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COMBUSTION HEAT RELEASE MODELS OF BIODIESELS

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ABSTRACT

Fossil fuels such as standard gasoline and diesel fuel are the most important source of energy for our society today, providing the bulk of global energy requirements for transportation, construction, heating, and agriculture. Many new developments in technology have made alternative sources of energy more economically feasible including advances in solar, wind, geothermal and nuclear energy. It is a domestic, clean-burning, renewable liquid fuel that can be used in compression-ignition engines instead of petroleum-based diesel with little or no modifications. Biodiesel blends are more commonly used than pure B100 fuels. The main reason for this is that running 100% biodiesel sometimes requires modifications to the engine, due to the higher content of alcohol present in biodiesel.

INTRODUCTION

Nowadays, the world energy demand has increased significantly due to the global industrialization and increase of population. As a result, the current limited reservoirs will soon be depleted at the current rate of consumption. The Oil and Gas Journal (O&GJ) estimates that at the beginning of 2004, the worldwide reserves still had 1.27 trillion barrels of oil and 6,100 trillion cubic feet of natural gas left. However, at today's consumption level of about 85 million barrels of oil per day and 260 billion cubic feet of natural gas per day, the current reserves can only be used for another 40 years for the oil and 64 years for the natural gas (Vasudevan and Briggs 2008). Moreover, increase of pollutant emissions from the use of petroleum fuel will affect human health, such as respiratory system, nervous system and skin diseases etc. Both the increased energy needs and environmental consciousness have stimulated the research of searching an alternative fuel. Biodiesel may be the best answer due to its following advantages: provides good engine performance and can be used without modification, provides the market with biodiesel from sufficient production of waste vegetable oils and animal fats, thus enhancing rural economies and biodegradable and nontoxic. Waste vegetable oils are generally low cost. They usually can be collected from large food processing and service facilities. However, due to the very high temperature that occurs during the food frying process, chemical reactions such as hydrolysis, polymerization and oxidation will have taken place, and these can lead to an increase of free fatty acid (FFA) level. Hence, acid catalysis is preferred since it is insensitive to FFA (Freedam 1984). In fact, the amount of waste vegetable oil generated in the world is huge and varies according to the amount of cooking oil consumed. Biodiesel blends are more commonly used than pure biodiesel (B100) fuels. The main reason for this is that running 100% biodiesel sometimes requires modifications to the engine, due to the higher content of alcohol present in biodiesel. These modifications require fuel lines to be changed to steel, as alcohol will corrode the rubber lines more commonly used. Because only 1 percent of petrol is toxic enough to prevent the formation of mould it is common to use B99 (99 % biodiesel and 1% petroleum diesel) instead of B100. The letter "B" designates the type of fuel, in this case Biodiesel, while the number after it designates the percentage of biodiesel. B5 contains 5% biodiesel mixed with 95% petroleum diesel. Following this rule, B20 has 20% biodiesel and 80% petroleum diesel. Blending the two different diesel fuels, allows the fuel to have the benefits of the lower emissions present in biodiesel, while allowing for a lower concentration of alcohol which allows for the engine to run without any modifications. The B20 of biodiesel blends can be used effectively as an alternative suitable fuel in compression ignition engines without any modification in the engine structure (Abuhabaya 2013). Engine performance characteristics are the major criterion that governs the suitability of a fuel. The methyl ester from waste oil was tested by Utlu and kocak (2008) in diesel engine, and the authors observed that the average decrease of torque and power values was 4.3% and 4.5% for biodiesel, respectively, compared to diesel fuel, although the maximum torque and power values of biodiesel decrease as 1.45% and 0.55%, respectively. Ozsezen et al. (2009) reported that the maximum brake torque for diesel fuel and biodiesel at 1500 rpm under full load condition was measured as 328.69 Nm and 319.80 N m, respectively. The maximum brake power (52.12 kW) was obtained for diesel fuel, and followed by biodiesel (50.71 kW). On the other hand, several research groups have investigated the properties of a biodiesel blend in diesel engines and found that particulate matter (PM), CO, and soot mass emissions decreased, while NOx increased. Raheman et al. (2004) studied the fuel properties of karanja methyl esters blended with diesel from 20% to 80% by volume. It was found that B20 (a blend of 20% biodiesel and 80% petroleum diesel) and B40 (a blend of 40% biodiesel and 60% petroleum diesel) could be used as an appropriate alternative fuel to petroleum diesels because they apparently produced less CO, NOx emissions, and smoke density. Lin et al. (2006) confirmed that emission of polycyclic aromatic hydrocarbons (PAH) decreased when the ratio of palm biodiesel increased in a blend with petroleum diesel. In general, biodiesel demonstrated improved emissions by reducing CO, CO2, HC, PM, and PAH emissions though, in some cases, NOx increased. The aim of this research is to investigate the viability of using biodiesel as an alternative, or additive, to basic diesel fuel. The engine performance is to be evaluated along with the emission characteristics for an engine running with biodiesel and traditional fuels. The objective of this research is to find an immediate alternative energy solution through a rigorous investigation of combustion heat release processes of different biodiesel blends, which does not involve a drastic overhaul of the world's engine structure. Obtaining a viable solution is one which can reduce the global green house emissions over the petroleum diesel counterpart, while maintaining a similar output in performance, emission and efficiency.

MATERIALS

Methanol and sodium hydroxide were purchased from Fisher Scientific (Loughborough, Leicestershire, UK). Vegetable oil was bought from local shops in Huddersfield, United Kingdom. Waste cooking oil was supplied by Huddersfield University Catering Services. The diesel B0 was obtained for specialist oil suppliers as commercially available diesel is B5. The biodiesel was blended at B10 (10% of biodiesel to 90% of standard diesel by volume), B20, B30, B40 and B100 and evaluated for engine performance and exhaust gas emissions compared to standard diesel.

EXPERIMENTAL SETUP DESIGN

In this research, the experiments were divided into three stages. First stage was biodiesel production from waste vegetable oils; second stage was fuel properties testing, and third stage was engine testing. Fuelpod machine manufacturer was used for the production of biodiesel from waste vegetable oil. The machine is a complete system used at the University of Huddersfield automotive laboratory for making biodiesel from any kind of vegetable oils.

The greatest difference properties between vegetable and diesel oils is their viscosities. The high viscosity of crude oil may contribute to the formation of carbon deposits in engines, incomplete fuel combustion and reduced life of an engine. Thus it is important to know the viscosity of vegetable oil before use it as fuel. Brookfield digital viscometer and Glass capillary viscometer were used to measure dynamic and kinematic viscosity. According to ASTM Biodiesel standard D6751 test method D445, the kinematic viscosity for biodiesel will be between 1.9 and 6.0 mm2/s at 40^{o}C. For this range of viscosities, a B size U-tube viscometer is suitable as it has range of between 2 to 10 mm^2/s. Also used was U-tube viscometer size D, which is suitable for vegetable oils, and has a kinematic viscosity range 20-100 mm^2/s. The results obtained are as a results section. The U-tube viscometers were kept in a water bath which provided stable temperatures of 20^{o}C, 40^{o}C and 70^{o}C.

The steady state engine test runs were carried out on an engine test bed using the JCB444 TCA 74kW engine. The test engine and dynamometer were controlled by a microprocessor system equipped with data acquisition and logging. Sensors were fitted to the engine and the dynamometer, to measure relevant parameters and send the data to the control system. The sensors measured engine load, engine speed, inlet air temperature, exhaust gas temperature, lubrication oil temperature, fuel consumption and the cooling water temperature. The system allows for highly accurate measurement of the main exhaust emission components. The specifications of the four-stroke, JCB444 TCA 74kW direct injection diesel engine, turbocharged diesel test engine were: bore = 103 mm, stroke = 132 mm, compression ratio = 17.2:1, fuel injection release pressure = 135 bar, max power = 74.2 kW @ 2200 rpm, max torque = 440.0 Nm @ 1300 rpm. The engine test rig and Schenk dynamometer shown in "Fig. 1."

Figure 7. Photo of test rig, Schenk dynamometer fitted with JCB 444 TCA 74kW engine

The engine was tested in a series of steady state operating conditions at engine speeds of 1500, 2200, 2600, 3000 and 3300 rev/min and engine loads of 100, 200, 300 and 400 Nm. At each of these conditions the engine was allowed to settle and warm up for about 15 minutes and then the results acquired at a rate of 15 per second with the values averaged over the last 10 minutes of operation. During the experiments, the cooling water and engine oil temperatures were constant at about 80°C, and the laboratory temperature was within 20-25°C. The gas analysers and the measuring equipment were calibrated before each experiment.

RESULTS AND DISCUSSION

The experimental ester production was repeated for each batch of pure and waste cooking oils to determine the yield of ester and glycerol. The ester conversion was obtained from the Fuelpod system. It was observed that the ester yield decreased with the increase in sodium hydroxide concentration. With 1.2% catalyst concentration, a complete soap formation was observed. This is because the higher amount of catalyst caused soap formation (Williams 2007). The rise in soap formation made the ester dissolve into the glycerol layer as shown in Fig. 2. Fatty acid contents are the major indicators of the properties of biodiesel since the amount and type of fatty acid content in the biodiesel largely determine its viscosity.

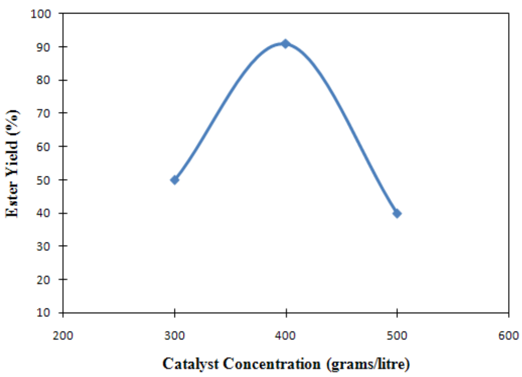

Figure 2. Effect of catalyst concentration on ester yield conversion

The experimental results obtained from the tests carried out on engine performance and exhaust emissions are presented in the following discussion. These include results at different speeds and loads for the different biodiesel blends. The results are discussed from the viewpoint of using biodiesel as an alternative fuel for compression ignition engines. As the purpose of these tests was to compare biodiesel and biodiesel blend fuels with their petroleum diesel counterpart the engine was first tested using petroleum diesel as the fuel to establish a base line for comparison. Petroleum diesel is a fossil fuel and is notorious for appearing to be a dirty fuel, but has a high energy content of about 44 MJ/kg. With diesel engines the air and fuel is not premixed, instead they mix as they enter the combustion chamber and combustion is initiated by the temperature rise due to compression alone. Diesel engine combustion is never perfect and dissociation occurs. This causes the engine to produce and emit pure carbon particles, which can cause the exhaust to appear black in colour. This in itself proved a problem for the sensor, as the carbon particles clogged the filters of the Horiba exhaust analyser faster than expected, and they (and the hoses connected to the exhaust) needed cleaning prior to any run.

Engine Performance for a Range of B100

Figs.3, 4, 5 and 6 shows the variation in the brake power, torque, brake specific fuel consumption and thermal efficiency with the engine speed of the test engine operated at full load with standard petroleum diesel and biodiesels. The brake power reached its peak value at the speed of about 2600 rpm for all fuels. The brake power of the engine with standard diesel was higher than for any biodiesel. Standard petroleum diesel produced 8.4% and 5.6% more power than biodiesel from Rapeseed oil at engine speed 2600 and 3300 rpm, respectively. Because the biodiesels have lower calorific values than that of standard diesel, both torque and brake power is reduced. However, difference in brake power between standard diesel and the biodiesels were very small in most cases. The brake specific fuel consumption (BSFC) for biodiesel operation was on an average 11.6% higher than that for standard diesel operation. This increase may be attributed to the collective outcomes of the higher fuel density, higher fuel consumption and lower brake power due to lower calorific value of the bio-diesel.

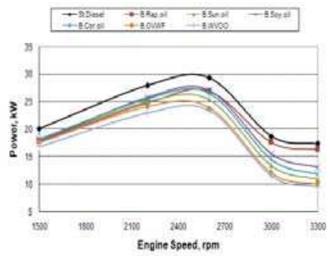

Figure 3. Power against engine speed at full load

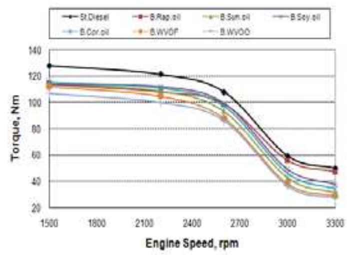

Figure 4. Torque against engine speed at full load

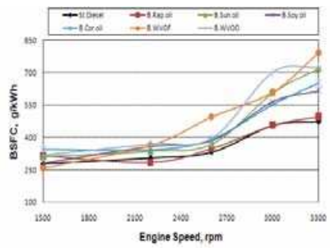

Figure 5. Fuel consumption against speed at full load

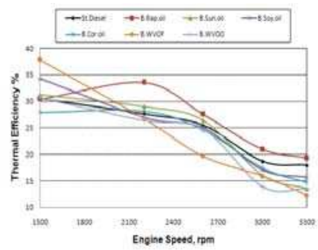

Figure 6. Thermal efficiency against speed at full load

Brake thermal efficiency for standard diesel and biodiesel as a function of engine speed are shown in Fig. 6. The maximum thermal efficiency for standard diesel and biodiesels was observed to occur close to 1500 rpm. It was seen that biodiesel has higher thermal efficiency than standard diesel and the mean difference in thermal efficiency between them was about 1.5%. The improvement of thermal efficiency with biodiesel can be attributed to the oxygen content and higher cetane number of biodiesel. These properties lead to favourable effects on the combustion process and a slight improvement thermal efficiency for biodiesel operation in spite of the lower calorific value of biodiesel.

Cylinder pressure profile comparisons

The cylinder pressure profile can be considered to be the pulse of an engine, and is most commonly used to study the combustion process. The function of cylinder pressure is related to crank angle for four strokes of the diesel engine cycle, and it has been used to obtain quantitative information about the combustion process. In addition, the pressure history and peak pressure inside the engine cylinder give an indication of the timing and quality of the combustion as shown in Fig. 7. This diagram presents the basic behaviour of combustion process for different types of fuel in order to obtain more details and understanding of this process. The Figures below show that the in-cylinder pressure has been increased alongside increasing engine speed and loads for all types of fuel, which indicates that biodiesel is an alternative diesel fuel.

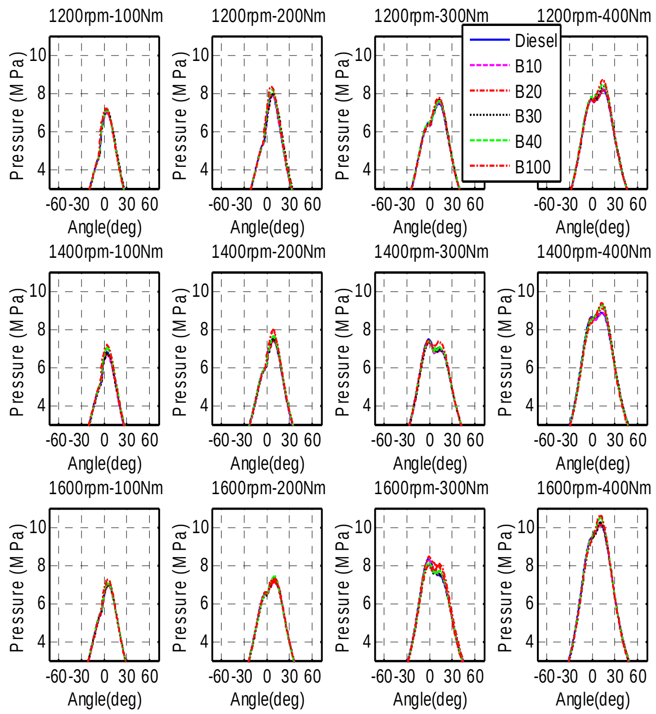

Figure7. In-Cylinder Pressure Diagram

Comparison of the rate of Cylinder pressure rise

The performance of maximum cylinder pressure is similar to the maximum rate of cylinder pressure as far as providing an estimate for the heat release phasing is concerned. For more information about the combustion process, the variation in the rate of pressure rises with crank angle for diesel and biodiesel blends at different engine loads with an engine speed of 1200, 1400 and 1600 rpm, which are nearly the same physical properties of engine combustion process as shown in Fig. 8.

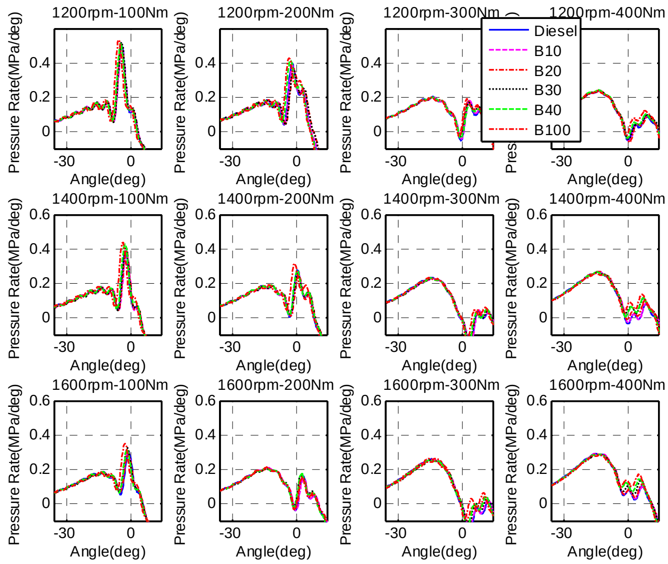

Figure 8. In-Cylinder pressure with pressure rate

Comparison of heat release rate

Although diesel engines are overall lean-burn systems, the combustion is predominantly and locally stoichiometric burn, because the flames tend to initialize and propagate to approximately stoichiometric regions. Therefore, the heat release slope is generally steep and the crank angle of heat release represents a stable and robust measure of the phasing of combustion, compared to maximum pressure and maximum rate of pressure, as shown in Fig. 9.

Comparison of Cumulative heat release

The resulting heat release rate is termed as the apparent or net heat release rate, apparent heat release model (dQ_{app}). Substituting $dQ_{app} = dQ_{gr} - dQ_{ht}$ and $d_{mc} = d_{mi} = 0$. Equation (1) gives the apparent heat release rate as follows:

$$\frac{dQ_{app}}{d\theta}=\frac{dQ_{gr}}{d\theta}-\frac{dQ_{ht}}{d\theta}=\frac{1}{\gamma-1}\left[\gamma p\frac{dV}{d\theta}+V\frac{dp}{d\theta}\right] \qquad (1)$$

Where p is the cylinder pressure, V is the cylinder volume, γ (gamma) is the ratio of the specific heats, dQht is the charge-to-wall heat transfer and dQgr the heat release during combustion.

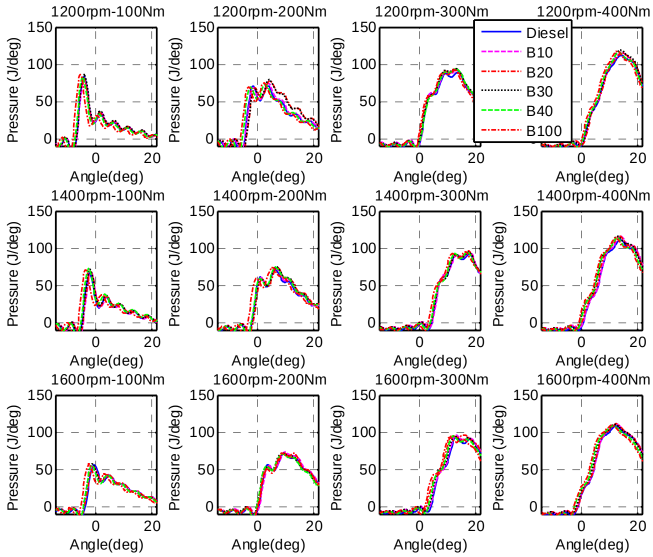

Figure 9. Variation of pressure against crank angle

The cumulative apparent heat release is obtained by summing the incremental values from Eq. (1) above, over the combustion period. Apparent heat release values are typically 15% lower than those obtained on a gross heat release basis. Apparent heat release values are very often used in preference to gross heat release values because this reduces the amount of computation and avoids the need for heat transfer parameters to be specified. Although the apparent heat release analysis generally provides reasonable accuracy for heat release phased close to the top dead center, however, under certain operating conditions.

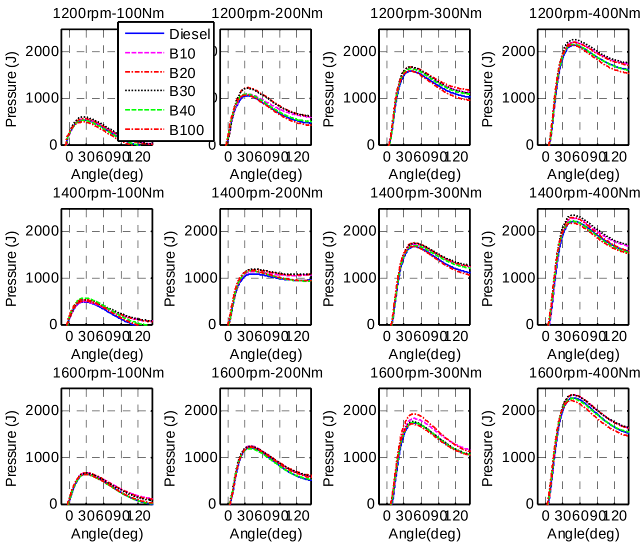

Figure 10. Cumulative apparent heat release

CONCLUSION

Empirical investigations are carried out for the implementation of real-time heat release analysis that will provide feedback for adaptive control of modern diesel combustion systems. The suitability of a number of cylinder-pressure derived parameters and heat release characteristics is discussed for real-time applications. The crank angle of heat released was shown to represent a stable and robust measure of the phasing of the heat release patterns that characterize the clean combustion techniques of modern diesel engines. The experimental work has investigated the diagnosis combustion process by cylinder pressure measurement for JCB diesel engines, and engine operating conditions with the different fuels of diesel and biodiesel. The combustion process of diesel engines is usually represented by a cylinder pressure signal. The combustion profile for biodiesel fuel that is very similar to that of the baseline diesel fuel, and a similar torque is demanded from the engine. The pressure of combustion increases marginally when increasing the percentage of biodiesel. Reviews indicate that engine performance characteristics with biodiesels are similar to those with fossil diesel, which makes biodiesel fuels an alternative to help overcome the current energy and environmental crises. One of the purposes of this study was to analyze the emissions present by running biodiesel fuels and its blends on a conventional diesel engine. From the literature review it was apparent that by running a biodiesel blend fuel there would be a decrease in emissions present while a slight decrease in engine efficiency. The experiential data did confirm these claims showing decreases in almost all the emissions CO, THC and CO_2 except for NOx.

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