and diesel fuel as alternatives in diesel engine. The blends were prepared in the proportions of B10, B20 and B30 representing 10%, 20% and 30% blend of biodiesel with diesel fuel (on volume basis) respectively. Performance parameters and emissions characteristics were measured experimentally by using these blends and their comparison was done with the standard diesel fuel. Tests were performed at varying engine loads from zero to full load conditions. Results show that thermal efficiencies of biodiesel blends of waste cooking oils are lower than that of standard diesel. Specific fuel consumption of biodiesel blends of waste cooking oil was found to be higher when compared with diesel fuel. Exhaust gas temperatures were also found to be higher for blends, when compared with diesel fuel. Regarding exhaust emissions, nitrogen oxides and carbon dioxide emissions were recorded higher for blends than that of diesel fuel, while hydrocarbon emissions, smoke opacity and carbon monoxide were found to be lower for biodiesel blends of waste cooking oil.

(Nagaraja et al., 2015) studied the emissions and performance parameters of the diesel engine fueled with the blends of preheated palm oil and diesel oil, running at variable compression ratios. The biodiesels were prepared on the volume basis, in proportions of 5%, 10%, 15% and 20% blends of palm oil with the standard diesel fuel. Experimental tests were performed at full load condition, engine speed of 1500 rpm and compression ratios of 16:1, 17:1, 18:1, 19:1 and 20:1. The variations of performance parameters and emission characteristics were investigated against the compression ratios. The performance parameters that were measured in this study consisted of indicated mean effective pressure, mechanical efficiency and brake power. From the results it was found that blend O20 (blend of 20% palm oil and 80% diesel fuel) shows the maximum mechanical efficiency among all the blends and its value is 14.6% more than that of standard fuel. At higher compression ratio, brake power of O20 was found to be 6% higher when compared with the diesel fuel, while indicated mean effective pressure of this blend was recorded lower at higher compression ratio as compared to that of diesel fuel. Exhaust temperature of all blends was found to be lower when compared with the standard diesel fuel. Regarding emissions, the decreasing trends of carbon monoxide and hydrocarbons emissions were found with the increase of blend ratio and compression ratio. Based on the results, the optimum performance of diesel engine was suggested for O20 at compression ratio of 20:1, for engine running at full load condition.

(Can, 2014) investigated the performance, combustion and exhaust emissions characteristics of diesel engine by using 5% and 10% blend of waste cooking oil with standard diesel fuel. Tests were conducted on the naturally aspirated, four stroke, single cylinder, direct ignition diesel engine. Engine was run at engine speed of 2200 rpm and brake mean effective pressures of 0.48 MPa, 0.36 MPa, 0.24 MPa and 0.12 MPa respectively. Detailed analysis of engine combustion and performance characteristics showed that the ignition delay decreases for the biodiesel blend at all engine loads. This is attributed to the high cetane number of biodiesel fuels. In-cylinder pressure rise rate and maximum heat release rate were found to be decreased for biodiesel blends when compared with the standard diesel. However, combustion duration for biodiesel blends were found to be increased as compared to that of standard diesel fuel. Maximum in-cylinder pressure was found to be almost the same in both cases of biodiesel blends and standard diesel fuel. Indicated mean effective pressure was found to be slightly dependent upon the center of heat release location and combustion timing. Regarding engine performance, brake specific fuel consumption was found to be increased for biodiesel blends of 5% and 10%, with a maximum value of 4% as compared to diesel fuel. Brake thermal efficiency was found to be decreased for biodiesel blends of 5% and 10%, with a maximum reduction of 2.8% as compared to diesel fuel. Regarding exhaust emissions, nitrogen oxides were found to be increased for biodiesel blends, with a maximum value of 8.7% as compared to diesel fuel. However, hydrocarbons and smoke were found to be decreased in biodiesel blends. Carbon monoxide emissions were found to be almost the same at low and medium engine loads, while some reductions were observed when the engine was running at full load condition. Carbon dioxide emissions for biodiesel blends were found to be slightly increased when compared with diesel fuel.

(Muralidharan and Vasudevan, 2011) investigated the performance, combustion and emission characteristics of diesel engine fueled with the blends of waste cooking oil methyl esters (biodiesel) and standard diesel fuel. The engine used was 4-stroke, single cylinder, and capable of variable compression ratio and multi fuel engine. Biodiesels were prepared in the proportions of 20%, 40%, 60% and 80% blends of biodiesel and standard diesel fuel. They used the transesterification process to convert the waste sun flower oil into biodiesel. Using the prepared biodiesel blends, the engine was run at engine speed of 1500 rpm and 50% load conditions. Compression ratio was varied at 18:1, 19:1, 20:1, 21:1 and 22:1. The variation of combustion pressure, fuel consumption and exhaust emissions were studied for biodiesel blends and their comparison was performed with standard diesel fuel. From the experimental results, it was found that biodiesel blends of waste cooking oil and diesel fuel show maximum rate of pressure rise, longer ignition delay and lower heat release rate when compared with the standard diesel fuel. Among all the blends studied, B40 was found to give maximum brake thermal efficiency at the given operating conditions of the engine. Regarding emissions, hydrocarbons and carbon monoxide emissions were found to be decreased, while, nitrogen oxides were found to be increased for biodiesel blends as compared to diesel fuel.

(Muralidharan et al., 2011) studied experimentally the performance, emission and combustion characteristics of the variable compression ratio diesel engine at different load conditions when fueled with the blends of biodiesel obtained from waste cooking oil and standard diesel fuel. The blends were prepared on the volume basis in proportions of 20%, 40%, 60% and 80%. During experiments, the operating engine was set to compression ratio of 21, engine speed of 1500 rpm and at different load conditions. The variations of performance, combustion and emission parameters was studied against the different loading conditions. The performance parameters that were investigated in their study consisted of specific fuel consumption, brake thermal efficiency, exhaust temperature, indicated mean effective pressure and brake power. The emissions investigated were carbon dioxide, carbon monoxide, hydrocarbons and nitrogen oxides. Overall, biodiesel blends showed encouraging results in terms of performance parameters and exhaust gas emissions. In terms of emissions, nitrogen oxides emissions were found to be higher, while, carbon dioxide, carbon monoxide and unburnt hydrocarbons were found to be lower when compared with the standard diesel fuel. The trends of combustion characteristics for biodiesel blends were found to be almost similar to that of standard diesel fuel, without significant differences.

(Channapattana et al., 2015) evaluated the performance and emission characteristics of diesel engine by using the biodiesel blends obtained from the non-edible linn oil and standard diesel fuel. Biodiesels blends that were used in the experiments include B20, B40, B60, B80 and 100% biodiesel. From the results, it was found that 100% biodiesel fuel shows 8.9% less brake thermal efficiency and higher values for brake specific consumption when compared with the standard diesel fuel. Regarding emissions, significant reductions were found in terms of carbon dioxide, carbon monoxide and hydrocarbons, while, nitrogen oxides were found to be increased when compared with diesel fuel.

(Shelke et al., 2016) investigated the combustion characteristics of diesel engine fueled with the blends of biodiesel obtained from cottonseed oil and diesel fuel. Transesterification processes was used to convert cottonseed oil into biodiesel using the potassium hydroxide as a catalyst. Biodiesels blends were prepared in the proportions of 5%, 10%, 15% and 20% (on volume basis). The combustion characteristics that were investigated include ignition delay, phases of combustion process (start of combustion, premixed, diffusion and after burning combustion phases) and combustion duration. These parameters were measured for all biodiesel blends and compared with the standard diesel fuel. From the results, it was found that biodiesels blends obtained from cottonseed oil and diesel show reduction in the maximum rate of pressure rise and ignition delay. Ignition delay was found to be decreased from 11^{o}CA to 6.5^{o}CA for B20 blend. Combustion duration was found be found longer for all biodiesel blends when compared with the base diesel fuel.

(Verma and Sharma, 2015) studied the performance and emission characteristics of the diesel engine fueled with the blends of biodiesels obtained from different sources and the standard diesel fuel. The biodiesels were obtained from the waste cooking oil, cottonseed oil, Jatropha oil and soybean oil, using the transesterification process. Their blends were prepared with the diesel fuel. From the results, it was found that fuel properties like flash point temperature, calorific value and cetane number of biodiesel blends were almost similar to that of petroleum diesel fuel. Regarding performance of engine, higher values of brake thermal efficiency and lower values of brake specific fuel consumption were obtained for the biodiesel blends. Regarding exhaust gas emissions, carbon monoxide, carbon dioxide, particular matters and hydrocarbons were found to be reduced in biodiesels blends, while, nitrogen oxides were found to be increased when compared with the petroleum diesel fuel. Authors concluded that the biodiesel may be the possible alternative of petroleum diesel fuel in diesel engine in terms of environmental benefits.

(Fattah et al., 2014) investigated the effect of addition of antioxidants in biodiesel on the diesel engine performance and emission characteristics. Palm biodiesel was obtained by means of transesterification process using the potassium hydroxide as catalyst in the chemical reaction. Two antioxidants, namely, 2(3)-tert-butyl-4-methoxy phenol (BHT) and 2,6-di-tert-butyl-4-methylphenol (BHA) were added in the concentration of 1000 ppm in B20 (blend of 20% biodiesel and 80% petroleum diesel) to study their effect on the engine performance and emission characteristics. From the experiments, it was found that oxidation stability of the biodiesel increases due to addition of antioxidants and physiochemical properties remain almost same. Tests were performed on the four stroke, 42 kW, 1.8 L diesel engine running at constant load and varying engine speed. Authors reported that brake power was found to be 0.68-1.02% lower and brake specific consumption of 4.03-4.71% higher for the biodiesel fuel having antioxidants in it, when compared with the petroleum diesel. Regarding emissions, 9.8-12.6% nitrogen oxides reduction was recorded for B20 as compared to the standard petroleum diesel fuel. Also, the emissions of carbon monoxide, carbon dioxide and hydrocarbons were found to be reduced.

(Abedin et al., 2014) investigated the performance and emission characteristics of diesel engine fueled with two different types of biodiesel blends. Biodiesels obtained from the palm and jatropha oil were used in their study. Depending upon the percentage of biodiesel in blend, fuels were categorized as PB10 (10% blend of palm biodiesel), PB20 (20% blend of palm biodiesel), JB10 (10% blend of jatropha biodiesel) and JB20 (20% blend of jatropha biodiesel). Performance and emission characteristics of the diesel engine were obtained for these fuels and compared with the standard diesel fuel. Experiments were performed on the diesel engine running at full load condition and engine speeds varying from 1000 to 4000 rpm. From the results, brake power was found to be decreased by average 2.3% to 10.7% for palm and jatropha biodiesel blends of 10% and 20%, respectively. Brake specific fuel consumption was found to be increased by average 26.4% for the studied blends of 10% and 20%. Regarding exhaust emissions, reductions were recorded for carbon monoxide and hydrocarbons emissions by amount of average 30.7% and 25.8%, respectively, for 20% blends. Nitrogen oxides emissions were found to be decreased by average 3.3% for palm blends and increased by average 3% for jatropha blends.

(Sanjid et al., 2014) investigated the performance and emission characteristics of diesel engine fueled with the combined blend of two biodiesels obtained from palm oil and jatropha oil. These biodiesels were obtained by performing the transesterification reaction. Biodiesels blends were prepared and categorized as PBJB5 and PBJB10. Experimental tests were conducted on the single cylinder diesel engine running at variable engine speed from 1400 to 2200 rpm. Brake specific fuel consumption was found to be increased for both biodiesel blends PBJB5 and PBJB10 when compared with diesel fuel. Regarding exhaust gas emissions, all emissions were found to be reduced for both biodiesel blends, except nitrogen oxides emission which were increased, when compared with the diesel fuel. Carbon monoxide emissions were about 9.53% and 20.49% lower, on average, as compared to standard diesel fuel. The reductions in hydrocarbon emissions were recorded by average 3.69% and 7.81% in PBJB5 and PBJB10, respectively.

(Rashed et al., 2016) investigated the performance and emission characteristics of three biodiesel blends (jatropha biodiesel, palm biodiesel, moringa biodiesel) and compared them with that of standard diesel fuel. All the three biodiesel blends were prepared in proportion of 20% biodiesel, categorized as JB20, PB20 and MB20. Experimental tests were performed on the multi cylinder, naturally aspirated, direct injection, four stroke diesel engine. Brake specific fuel consumption was found to be increased and brake power was found to be reduced for all the biodiesel blends when compared with the diesel fuel. Regarding emission characteristics, it was found that three exhaust emissions i.e. carbon monoxide, carbon dioxide and hydrocarbons reduce for biodiesel blends as compared to diesel fuel. Contrary to these emissions, nitrogen oxides were found to be increased in biodiesel blends. Among the three biodiesel blends, palm biodiesel blended fuel was found to be suitable candidate regarding performance and emission characteristics.

(Senthilkumar et al., 2015) investigated the performance and emission characteristics of various blends of palm biodiesel to figure out the optimum value of blend ratio of palm biodiesel. Blends of palm biodiesel were prepared in the percentages of 20%, 40%, 45% and 50%. Experimental tests were performed on the diesel engine running under 8 mode testing cycle. Multi-functional fuel additive was added in the optimum blend ratio of palm biodiesel to further enhance its performance and reduce emissions. From the results, it was found that hydrocarbons, carbon monoxide and carbon dioxide emissions were reduced by 73%, 46% and 1% respectively. Authors concluded that blend ratio of 40% is optimum value and it can enhance the emissions at maximum level.

(Gad et al., 2018) investigated experimentally the performance and emission characteristics of diesel engine fueled with the biodiesel and oil blends of palm oil with diesel fuel. Biodiesel and oil blends were prepared in volume proportions and categorized as B20 (20% blend of palm oil biodiesel and diesel), B100 (100% blend of palm oil biodiesel and diesel fuel) and PO20 (20% blend of palm oil and diesel fuel). Performance and emissions characteristics of these fuels were compared with those obtained from standard diesel fuel. Tests were performed on the diesel engine running at varying loads from zero to full load conditions for all fuels tested. From the results, it was found that thermal efficiency of oil and biodiesel blends is less as compared to that of diesel fuel. Specific fuel consumption for both biodiesel and oil blends was found to be higher when compared with the diesel fuel. Regarding exhaust emissions, hydrocarbons and carbon monoxide emissions were found to be reduced for oil blends, while they were found to be increased for biodiesel blends. For biodiesel and oil blends, nitrogen oxides emissions were found to be increased slightly. Authors concluded that B20 is the optimum blend of palm oil biodiesel and standard diesel fuel, based on the performance and emissions characteristics of diesel engine.

(Srithar et al., 2017) studied the thermophysical properties of dual biodiesel blends obtained by mixing of two different biodiesels with the standard diesel fuel at various mixing ratios. Two biodiesels were obtained from mustard oil and pinnata oil. Experimental tests were performed on the direct injection, single cylinder, air cooled diesel engine running at varying loads from zero to full load conditions, at engine speed of 3000 rpm. Performance and emissions characteristics of these fuels were obtained and compared with the diesel fuel. Authors reported that brake thermal efficiency was found to be increased for dual biodiesel blends when compared with the diesel fuel. Regarding exhaust emissions, nitrogen oxides, smoke and unburnt hydrocarbons were found to be increased as compared to diesel fuel. Exhaust temperature was recorded lower for the dual biodiesel as compared to diesel fuel.

(Sivaramakrishnan, 2018) investigated the performance and emission characteristics of multi fueled variable compression ratio diesel engine when fueled with the blends of karanja biodiesel with the diesel fuel. Blends of karanja biodiesel were prepared in volume percentages, as B20, B25 and B30. Performance and emission characteristics of these fuels were tested at compression ratios of 15:1, 16:1, 17:1 and 18:1, and compared with the standard diesel fuel. Brake thermal efficiency was found to be increased with increasing compression ratio. The maximum brake thermal efficiency of 5% higher was obtained for B25 at compression ratio of 18, when compared with the diesel fuel. Specific fuel consumption for the biodiesel blends was found to be decreased when compared with the diesel fuel. Unburnt hydrocarbons and carbon monoxide emissions were found to be reduced for biodiesel blends as compared to diesel fuel. Based on the performance and emission characteristics of diesel engine at various compression ratios, the optimum blend suggested by the authors was B25 at compression ratio of 18:1.

(Hemanandh and Narayanan, 2015) investigated the performance and emission characteristics of four stroke diesel engine when fueled with the biodiesel blends of hydrotreated refined sunflower oil with the standard diesel fuel. Biodiesel blends were prepared in the volume percentages as HTSF B25 and HTSF B100. Engine was run at different load conditions from zero to full load conditions at engine speed of 1500 rpm. Exhaust emissions were found to be reduced in the tested biodiesel blends. HTSF B100 showed greater emission reductions as compared to HTSF B25. Carbon monoxide, unburnt hydrocarbons and nitrogen oxides emissions in HTSF B100 were found to be reduced by 37%, 55% and 18.8% respectively, when compared with the standard diesel fuel. Brake thermal efficiency for HTSF B25 and HTSF B100 was found to be increased by 10% and 38% as compared to standard diesel fuel. Authors concluded that, biodiesel blend of hydrotreated refined sunflower may be suitable alternative of petroleum diesel fuel in diesel engine.

(Agarwal and Rajamanoharan, 2009) investigated the performance and emission characteristics of the diesel engine used in agriculture sector, when fueled with the blends of karanja oil with diesel fuel. Blends of karanja oil with the diesel fuel were prepared in the volume percentages of 10%, 20%, 50% and 75%. Experimental tests on the engine were performed in two different cases, one with preheating the fuels and second without preheating the fuels. Effect of these fuels on the performance and emission characteristics of the diesel engine were measured and compared with each other, and with the standard diesel fuel. Experimental results show that lower blend of karanja oil with diesel shows significant improvement in the performance parameters and exhaust emissions for the both cases (preheating and without preheating) of blends. The exhaust emissions including carbon monoxide, carbon dioxide and nitrogen oxides were found to be reduced for lower blend of karanja oil when compared with the standard diesel fuel. The optimum blend of karanja oil with diesel suggested by the authors was blend of 50%, based on the performance and emission characteristics as compared to the standard diesel fuel. Authors concluded that this might be the suitable alternative of diesel fuel in diesels engine of agriculture sector.

(Deepanraj et al., 2011) investigated the performance and emission characteristics of four stroke single cylinder diesel engine fueled with the blends of palm oil biodiesel with the standard diesel. Fuels were prepared in volume percentages as B10, B20, B30, B40 and B50. Performance parameters such as brake thermal efficiency, specific fuel consumption, exhaust temperature and exhaust emissions such as carbon monoxide, carbon dioxide and nitrogen oxides were measured at constant engine speed and compared with the standard diesel fuel. From the results, it was found that brake thermal efficiency of the lower blends of biodiesel increases when compared with the diesel fuel. Fuel consumption for these lower blends of biodiesel was found to be reduced as compared to that of diesel fuel. Authors concluded that blends of biodiesel in percentage from 20-40% with the diesel engine may be the suitable alternative fuel of petroleum diesel in diesel engine.

(Yusop et al., 2018) investigated the exhaust emissions of diesel engine such as particulate matters and nitrogen oxides, when fueled with the blends of palm oil biodiesel with the diesel fuel. Blends of palm oil methyl esters with the diesel fuel were prepared in the volume percentages as B5, B10, B20 and B100. Engine combustion parameters like rate of heat release of engine and in-cylinder pressure, and exhaust emissions were analyzed experimentally at the various loading conditions of the diesel engine. These parameters were measured for all the fuels tested and finally compared with the diesel fuel. From the results, PM emissions of B100 were found to be reduced when compared with the diesel fuel. In terms of SOF (soluble organic fraction), B100 showed higher values at all loading conditions when compared with the diesel fuel. Meanwhile, DS (dry soot) for the blend B100 was found to be reduced than diesel fuel. Generally, SOF and PM were found to be increased with the increased engine loads, while, dry soot concentrations were found to be reduced. Regarding engine combustion characteristics, shorter ignition delay was recorded for B100 due to the increased in-cylinder pressure and high value of cetane number. Regarding engine performance, B100 showed lower value of brake power as compared to diesel fuel. In terms of exhaust emission of fuels, nitrogen oxides emissions were found to be increased as the percentage of biodiesel blend increased. These emissions also continued to increase with the increasing engine loads. Authors concluded that blends of palm oil methyl esters show lower values of PM concentration but higher values of nitrogen oxides emissions.

(Asokan et al., 2018) investigated experimentally the performance, combustion and emission characteristics of diesel engine fueled with the mixture of two different biodiesels of watermelon and papaya seed oil with the diesel fuel. Transesterification process was used to convert the watermelon and papaya seed oils into biodiesels using the potassium hydroxide as catalyst. Different blends of mixture with the diesel fuel were prepared in volume percentages as B0, B20, B30, B40 and B100. Experimental tests were conducted on the four stroke, single cylinder diesel engine. Based on the performance, combustion and emission characteristics, B20 was found to be the superior among all the other blends tested. Combustion and performance parameters of B20 were found to be similar to that of diesel fuel. Exhaust emissions of B20 blend were recorded lower when compared with the diesel fuel. B20 showed smoke, unburnt hydrocarbons and carbon monoxide emissions less than diesel fuel by 8.3%, 23.8% and 27.27% respectively. Authors concluded that B20 is the most suitable blend among all the blends tested and it may be possible substitute of diesel in diesel engines.

2.4.2 Summary of biodiesel fuels on performance, combustion and emissions characteristics of diesel engine

Table 1: Summary of biodiesel fuels on performance, combustion and emissions characteristics of diesel engine

Authors	Engine used	Biodiesel used	Test conditions	Effect on		
				Performance	**Combustion**	**Emissions**
(Rao et al., 2008b)	single cylinder, four stroke, RP: 3.7 kW, CR: 16.5:1	Neem, Jatropha and Pongamia biodiesels	Constant speed (1500 rpm) and variable load conditions	B10 and B20 showed BTE similar to that of diesel fuel	-	HC, smoke and CO emissions are reduced
(Nithyananda et al., 2013)	single cylinder, four stroke, RP: 3.75 kW, CR: 16:1-25:1	Mixed Pongamia-coconut and neem methyl esters	Constant speed (1500 rpm) and variable load conditions	BSFC for all blends slightly increased	-	-
(Augustine et al., 2012)	single cylinder, four stroke, RP: 5.2 kW, CR: 17.5:1	Preheated cottonseed biodiesel	Constant speed (1500 rpm) and variable load conditions	BTE increased and BSFC decreased for all blends	-	HC and CO reduced by 16% and 34% respectively
(Aydin and Bayindir, 2010)	single cylinder, four stroke, RP: 10 HP, CR: 18:1	Cottonseed biodiesel	Variable engine speed (1250-2500 rpm)	Engine torque and BSFC increased for B5	-	NO_x, CO and SO_2 reduced for all blends
(Nabi et al., 2009)	single cylinder, four stroke, RP: 4.476 kW, CR: 16.5:1	Cottonseed biodiesel	Constant engine speed (850 rpm) and variable engine torque	BSFC and BTE increased	-	CO and PM reduced, while NO_x increased

Authors	Engine used	Biodiesel used	Test conditions	Effect on		
				Performance	Combustion	Emissions
(Karabektas et al., 2008)	single cylinder, four stroke, RP: 4.476 kW, CR: 18:1	Cottonseed biodiesel	Varied engine speed (1800-3200 rpm)	Brake power reduced for all blends	-	CO reduced, while NO_x increased
(Daho et al., 2013)	single cylinder, four stroke, Maximum torque: 38.5 Nm, CR: 18:1	Cottonseed oil	Constant engine speed (2500 rpm) and variable load conditions	BSFC increased, TE increased by 2.7-5.6% at higher loads	peak fuel pressure increased; premixed combustion reduced	CO emissions reduced, NO_x emissions increased and CO_2 remained unchanged
(Agarwal and Agarwal, 2007)	single cylinder, four stroke, RP: 7.4 kW, CR: 17.5:1	Jatropha oil	Constant speed (1500 rpm) and variable load conditions	Exhaust temperature and BSFC increased for unheated jatropha oil, TE reduced for unheated jatropha oil	-	Smoke capacity, HC, CO, CO_2 emissions of preheated blends were close to diesel fuel
(Jindal et al., 2010)	single cylinder, four stroke, RP: 3.5 kW, CR: 17.5:1	Jatropha biodiesel	Constant engine speed (1500 rpm) and variable load conditions	BSFC increased for increasing compression ratio	-	Smoke opacity, NOx and HC emissions were reduced by 10%, 25% and 50% respectively.

Authors	Engine used	Biodiesel used	Test conditions	Effect on		
				Performance	Combustion	Emissions
(Mohammed and Nemit-allah, 2013)	single cylinder, four stroke, CR: 18, DI, WC	Jatropha biodiesel	Variable engine speed (1000-2000 rpm)	BTE, engine torque and engine power reduced, BSFC increased for all blends	shorter ignition delay and peak cylinder pressure increased	CO emissions reduced, NO_x emissions increased
(Paul et al., 2014)	Four stroke, 2 cylinder, RP: 7.35 kW, DI, WC	Jatropha biodiesel	Constant engine speed (1500 rpm), variable engine load conditions	BTE reduced, while BSFC increased for all biodiesel blends	Cylinder pressure increased	Smoke and PM emissions reduced, CO_2 and NO_x increased
(Sureshkumar et al., 2008)	Four stroke, single cylinder, RP: 3.68 kW, CR: 16.5, WC	Pongamia biodiesel	Constant engine speed (1500 rpm), variable engine load conditions	BSEC reduced for B20 and B40, EGT reduced for all blends	-	CO, HC, CO_2 and NOx reduced for all blends
(Rao et al., 2008a)	Four stroke, single cylinder, RP: 4.4 kW, CR: 17.5, DI, AC	Pungam and rice bran biodiesels	Constant engine speed (1500 rpm), variable engine load conditions	BTE reduced for B20, EGT increased for all blends	ignition delay reduced and peak pressure increased for all blends	HC, CO and smoke opacity reduced, NO_x and CO_2 increased for all blends
(Gogoi and Baruah, 2011)	Four stroke, single cylinder, RP: 3.5 kW, CR: 12-18	Koroch seed oil biodiesel	Variable load	BSFC increased and BTE reduced for biodiesel blends	pressure crank angle was similar for biodiesel blends, earlier heat release rate obtained for biodiesel blends	-

Authors	Engine used	Biodiesel used	Test conditions	Effect on		
				Performance	**Combustion**	**Emissions**
(Lahane and Subramanian, 2015)	Four stroke, single cylinder, CR: 19.5:1, RP: 7.4 kW	Biodiesel blends	constant speed (1500 rpm)	Torque and BTE reduced, BSEC increased for biodiesel blends	rate of pressure and ignition delay increased for biodiesel blends0	HC, CO and smoke opacity reduced; NO_x emissions increased
(Anand et al., 2010)	Four stroke, single cylinder, RP: 5.2 kW, CR: 17.5:1	Turpentine oil biodiesels	Constant speed (1500 rpm), variable load	BSFC increased, BTE reduced	in-cylinder pressure and heat release rate increased	HC, CO, NO_x reduced and CO_2 for biodiesel blends
(Haiter et al., 2012)	Four stroke, single cylinder, RP: 5.2 kW, CR: 17.5:1	Mahua biodiesel	Constant speed (1500 rpm), variable load	BTE and EGT reduced, BSFC increased	heat release rate and peak cylinder pressure increased	CO_2, CO and NOx increased for biodiesel blends
(Puhan et al., 2005)	Four stroke, single cylinder, RP: 5.2 kW, CR: 17.5:1	Mahua biodiesel	Constant speed (1500 rpm), variable BMEP	EGT and BSFC increased and BTE reduced for blends	-	HC, CO and CO_2 reduced for biodiesel blends
(Godiganur et al., 2009)	Direct ignition, 6-cylinder, CR: 17.6:1	Mahua biodiesel	Constant speed (1500 rpm), variable load	BTE reduced and BSFC increased for biodiesel blends	-	HC and CO reduced, NO_x increased
(Muralidharan and Vasudevan, 2011)	Four stroke, single cylinder, RP: 44 kW, CR: 17.5:1	Waste cooking oil biodiesel	Constant speed (1500 rpm), variable load	BTE reduced and SFC increased for biodiesel blends	cylinder pressure increased	CO, HC and smoke opacity reduced
(Ozsezen and Canakci, 2011)	Four stroke, 6-cylinder, Maximum	Canola and waste cooking	variable speed (1000-2000 rpm)	BSFC increased for all biodiesel blends	Shorter ignition delay for both types of biodiesel blends	NO_x increased, CO_2, CO, HC

Authors	Engine used	Biodiesel used	Test conditions	Effect on		
				Performance	Combustion	Emissions
	power 81 kW at 2600 rpm. CR: 15.9:1	oil biodiesel blends				reduced for all biodiesel blends
(Lin et al., 2007)	Four stroke, 4-cylinder, CR: 21.6:1	Waste cooking oil biodiesel blends	variable speed (1000-2000 rpm)	-	-	CO_2 and NO_x increased, CO and SO_2 reduced
(Shirneshan, 2013)	Four stroke, four cylinder, water cooled, CR: 17:1	Waste frying biodiesel	Constant speed (1800 rpm)	-	-	CO2, CO, HC reduced; whereas NO_x increased
(An et al., 2013)	Four stroke, four cylinder, RP: 75 kW, CR: 18.5:1	Waste cooking oil biodiesel	Variable speed (800-3600)	BTE, BSFC increased for all biodiesel blends	Cylinder pressure, combustion duration and ignition delay reduced for all biodiesel blends	CO_2 and HC reduced, CO increased for all biodiesel blends. NO_x increased for B100
(Sanli et al., 2015)	Four stroke, 6-cylinder, CR: 16.4:1	Waste frying biodiesel	Variable speed (1100-1700 rpm)	BSFC increased for all biodiesel blends, BTE increased for pure blends	Combustion pressure and maximum in-cylinder pressures	NOx and CO_2 increased for esters, CO and smoke opacity reduced for all blends
(Makarevičienė et al., 2014)	3-cylinder, maximum power 30 kW	Microalgae oil biodiesel blends	Constant speed (1500 rpm), variable load	BTE and BSFC increased for biodiesel blends	-	HC and smoke reduced for all blends

3 PROJECT AIM

The aim of this project is to investigate experimentally the performance, combustion and emissions characteristics of diesel engine fueled with different blends of commercially available biodiesel blends with diesel fuel. Biodiesel blends will be prepared in different proportions (w.r.t volume) with the diesel fuel and experiments will be performed on the engine test bed. The performance, combustion and emission characteristics of different biodiesel blends will be measured and compared with the standard diesel fuel. Regarding engine performance, the parameters that will be measured and analyzed include power, torque, fuel consumption, brake specific fuel consumption and exhaust temperature. Engine emissions that will be considered include unburnt hydrocarbons, carbon monoxide, carbon dioxide, nitrogen oxides and oxygen. These parameters will be measured for all the fuels considered and their comparison would be performed with the standard diesel fuel.

4 METHODOLOGY

The engine performance parameters that were measured in experiments included: engine power, torque, exhaust temperature, fuel consumption and engine efficiency. Exhaust emissions that were measured in experiments included: carbon monoxide (CO), carbon dioxide (CO_2), unburnt hydrocarbons (HC), oxygen (O_2) and nitrogen oxide (NO_x) emissions. Regarding engine combustion analysis, in-cylinder pressure of combustion was measured.

4.1 Project Resources

This project requires the following materials and equipment:

i.	Fuel viscometer	(Available in P7 USQ)
ii.	Engine setup	(Available in P7 USQ)
iii.	Diesel fuel	(Available in P7 USQ)
iv.	Australian produced biodiesel	(Available in P7 USQ)
v.	Gas analyser	(Available in P7 USQ)
vi.	Glassware	(Available in P7 USQ)

4.2 Experimental Setup

All the experiments were performed on the GUNT 2002 engine setup shown in figure 4.1. Engine specification are shown in table 2. There were number of accessories or sensors attached to the engine setup which allowed us to take measurements. This engine setup had an eddy current dynamometer which was used for varying loads and engine speeds. The air intake flow to the engine setup was measured by an air mass sensor. One flow meter was connected to the engine setup whose function was to measure the fuel consumption. In-cylinder combustion pressure was measured by a piezometer. There were several thermocouples connected to the engine setup that gave us the readings of temperatures of ambient air, exhaust gases, cooling water and lubricating oil. There was one exhaust gas analyzer connected to the engine setup which measured the exhaust emissions like carbon dioxide, carbon monoxide, unburnt hydrocarbons and nitrogen oxides emissions. Exhaust gas analyzer is shown in figure 4.2. There was one data acquisition system connected to the engine setup which took the experimental readings and displayed it on the computer. These readings were further used for analysis.

Figure 4.1: Engine setup

Figure 4.2: Exhaust gas analyzer

Table 2: Engine specifications

Engine type	Yanmar, single cylinder
Bore & stroke	90 mm & 74 mm
Compression ratio	19:1
Capacity	470 cm^3
Minimum speed	800 rpm
Maximum speed	3000 rpm
Lubricant quantity	1.56 liter
Cooling system	Water based

4.3 Fuels preparation and measurement of viscosity

In the first step of performing experiments on engine setup, fuels were prepared. These fuels included the pure diesel fuel and biodiesel blends of commercially available biodiesel with the standard diesel. The fuels prepared were:

i) Diesel fuel

ii) 100% biodiesel (B100)

iii) 50% blend of biodiesel and diesel (B50)

iv) 20% blend of biodiesel and diesel (B20)

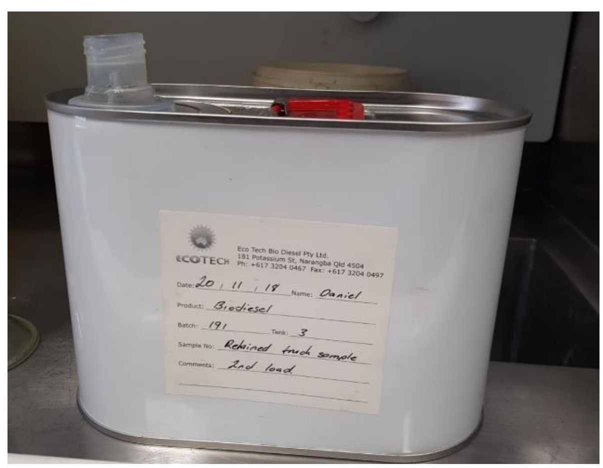

Figure 4.3: Biodiesel fuel

Viscosities of these fuels were measured by means of Brookfield viscometer available in laboratory. The setup of viscometer is shown in figure. Viscosities were measured at different temperatures for example $15^{o}C$ and $40^{o}C$ and their effect on the temperature was investigated. Also, the viscosities of the biodiesel blends were compared with that of pure diesel fuel.

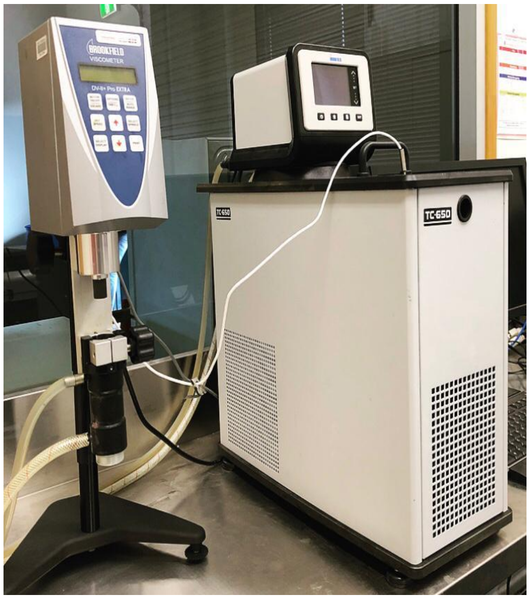

Figure 4.4: Viscometer setup

4.4 Testing Procedure

First of all, the desired combinations of fuels were prepared. These fuels contained the pure diesel fuel and biodiesel blends in different proportions. There viscosities were investigated at different temperatures and measurements will be taken. Before starting experiments on the diesel engine, the equipment and systems connected to the engine were properly checked and their working was made sure. These systems included emissions monitoring system, lubricating oil system, cooling system and diesel engine system. Experiments were performed at different engine speeds of 1800 rpm, 2000 rpm, 2600 rpm, 2900 rpm and 3800 rpm. When the engine was running at steady state at each engine speed, then experimental data was measured and recorded. Measurement were taken for two trails of each fuel at the same engine speed. Engine performance parameters, exhaust emissions and in-cylinder pressure were measured for each fuel. Data acquisition system was connected to the engine testbed which recorded experimental data and imported into excel sheets. The data obtained in excel sheets was used for further analysis.

5 RESULTS AND DISCUSSION

5.1 Performance Parameters

5.1.1 Engine brake power

Variation of engine brake power with engine speed is shown in figure 5.1. All power curves for the four fuels are found to be overlapping to each other. This means that engine brake power produced by each fuel is almost same at each engine speed. When the engine speed increases from engine speed of 1800 rpm to 2900, engine brake power increases. After that engine speed, power decreases to the engine speed of 3800 rpm. Power obtained by blend B50 at engine speed of 2900 is almost 15.15% less as compared to that of diesel. At other engine speeds, there is negligible difference between powers of all four fuels and it is found to be almost same.

From engine brake power point of view, there is no significant difference between the biodiesel blends and diesel fuel. Overall, it can be concluded that at each engine speed the engine brake power is almost same as that of biodiesel blend.

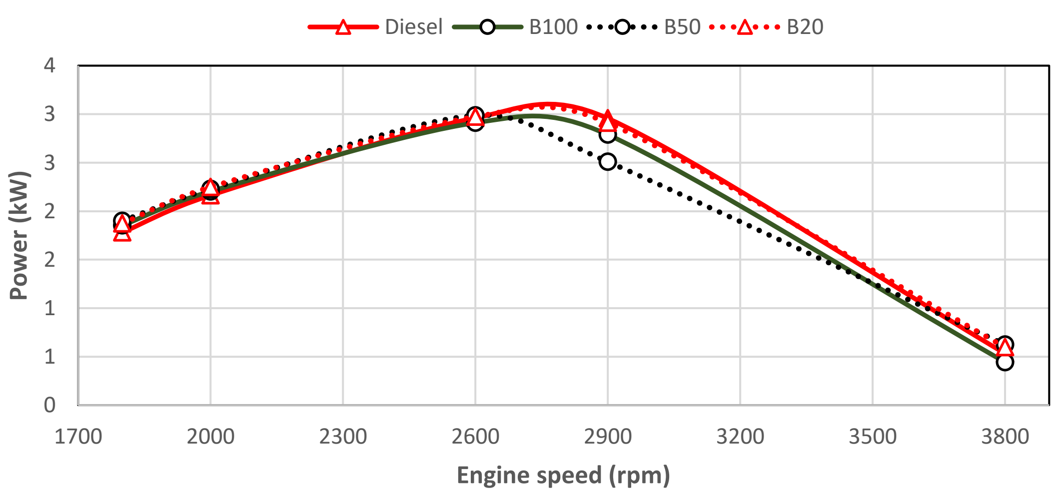

Figure 5.1. Engine brake power vs engine speed

5.1.2 Torque

Variation of engine torque against engine speed is shown in figure 5.2. The torque produced by engine is directly proportional to the power developed by the engine. Therefore, the trends of torque are found to be similar to that of power. When the engine speed is increased from 1800 to

2600 rpm, torque increases by small amount for all fuels. At these engine speeds, the torque for all fuels is almost same. When the engine speed is further decreased from 2600 to 3800 rpm, torque produced by engine for all fuels decreases. Fuel B50 shows 10% less torque as compared to that of diesel at engine speed of 2900 rpm. At engine speed of 3800 rpm, the torque produced by engine is almost same for all fuels.

Similar to that engine brake power, overall, there is no significant difference between the engine torque of biodiesel blends and diesel fuel.

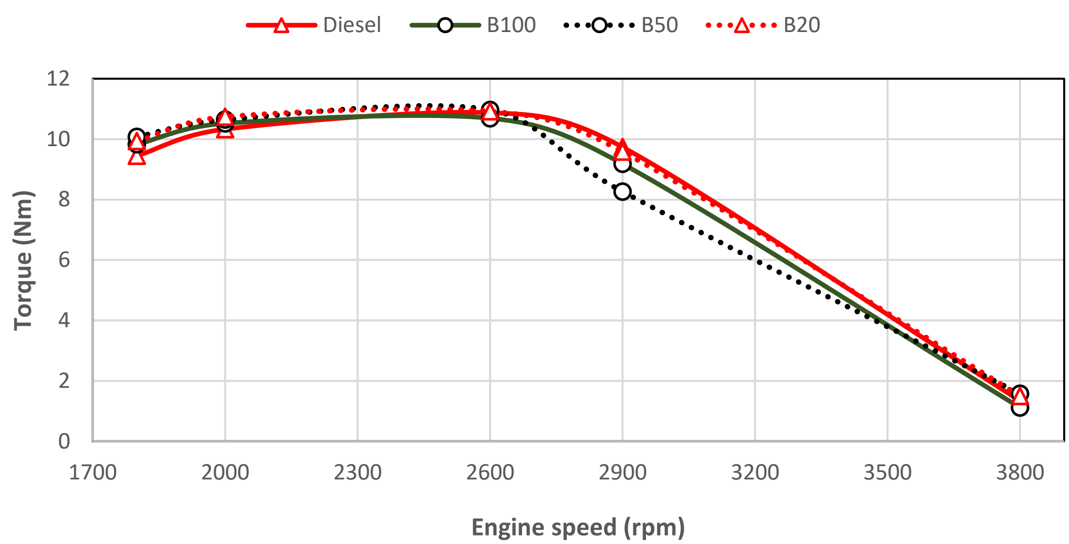

Figure 5.2. Torque vs engine speed

5.1.3 Fuel consumption

Fuel consumption means the amount of fuel required by the diesel engine in one hour. Cost of using fuel in engine is dictated by this parameter. If the engine is consuming higher amount of fuel then the cost of using fuel will be higher. If the engine consumes lesser amount of fuel, fuel cost will be lesser. Value of this performance parameter should be less as possible, so that fuel cost can be reduced.

Variation of fuel consumption against the engine speed is shown in figure 5.3. When the engine speed is increased from 1800 rpm to 2600 rpm, fuel consumption for all four fuel increases and then it decreases from engine speed 2600 rpm to 2900 rpm. Fuel consumption of blend B100 and B50 is 17.11% and 29.7% more as compared to that of diesel fuel at engine speed of 1800 rpm. Blend B20 shows 2.68% less fuel consumption as compared to diesel fuel at engine speed of 1800 rpm. The same trend is observed at engine speed of 2000 rpm i.e. fuel consumption of blend B100 and B50 is higher at engine speed of 2000 rpm when compared with diesel fuel, while that of blend B20 is almost same as that of diesel fuel. Higher values of B100 and B50 as compared to diesel fuel at engine speed of 2000 rpm are 9% and 2% respectively. At engine speed of 2600 rpm, fuel consumption of all four fuels is maximum. Fuel consumption of blend B20 is almost same as that of diesel, while, that of B100 and B50 are 7.6% and 3% higher.

When the engine speed is further increased from 2600 rpm to 3800 rpm, fuel consumption for all four fuels decreases. Fuel consumption of B100 and B20 are found to be 10.6% and 21% higher, while that of B50 is 4.18% lower as compared to that of diesel fuel at engine speed of 2900 rpm. At engine speed of 3800 rpm, fuel consumption of B100 and B50 are almost 11% higher, while that of B20 is 28% lower as compared to diesel fuel.

From this analysis, it can be concluded that fuel consumption of biodiesel blends increases when the amount of biodiesel in blend is increased. Only the blend B20 shows lower value of fuel consumption in which amount of diesel is maximum i.e. 80% as compared to other three biodiesel blends. The blend in which diesel will have maximum amount will show fuel consumption more closely to that of diesel fuel.

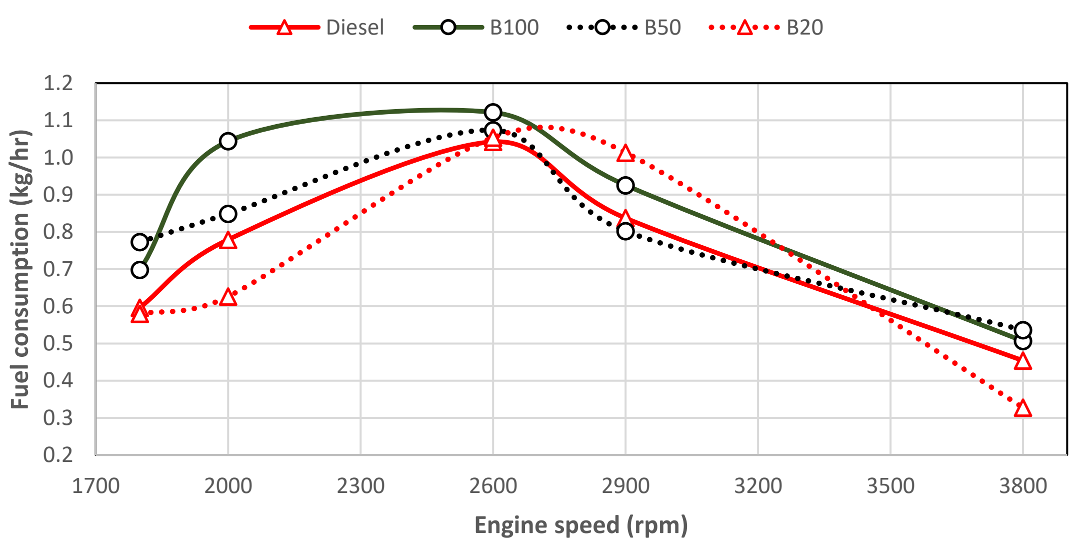

Figure 5.3. Fuel consumption vs engine speed

5.1.4 Brake specific fuel consumption

Brake specific fuel consumption means the amount of fuel required by the diesel engine to produce unit kW of power in one hour. This parameter is used when the different fuels need to be compared.

The best fuel is the one whose smaller amount produces higher amount of power in diesel engine. Like fuel consumption, smaller value of brake specific fuel consumption is always required. Variation of brake specific fuel consumption against the engine speed is shown in figure 5.4. This shows that brake specific fuel consumption of B100, B50, B20 is little bit higher than diesel fuel when the engine speed is increased from 1800 rpm to 2600 rpm. At engine speed of 1800 rpm, brake specific fuel consumption of all fuels is almost same. At engine speed of 2000 rpm, B100, B50 and B20 show 97%, 58% and 15.7% higher values of brake specific fuel consumption as compared to diesel fuel. At engine speeds of 2600 rpm and 2900 rpm, values of brake specific fuel consumption for all fuels is almost same. Brake specific fuel consumption increases for all fuels when the engine speed is increased from 2900 rpm to 3800 rpm. B100 and B50 show 40% and 16% higher values of brake specific fuel consumption as compared to diesel fuel at engine speed of 3800 rpm, while B20 shows 37% lower value.

From this performance parameters, it can be concluded that biodiesel blends, except B20, show higher values of brake specific fuel consumption at all engine speeds. In B20, percentage of diesel is maximum as compared to other three biodiesel blends, therefore, it shows more closely values of brake specific fuel consumption to that of diesel fuel.

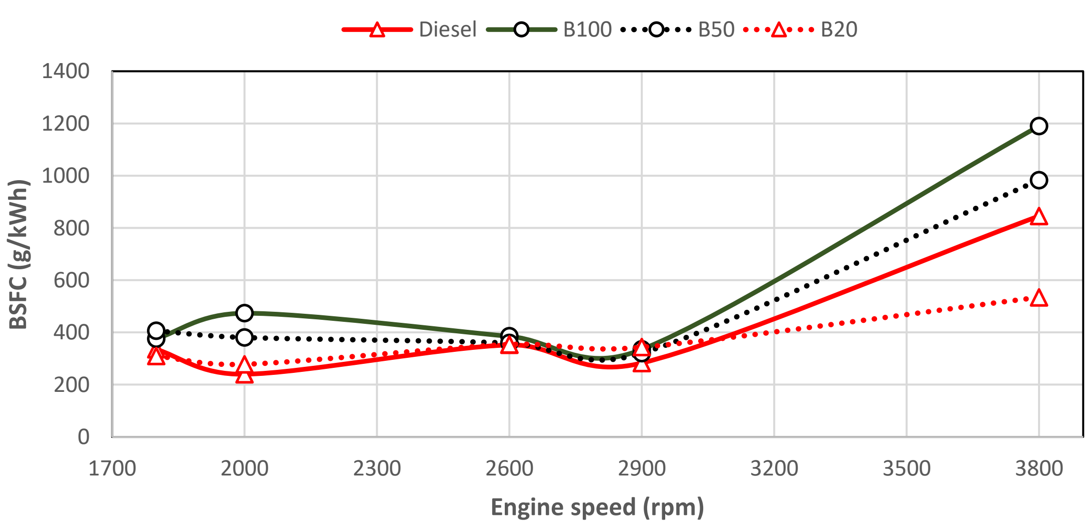

Figure 5.4. Brake specific fuel consumption vs engine speed

5.1.5 Exhaust temperature

Variation of exhaust temperature for all four fuels against the engine speed is shown in figure 5.5. This shows that exhaust temperature increases for all four fuels when the engine speed is increased from 1800 rpm to 2600 rpm. For the further engine speeds from 2600 rpm to 3800 rpm, exhaust temperature of all four fuels decreases. At each engine speed, exhaust temperature of pure diesel and blend B20 is almost same and there exists no significant difference between these two fuels. Biodiesel blends B100 and B50 show lower values of exhaust temperatures as compared to that of diesel fuel at each engine speed. This difference almost increases when the engine speed is increased. Overall, the maximum difference of exhaust temperature from the diesel fuel is shown by blend B100. It shows 2.50%, 1.92%, 4.3%, 7.38% and 7.13% lesser values of exhaust temperature at as compared to that of diesel fuel at engine speeds of 1800 rpm, 2000 rpm, 2600 rpm, 2900 rpm and 3800 rpm respectively.

From this performance parameter, overall, it can be concluded that exhaust temperature of biodiesel blends (B50 and B100) is lower than that of diesel fuel. Only the biodiesel blend B20 shows higher values of exhaust temperature when compared with the diesel fuel.

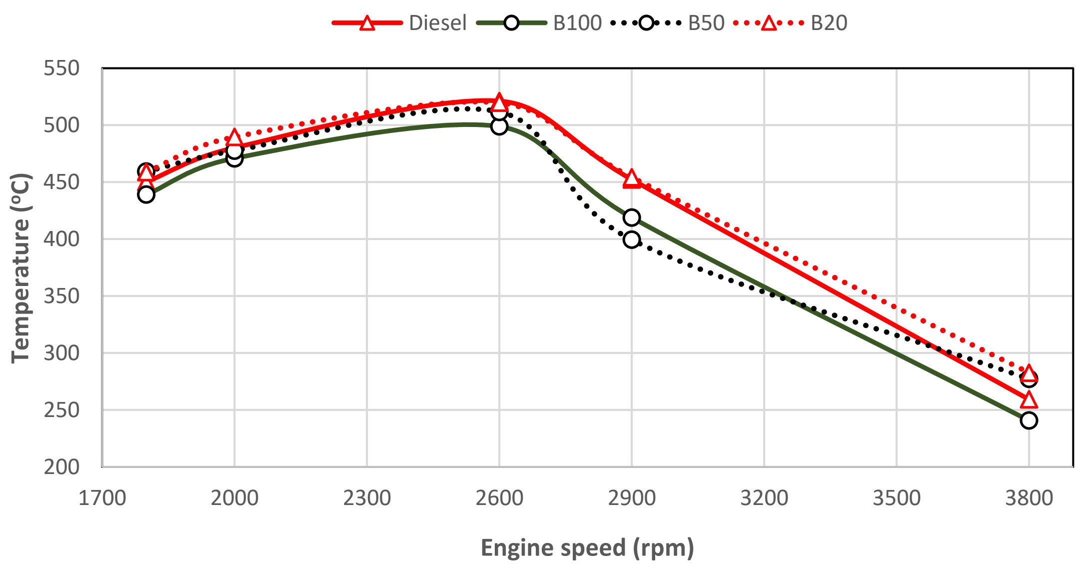

Figure 5.5. Exhaust temperature vs engine speed

5.2 Exhaust Emissions

5.2.1 Hydrocarbon emissions

Variation of hydrocarbon emissions for all fuels against the engine speed is shown in figure 5.6. This shows the unburnt hydrocarbons emissions obtained in case of diesel fuel are higher than all biodiesel blends at each engine speed. Initially, the hydrocarbon emissions for diesel fuel, B20 and B50 increase when the engine speed is increased from 1800 rpm to 2000 rpm, then they decrease slightly from engine speed of 2000 rpm to 2600 rpm. These emissions decrease drastically from engine speed of 2600 rpm to 2900 rpm. Onward from 2900 rpm to 3800 rpm, hydrocarbons emissions remain almost constant for all fuels. At engine speed of 1800 rpm, hydrocarbon emissions produced by blend B20, B50 and B100 are 51%, 41% and 51% lower as compared to that of diesel fuel. Maximum lower hydrocarbon emissions are produced by blend B100. B100 shows 76.5%, 86%, 58% and 14% lower hydrocarbons emissions as compared to diesel fuel at engine speeds of 2000 rpm, 2600 rpm, 2900 rpm and 3800 rpm. The lower unburnt hydrocarbon emissions in biodiesel blends can be attributed to higher concentration of oxygen contents in them, which lead complete combustion of hydrocarbons and produces less amount of unburnt hydrocarbon emissions.

From this parameter of exhaust emissions, it can be concluded that hydrocarbon emissions obtained in biodiesel blends are less as compared to diesel fuel at each engine speed. As the concentration of biodiesel increases in the blend of biodiesel and diesel, the amount of unburnt hydrocarbon emissions decreases.

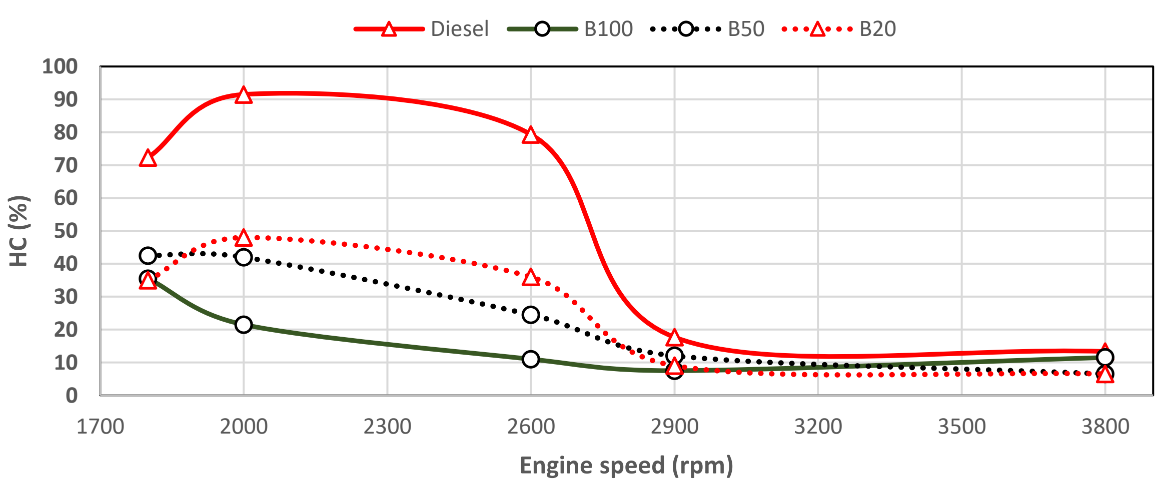

Figure 5.6. Hydrocarbon emissions vs engine speed

5.2.2 Carbon monoxide emissions

Variation of carbon monoxide emissions for all fuels against the engine speed is shown in figure 5.6. This shows the carbon monoxide emissions obtained in case of diesel fuel are higher than all biodiesel blends at each engine speed. Initially, the carbon monoxide emissions for diesel fuel, B20 and B50 increase when the engine speed is increased from 1800 rpm to 2000 rpm, then they decrease slightly from engine speed of 2000 rpm to 2600 rpm. These emissions decrease drastically from engine speed of 2600 rpm to 2900 rpm. Onward from 2900 rpm to 3800 rpm, carbon monoxide emissions remain almost constant for all fuels. At engine speed of 1800 rpm, carbon monoxide emissions produced by blend B20, B50 and B100 are 53%, 52.7% and 63% lower as compared to that of diesel fuel. Maximum lower carbon monoxide emissions are produced by blend B100. B100 shows 78.5%, 86.7%, 80.8% and 77.61% lower carbon monoxide emissions as compared to diesel fuel at engine speeds of 2000 rpm, 2600 rpm, 2900 rpm and 3800 rpm.

From this parameter of exhaust emissions, it can be concluded that carbon monoxide emissions obtained in biodiesel blends are less as compared to diesel fuel at each engine speed. As the concentration of biodiesel increases in the blend of biodiesel and diesel, the amount of unburnt hydrocarbon emissions decreases.

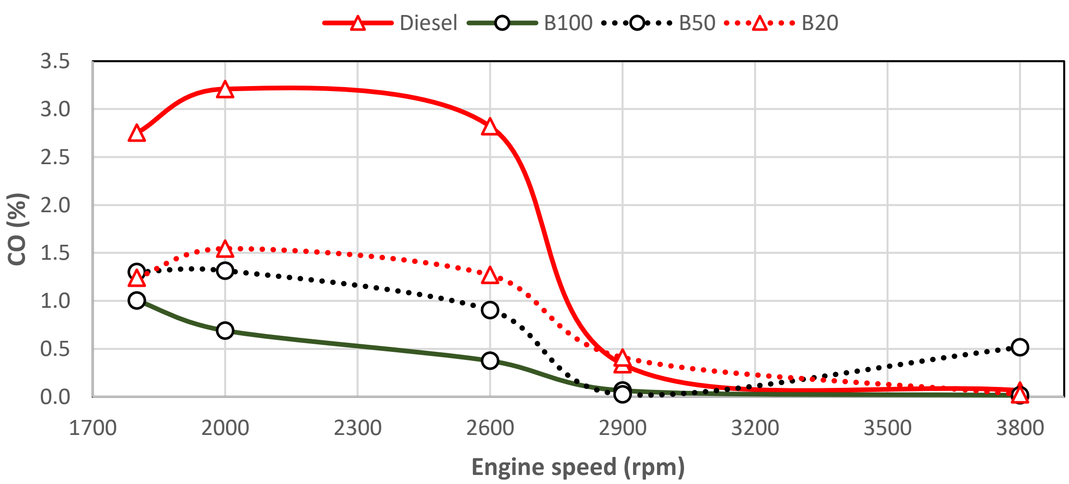

Figure 5.7. Carbon monoxide emissions vs engine speed

5.2.3 Carbon dioxide emissions

Variation of carbon dioxide emissions for all fuels against the engine speed is shown in figure 5.6. This shows the carbon dioxide emissions obtained in case of diesel fuel are higher than all biodiesel blends at each engine speed. Initially, the carbon dioxide emissions for diesel fuel, B20 and B50 increase slightly when the engine speed is increased from 1800 rpm to 2900 rpm, then they decrease drastically from engine speed of 2900 rpm to 3800 rpm. At engine speed of 1800 rpm, carbon dioxide emissions produced by blend B20, B50 and B100 are 55%, 52.16% and 59% lower as compared to that of diesel fuel. Maximum lower carbon dioxide emissions are produced by blend B100. B100 shows 76%, 61%, 75% and 58.4% lower carbon dioxide emissions as compared to diesel fuel at engine speeds of 2000 rpm, 2600 rpm, 2900 rpm and 3800 rpm.

From this parameter of exhaust emissions, it can be concluded that carbon dioxide emissions obtained in biodiesel blends are less as compared to diesel fuel at each engine speed. As the concentration of biodiesel increases in the blend of biodiesel and diesel, the amount of unburnt hydrocarbon emissions decreases.

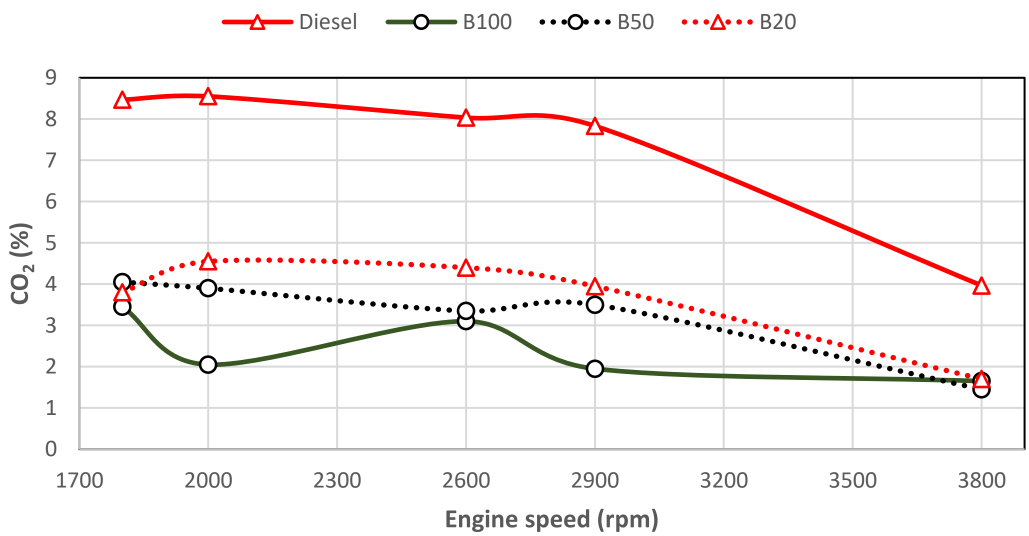

Figure 5.8. Carbon dioxide emissions vs engine speed

5.2.4 Oxygen emissions

Variation of oxygen emissions for all fuels against the engine speed is shown in figure 5.9. This shows that the oxygen emissions produced by the biodiesel blends are higher as compared to that of diesel fuel. Oxygen emissions produced by the all fuels are found to be little bit increasing with the engine speed. Oxygen emissions of blend B20 are the minimum between all biodiesel blends, while that of blend B100 are maximum. At engine speed of 1800 rpm, oxygen emissions of B100 and B20 are 138.28% and 123% higher as compared to diesel fuel. At engine speed of 3800 rpm, oxygen emissions of these blends are found to be 24% and 18% higher when compared with the diesel fuel. The increased amounts of oxygen emissions in biodiesel blends are due to higher oxygen contents in biodiesels as compared to diesel fuel.

From this parameter of exhaust emissions, it can be concluded that the oxygen emissions in biodiesels blends are higher as compared to diesel fuel at each engine speed. Considering oxygen emissions, biodiesels are desired and more useful as compared to diesel fuel.

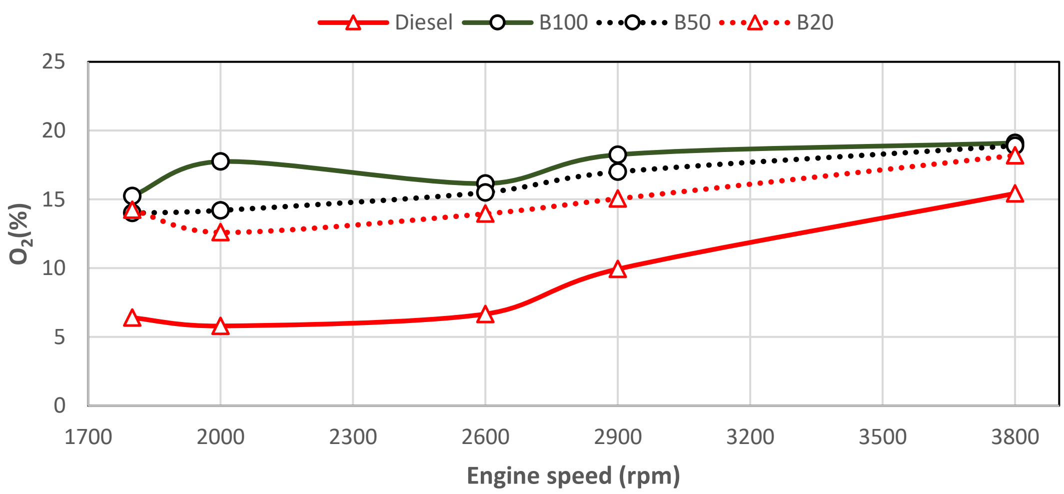

Figure 5.9. Oxygen emissions vs engine speed

5.2.5 Nitrogen oxides emissions

Variation of nitrogen oxides emissions for all fuels against the engine speed is shown in figure 5.10. From this figure, it can be seen that nitrogen oxides emissions in diesel fuel are more as compared to biodiesel blends at each engine speed. The trends of nitrogen oxides emissions show that, initially, they decrease when the engine speed is increased from 1800 rpm to 2600 rpm. For engine speed of 2600 rpm to 2900 rpm, these emissions increase. From 2900 rpm to 3800 rpm, nitrogen oxides emissions are found to be decreasing. Between all biodiesel blends, B20 shows the highest nitrogen oxide emissions, while B100 shows the minimum nitrogen oxides emissions. Nitrogen oxide emissions for B20 and B100 are found to be 47% and 55% lower as compared to diesel fuel at engine speed of 1800 rpm. At engine speed of 2600 rpm, nitrogen oxides emissions for B20 and B100 are found to be 58% and 63% lower as compared to diesel. These emissions are 53% and 372% lower for B20 and B100 at engine speed of 3800 rpm.

From this parameter of exhaust emissions, it can be seen that nitrogen oxides emissions are reduced in the biodiesel blends as compared to diesel fuel at each engine speed. As the concentration of biodiesel in the blend increases, nitrogen oxides are further reduced. Since, these emissions should be minimum, therefore, biodiesels are preferred and more useful as compared to diesel fuel.

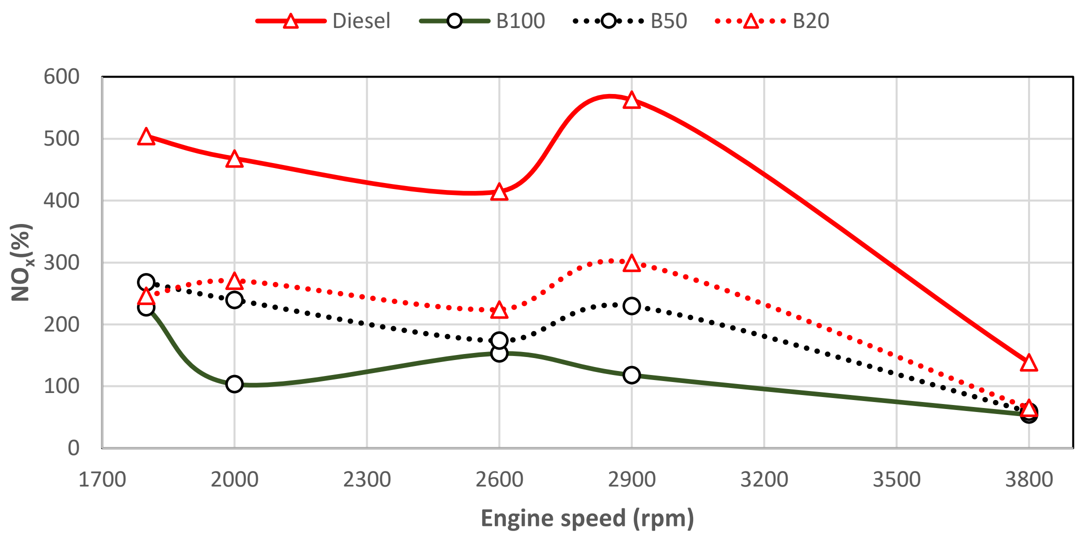

Figure 5.10. Nitrogen oxides emissions vs engine speed

5.3 Combustion analysis

In combustion analysis, the in-cylinder pressure was measured for all four fuels at each engine speed. Figure 5.11 shows the in-cylinder pressure profile in combustion process for all four fuels at engine speed of 1800 rpm. This figure shows the all four fuels follow the similar trend in the combustion process. With the passage of time, the in-cylinder pressure increases to a maximum value and then it starts decreasing to a minimum value. Air fuel mixture is the primary factor which causes the increase of in-cylinder pressure in the combustion process. When the fuel is injected into diesel engine cylinder, some of the fuel injects instantly due to its auto ignition temperature. This mechanism increases the in-cylinder pressure. Second, the when the fuel mixes properly with the air fuel ration then combustion process starts. As a result of combustion, chemical reaction takes place and products are formed. Heat is released during this process. This heat causes the increase of pressure in combustion process. When the combustion process stops, then the produce gases occupy full volume of the cylinder and expand thoroughly. This expansion causes to reduce the in-cylinder pressure. Figure shows that the fuels show peak values of in-cylinder pressure at different intervals of time and there is exist little bit difference between the pressure profiles of biodiesel blends with the diesel fuel.

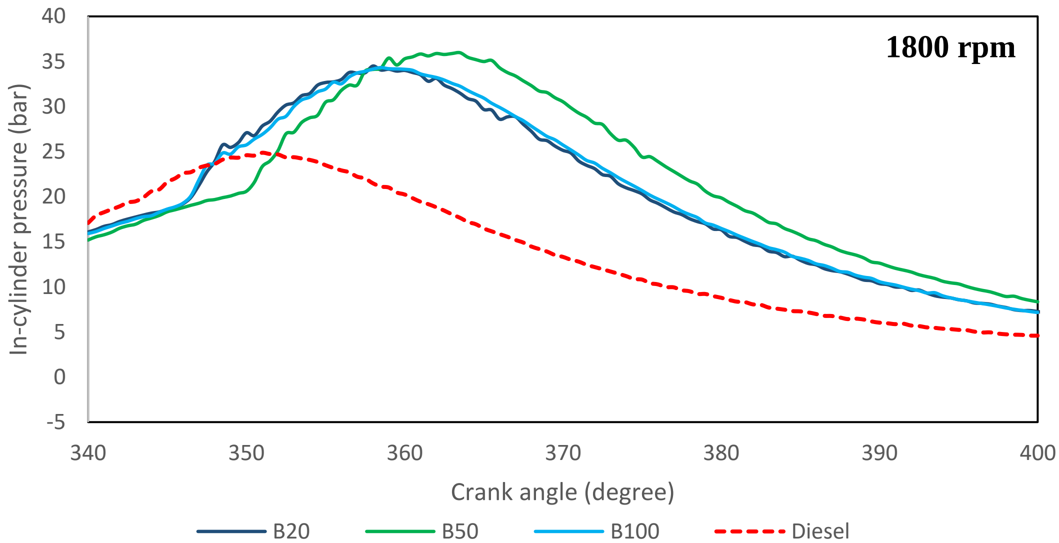

Figure 5.11. In-cylinder pressure vs crank angle at engine speed of 1800 rpm

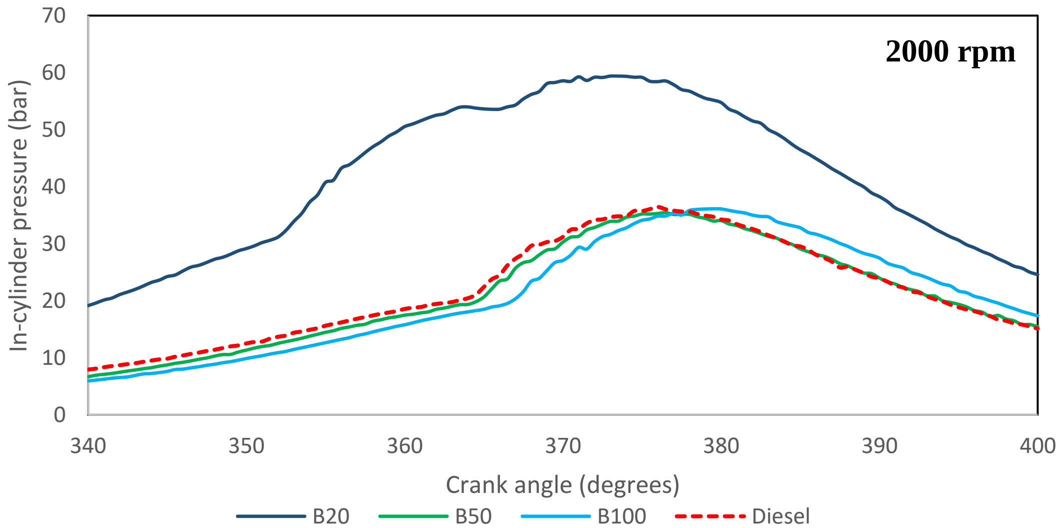

Figure 5.12. In-cylinder pressure vs crank angle at engine speed of 2000 rpm

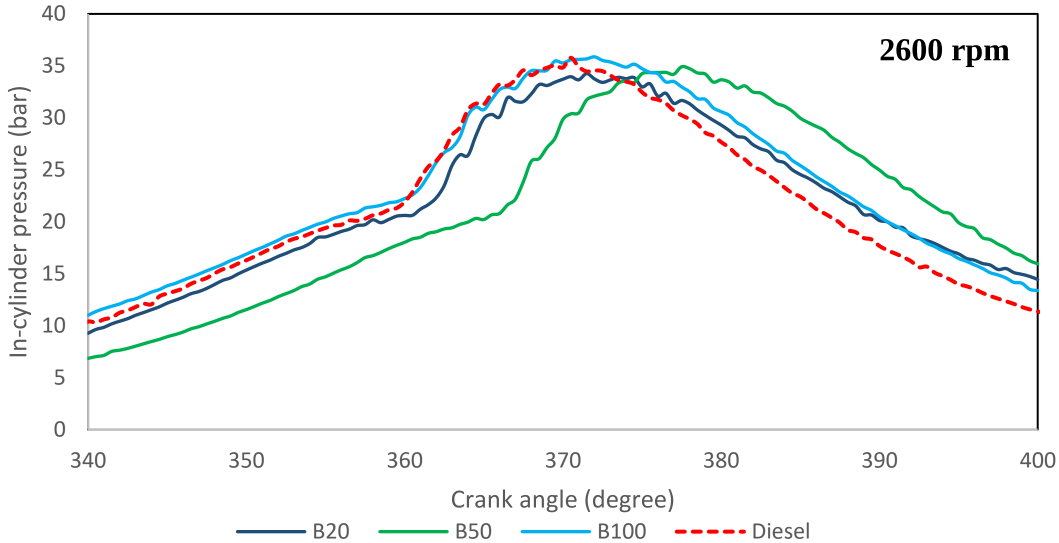

Figure 5.13. In-cylinder pressure vs crank angle at engine speed of 2600 rpm

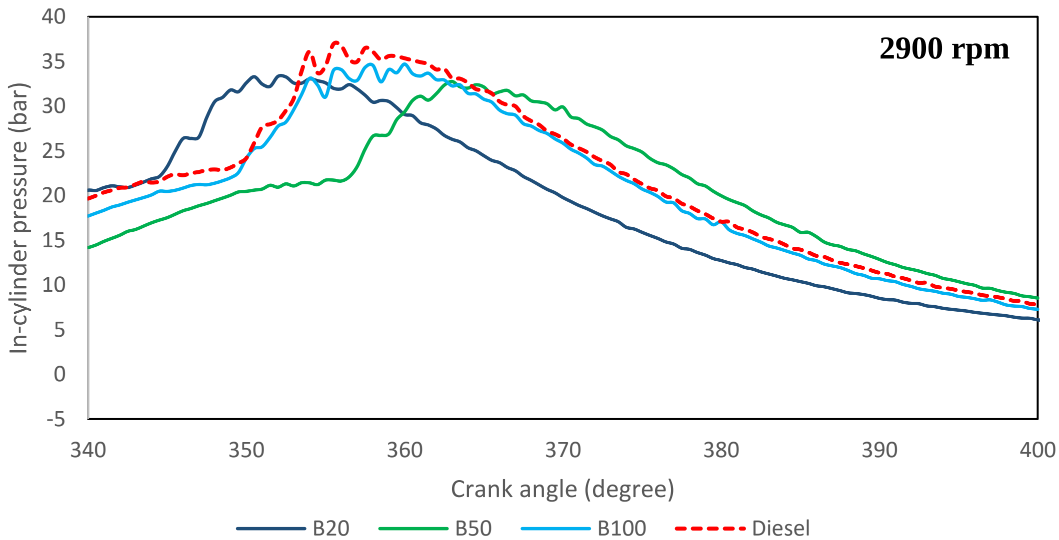

Figure 5.14. In-cylinder pressure vs crank angle at engine speed of 2900 rpm

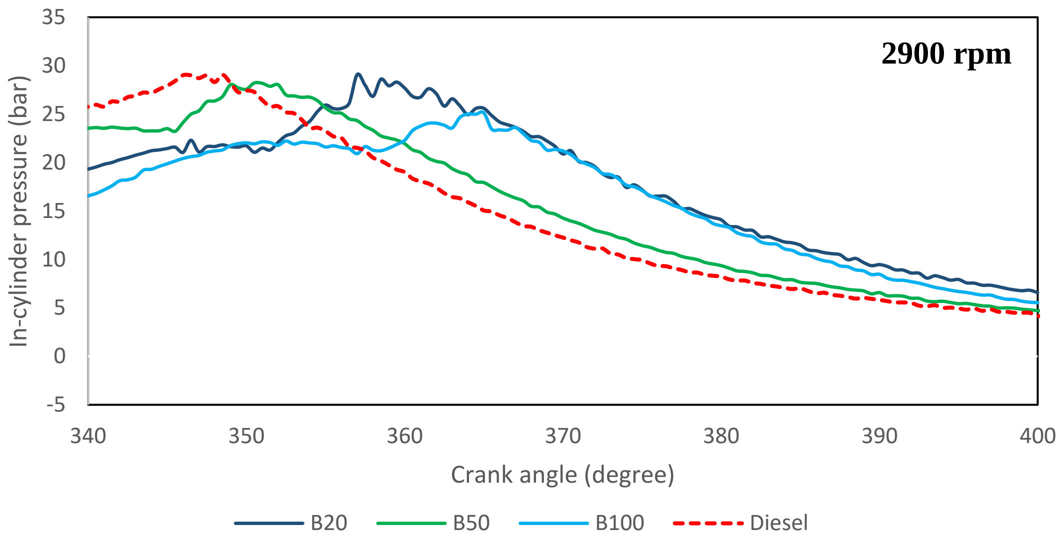

Figure 5.15. In-cylinder pressure vs crank angle at engine speed of 3800 rpm

6 CONCLUSION

The aim of this research work was to investigate the performance, combustion and emission characteristics of diesel engine fueled with the biodiesel blends of commercially available Australian biodiesel with the diesel fuel. Different blends were prepared w.r.t percentages of biodiesel and diesel. These blends included B20, B50, B100. Experiments were performed on the single cylinder 4-stroke diesel engine and the above mentioned three biodiesel blends were tested. The comparison of these blends was performed with the standard diesel fuel. In performance analysis, the parameters which were measured experimentally consisted of fuel consumption, brake specific fuel consumption, torque, brake power and exhaust temperature. In exhaust emissions analysis, the emissions which were measured experimentally consisted of carbon monoxide, carbon dioxide, unburnt hydrocarbons, oxygen and nitrogen oxides emissions.

The brake power of engine fueled with different blends and diesel fuel is almost same. There is no significant difference between the brake power of biodiesel blends and diesel fuel at each engine speed. Similar to engine brake power, overall, there is no significant difference between the engine torque of biodiesel blends and diesel fuel. Fuel consumption of biodiesel blends increases when the amount of biodiesel in blend is increased. Only the blend B20 shows lower value of fuel consumption in which amount of diesel is maximum i.e. 80% as compared to other three biodiesel blends. The blend in which diesel will have maximum amount will show fuel consumption more closely to that of diesel fuel. Biodiesel blends, except B20, show higher values of brake specific fuel consumption at all engine speeds. In B20, percentage of diesel is maximum as compared to other three biodiesel blends, therefore, it shows more closely values of brake specific fuel consumption to that of diesel fuel. Exhaust temperature of biodiesel blends (B50 and B100) is lower than that of diesel fuel. Only the biodiesel blend B20 shows higher values of exhaust temperature when compared with the diesel fuel.

Hydrocarbon emissions obtained in biodiesel blends are less as compared to diesel fuel at each engine speed. As the concentration of biodiesel increases in the blend of biodiesel and diesel, the amount of unburnt hydrocarbon emissions decreases. Carbon monoxide emissions obtained in biodiesel blends are less as compared to diesel fuel at each engine speed. As the concentration of biodiesel increases in the blend of biodiesel and diesel, the amount of unburnt hydrocarbon emissions decreases. Carbon dioxide emissions obtained in biodiesel blends are less as compared to diesel fuel at each engine speed. As the concentration of biodiesel increases in the blend of biodiesel and diesel, the amount of unburnt hydrocarbon emissions decreases. Oxygen emissions in biodiesels blends are higher as compared to diesel fuel at each engine speed. Considering oxygen emissions, biodiesels are desired and more useful as compared to diesel fuel. Nitrogen oxides emissions are reduced in the biodiesel blends as compared to diesel fuel at each engine speed. As the concentration of biodiesel in the blend increases, nitrogen oxides are further reduced. Since, these emissions should be minimum, therefore, biodiesels are preferred and more useful as compared to diesel fuel.

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8 APPENDICES

Appendix A: Project Timelines

The following table shows the schedule of the complete project:

Table 8-1: Project Timelines

Task	**March**	**April**	**May**	**June**	**July**	**August**	**September**
Ideal developing and literature review							
Safety precautions to P7 lab							
Research approach and safe work procedure (SWP)							
Preparing the fuel, engine setup and performing test							
Data analysis							
Writing the thesis							
The submission of the dissertation							

Appendix B: Ethics issues related to project

There are no ethical issues associated with this project, so no ethical approval is required from the university office of research. The only ethic that need to be reported is to keep the university and supervisor acknowledged about the research done in laboratory.

Appendix C: Safety precautions in laboratory

While working in the lab, all the rules and regulations assigned by supervisor and the University will be followed:

i. Not drinking or eating in the laboratory.
ii. Wearing appropriate clothing and footwear and conducting myself in a responsible manner while working in the laboratory.
iii. Reporting all the incidents to the supervisor.
iv. Monitoring the experiments personally all the time in laboratory.
v. Respecting lab equipment and colleagues.
vi. Risk Management Plan (RMP) is developed for the project along with Safe Work Procedure (SWP).

Appendix D: P7 Induction checklist

UNIVERSITY OF SOUTHERN QUEENSLAND

P7 Induction

P7 INDUCTION CHECKLIST

Revised by: **Brian Aston**
Revision Date: **31st May 2016**

To be completed by all personnel working in the P7 building.

Emergency Procedures for P7 building 2222 .... ☑
Exits .... ☑
Assembly point .... ☑
Alarm system .... ☐
Appropriate clothing – no loose clothing, footwear, remove jewellery .... ☑

- **Show Location of:**

SDS's (Safety Data Sheet), SWP location and procedures .... ☑
First Aid Kit, Usage Log, Incident reporting and hazard reporting procedures .... ☑
Safety Notice Board .... ☑
Fire Extinguishers .... ☑
Evacuation alarms .... ☑
PPE (personal protective equipment) .... ☑
Wash Station (Outside P7 Southern Door or Northern Exit Door) .... ☑
Toilets .... ☑
Telephones .... ☑

- **Protocols for P7**

PPE as specified by SWP or SDS's.. ☑
Report to P7 staff .... ☑
Follow all instructions given by P7 staff.. ☑
Complete safety induction and read SWP before using any new tools or equipment .... ☑
Do not interrupt anyone who is operating equipment or tools .... ☑
Intellectual Property and Confidentiality .... ☑
Housekeeping - clean up and tools away .... ☑

- **Use of Equipment**

SWP read and understood for specific machine, tool or task .... ☑
Risk Assessment required? yes/no .... ☑
Competency assessed by P7 staff before using equipment or undertaking task .... ☑
Only one engine maybe operated at any one time in the engine test cell...................... ☑

Name (print)...[redacted]..........

Inductee Sign ...[redacted]..Date.[redacted]

Trainer Sign....[redacted]..............................Date [redacted]

1
Revisesd Tuesday, 31 May 2016

P7 Laboratory Safety Guidelines

The safety code defined in this document is designed to reduce the risk to both yourself and your fellow researchers. It is very important that you follow them.

An important part of your engineering training is to learn the safety standards you will be expected to comply with during your career as engineers or engineering academics.

Who does it apply to?

All personnel working in P7.

Personal Protective Equipment (PPE):

General Rules:

- Comply with all PPE signage when entering work area and P7 laboratories.
- Wear non-flammable type clothing such as cotton or wool that cover the arms and legs and no loose fitting baggy clothing or dangling jewellery or loose long hair. Long hair must be tied back using a hair net.

Rules relating to Specific Areas.

Workshop & Instrument Lab:

- Wear accredited safety glasses and work boots

Fuels Lab:

- Wear accredited safety glasses and work boots and disposable gloves when handling fuel.

Main Engine Test Cell:

- Wear accredited safety glasses and work boots and suitable hearing protection and disposable gloves when handling fuel.

Fuel Stores:

- When decanting fuel, always wear accredited safety glasses, work boots and disposable gloves.

Using Engine Crane:

- Hard Hats and work boots must be worn when operating the engine crane.

General Safety Laboratory/Workshop Practices

- Never work in the laboratory alone, always have another qualified person in the area with you.
- Never leave an on-going experiment unattended. If the experiment spans overnight or longer, ensure it is left in a safe state and is adequately labelled/signed to ensure the safety of all laboratory personnel.
- Never store heavy items above table height, any overhead storage of supplies on top of cabinets should be limited to lightweight items only.
- When decanting flammable liquids from one container into another, always connect the two vessels with an earth strap.
- Wearing an "iPod" or other device that interferes with hearing and obstructs you from hearing audible emergency alarms is not permitted within the building.
- Do not use any equipment unless you are trained and approved as a user by your instructor or staff. Ask questions if you are unsure of how to operate something.
- Perform only those experiments authorized by the instructor or supervisors and that have risk assessments completed.
- Never do anything in the laboratory that is not called for in the laboratory procedures or by your instructor. Carefully follow all instructions, both written and oral. Unauthorized experiments are prohibited.
- Food and drink are only allowed in designated areas.
- If any laboratory equipment is malfunctioning, making strange noises, sparking, smoking, or smells "funny," Get an instructor or staff immediately. It is imperative that the instructor or staff knows of any equipment problems.
- All accidents, no matter how minor, should be reported to the faculty/staff member supervising the laboratory immediately.
- Keep aisles clear and maintain unobstructed access to all exits, fire extinguishers, electrical panels, emergency showers, and eyewashes.
- Do not use corridors for storage or work areas.
- Avoid using extension cords whenever possible. Extension cords should not go under doors, across aisles, be hung from the ceiling, or plugged into other extension cords.

- When using compressed air, approved nozzles are only allowed to use and never direct the air towards any person.
- Guards on machinery must be in place during operation.
- Exercise care when working with or near hydraulically- or pneumatically-driven equipment. Sudden or unexpected motion can inflict serious injury.
- Flammable chemicals must be stored in an Approved Flammable Storage Cabinet.
- Make sure all chemicals are clearly and currently labelled with the appropriate ChemWatch label.
- When you have completed your project, all components must be dismantled and returned to their proper locations and entered into the loans book as "returned" and date it. You are responsible for disposal of ALL unwanted materials.
- Please report any unsafe behaviour or condition to the instructor, supervisors or staff.
- Please ensure the front door and back doors are locked properly to maintain security standards.
- Clean all spilled liquids from floors which can cause slipping.
- Getting close to running machines or hazardous areas is not allowed without permission of authorized staff.
- When working in the engine and fuel laboratories make sure the ventilation system for that area is switched on.
- Students and staff are expected to demonstrate mature judgment and common sense when working in the laboratories.

- **Student Acknowledgement of Responsibilities when working in Faculty of Health Engineering & Sciences Laboratories**

- I, [redacted] ______acknowledge that I am responsible to immediately inform the Technical Officer responsible for the P7 Engine Laboratory of any chemical or instrument I will use during my research in these laboratories so that adequate safety documentation can be carried out before commencement of the experiments.
- I am also responsible to sign and date any documents, SDS or SWP, given to me by the Technical Officer in charge, before commencement of the experiments.
- I acknowledge that failure to do so may result in exclusion from the labs and may result in not being able to obtain insurance cover in case of an accident.
- [redacted]
- Print your Name
- [redacted] [redacted]
- Signature, Date