Combustion Characteristics of Direct Injection (DI) Diesel Engine Fueled with 2-butyl Alcohol/ Diesel Blends at Different Speed

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Abstract

Alcohol is one of the alternative fuels that can give significant different on engine combustion characteristic as well as exhausts emission. In this study, the influence of 2-butyl alcohol/ Diesel blends on the combustion characteristic of a DI diesel engine was investigated by using three different fuel blends (Diesel, DBu5, and DBu10). Both 2-butyl alcohol and diesel fuel were blended together before tested on 3 liter common-rail direct injection diesel engine by their percentage (volume) of 2-butyl alcohol 5% (DBu5) and 2-butyl alcohol 10% (DBu10). The test results were analysed and compared with a base diesel engine operate at same speed and load. The tests in a compression ignition engine including analysis of combustion characteristics. The experiments were handled at five different speeds in the same operating condition. The results shows that the use of 2-butyl alcohol fuels blends, ignition delay is increased, maximum in-cylinder pressures are marginally reduced and in-cylinder temperatures are reduced during the combustion. The addition of 2-butyl alcohol can considerably improve CO_2 emissions and slightly increase on NOx and CO.

Key Words: 2-butyl alcohol, DI diesel engine, Combustion characteristics

Introduction

This modern era, the use of engine technology is growing rapidly. Diesel engine is capable of reducing NOx production rates with an excellent fuel economy. Diesel engines usually provide fuel savings of 25 to 30% better than the same gasoline engine and about 15 to 25% better than hybrid-powered cars (Balat & Balat, 2008).

Alcohol is considered as a potential biofuel for road vehicle in near future (Doğan, 2011; D. C. Rakopoulos et al., 2010; Szulczyk, 2010; Yilmaz et al., 2014; Zhang & Balasubramanian, 2014). 2-butyl alcohol (also known 2-Butanol) mainly produces from agricultural feedstock such as sugar cane, potato and corn (Doğan, 2011). Butanol is produce through a fermentation process. During this process, acetic acid and glycols are formed. The Butanol is subsequently isolated after fermentation by using adsorption and distillation techniques. Butanol is an excellent fuel for compression ignition (CI) engines (Çay et al., 2013). Butanol has lower heating value, a higher cetane number, larger viscosity, lower volatility, a higher flashpoint and better lubricity. In addition, diesel fuel can be mixed with butanol without critical phase separation in certain time. Butanol molecules contain hydroxyl and alkyl, that easier to merged into diesel fuel. In fact, butanol has very good inter-solubility with diesel fuel without any surfactant (Yao et al., 2010).The Butanol has four main isomer. Every isomer has different melting and boiling points. Iso-butanol and n-Butanol have limited solubility, while sec-butanol has substantially greater solubility. Tert-butanol is fully miscible with water. By owing these advantages, butanol–diesel fuel blends studies began to increase in the recent years (Doğan, 2011; D. C. Rakopoulos et al., 2011; Yao et al., 2010; Yoshimoto et al., 2013). These characteristics show that butanol has the potential to overcome low-carbon alcohol problems. Furthermore, the great potential is to use Butanol in diesel engine to reduce the dependency of diesel engine to petroleum diesel.

In this work, for the 2-butyl alcohol-diesel blends, a combustion analysis is performed for studying the relevant combustion behaviour from other researcher. The experimental cylinder pressure from the kistler crank angle encoder placed at engine, are directly processed in connection with Dewetron system. The combustion results combined with the differing physical and chemical properties of the 2-butyl alcohol against those for the diesel fuel, which constitutes the ‘baseline’ fuel, aid the correct interpretation of the observed engine behavior combustion wise when running with this 2-butyl alcohol-diesel blend.

Material And Methodology

Experimental setup

The experimental setup consists of an Isuzu 4JJ1 turbocharger, four cylinder diesel engines as engine test bed and a data acquisition system in control room. This engine is equipped with an exhaust gas recirculation system; however, in this study the EGR mode is set to off. The schematic of the experimental setup is shown in Figure 1 and specification of the test engine was given in the Table 1. A 150kW ECB-200F SR No. 617 from Dynalec Controls eddy-current dynamometer was used in the experiments. A universal propeller shaft was used to transfer the energy from the engine to the dynamometer. The dynamometer brake and the operating conditions of the engine are characterized by the speed and torque. The control system of the dynamometer has been mounted in the control room. The engine speed can be controlled at the desired value. Brake torque is measured by the eddy current dynamometer and it value was displayed through a Dynalec dynamometer controller and DeweCA system. The function of dynamometer is to absorb the power electromechanically and delivered by the engine. The heat generated by the applied torque has been removed by utilizing the external cooling tower. Engine Power Test Code for Compression Ignition SAE J1349 was used as standard for testing the engine (SAE, 2004).

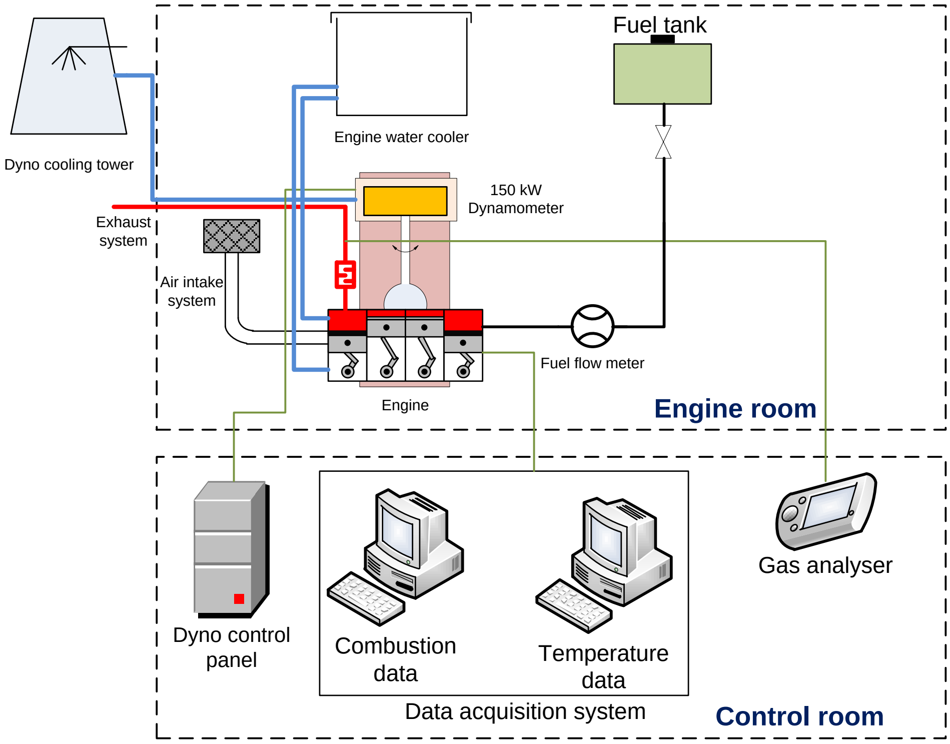


Figure 1: Schematic diagram of the experimental setup

The Isuzu 4JJ1 engine as shows on Table 1 was used in this experiment. The engine was tested at different loads and engine speeds (1000 rpm to 3000 rpm) using different percentage of Diesel with 2-butyl alcohol (5% and 10%) blends at half load. Researchers summarized the DBu5 (Diesel - 2-butyl alcohol 5 %) and DBu10 (Diesel – 2-butyl alcohol 10 %). At the beginning of each test, the throttle position was adjusted to give a speed of 1000 rpm at a lowest dynamometer load. In the experiments, the load was increased slowly as the engine speed increase by 500 rpm up to 3000 rpm. For each engine speed, the load is constant at 50% while the fuel consumption rate was recorded. The engine was started with the original diesel fuel first and left to warm up for about 25 to 30 min, and then the diesel-2-butyl alcohol blend was gradually introduced. At the end of each test, the engine was run using original diesel fuel for about 30 to 45 min in order to flush the fueling system from any diesel-2-butyl alcohol blended residues.

Table 1: Specification of the engine

Engine Parameters	**Value**
Model	Isuzu 4JJ1 (Turbocharged)
Bore (mm)	95.4
Stroke (mm)	104.9
Displacement (L)	2.999 L
Number of cylinders	4 in-line
Compression ratio	17.5

Fuel preparation

Table 2: Properties of diesel fuel and 2-butyl alcohol

Fuel Properties	Unit	Measurement	Diesel fuel	2-butyl alcohol
Density at 20°C	kg/m^3	ASTM D4052	837	810
Cetane number	-	ASTM D613	50	25
Kinematic Viscosity at 40°C	mm^2/s	ASTM D445	2.6	3.6
Lower Heating Value	MJ/kg	ASTM D240	43.25	33.1
Specific heat capacity	J/kg°C	ASTM D2766	1850	2545
Flash point	°C	ASTM D93	52	35
Oxygen	%weight		0	21.6
Boiling point	°C			102

Results calculation method

The basic heat release rate calculation was extended by Krieger and Borman (Krieger & Borman, 1966) to obtain an apparent fuel mass burning rate. Many other researchers have also investigated and extended the work related to heat release rate calculations. Simple method of analysis which yields the rate of heat release of the fuel's chemical energy (heat release) through the diesel engine combustion process is governed by basic assumptions and also from the first law of thermodynamics. These assumptions state that the trapped charge behaves as an ideal gas contained in a uniform single zone of constant composition from the intake valve closing to the exhaust valve opening and the energy released by combustion can be modelled as a heat addition to the cylinder. Based on these assumptions the rate of heat release is calculated as a function of the cylinder pressure and temperature at certain crank angle degree using the first law of thermodynamics. Heat release analysis computes how much heat would need to have been added to the cylinder contents, in order to produce the observed pressure variations. From the first law of thermodynamics the following equation is used (Heywood, 1988)

$$\frac{dQ_{net}}{d\theta} = \frac{\gamma}{\gamma - 1} p \frac{dV}{d\theta} + \frac{1}{\gamma - 1} V \frac{dp}{d\theta} \tag{1}$$

Results And Discussion

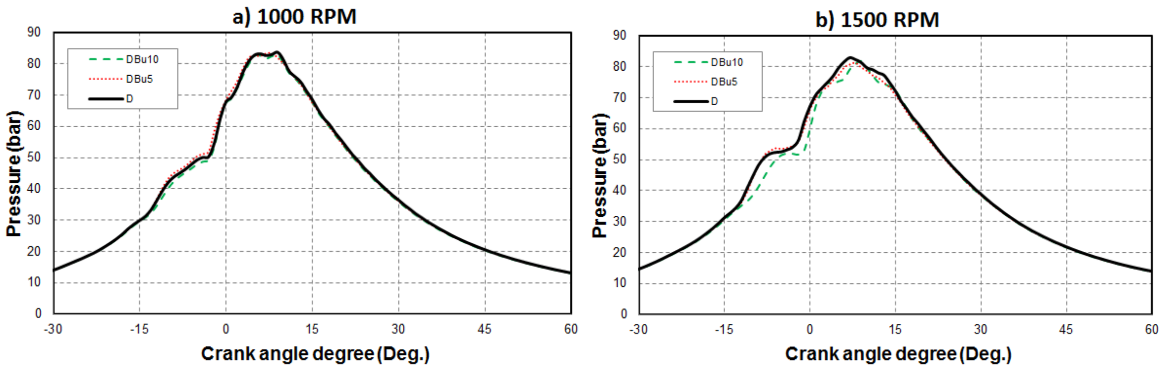
Results are discussed base on the new information of blended fuel experimented on the engine combustion characteristics, also from creative results of the blend combustion in the diesel engine or more detailed emissions reduction benefits compared to the other researches for diesel–2-butyl alcohol blends.

In-cylinder Pressure

The several of pressure inside the cylinder with respect to the crank angle degree for fuel-blends; in comparison with diesel fuel at different engine operating is revealed in Figure 2. Essentially, it shows that the in-cylinder pressure is increased with the increasing of engine load as well as advance of injection timing and peak cylinder pressure come off well along in terms of the crank angle for blends at low loads.

Figure 2 depicts the traces of maximum in-cylinder pressure of conventional diesel blended fuel DBu5, and DBu10 using the average of 100 consecutive cycles to reduce the engine cyclic variation effects. It is obvious that, at the same engine operating conditions, there is a slight difference during the combustion stroke. The peak pressure has reached up to 86.3 bar at 10 deg. ATDC and 3000 rpm for the DBu10, while it is raised to 83.6 bar at 9 deg ATDC and 3000 rpm for base diesel. The difference in peak pressure rise (4%) is due to the high oxygen content and specific heat capacity of blended fuel contains 2-butyl alcohol. This statement support by (Kumar et al., 2013), that butanol had a higher normalized peak pressure, indicating that 2-butyl alcohol had higher potential thermal efficiency. All maximum peak pressure achieved at high speed. These results are in agreement with those from a previous study (Jin et al., 2011; Kumar et al., 2013; Liu et al., 2014; Yusri et al., 2016) which finds an increase in the maximum in-cylinder pressure with the increasing blending ratio of alcohol blended fuel compared to the base diesel.

Injection timing also significantly affects engine performance as well as exhaust emissions. A trend is observed from the figure 2c that with increasing 2-butyl alcohol fraction, the start of combustion is delayed, the combustion phasing is retarded, and the peak HRR (figure 3c) increases up to 45% of DBu10. This was due to lower cetane number and higher specific heat capacity of 2-butyl alcohol extended the diesel ignition delay period.



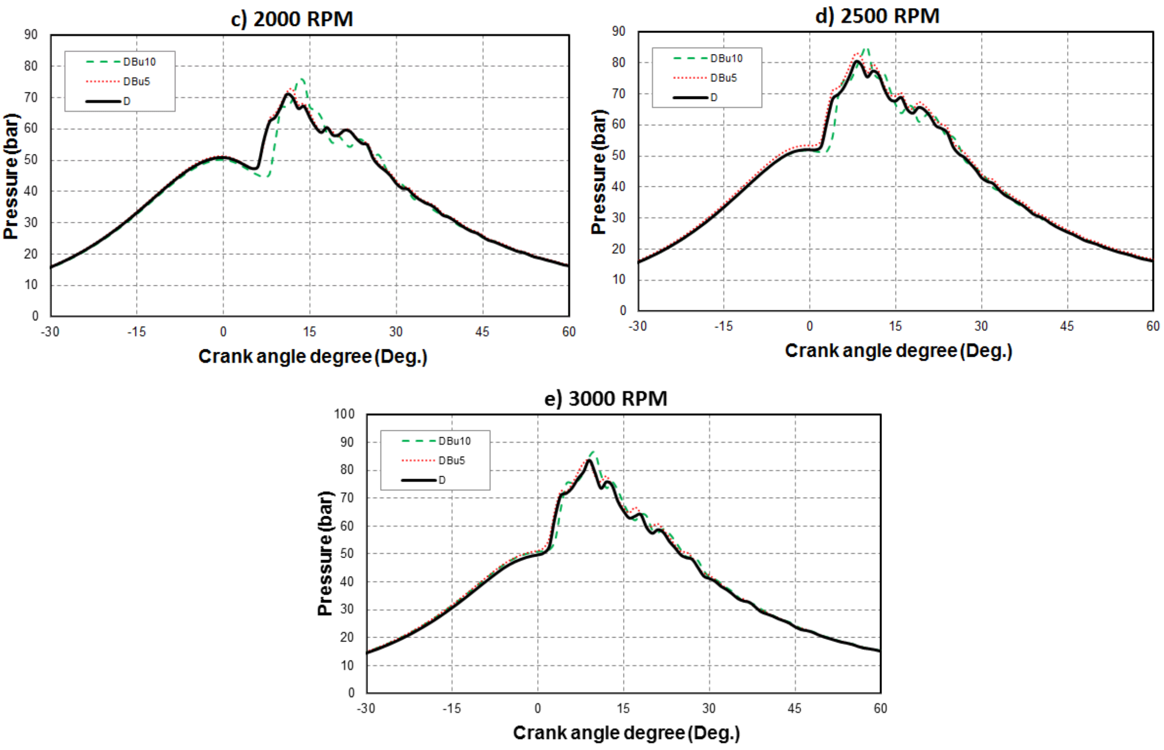


Figure 2: In-cylinder pressure at half Load

Heat release rate

The heat release is used to calculate how much heat will be required to add the contents of the cylinder, to generate pressure variation observed. The heat release rate is calculated from in-cylinder combustion aimed to investigate the combustion characteristics of the diesel engine and the fuel used (Heywood, 1988; Pulkrabek, 2004). The process of direct injection combustion diesel engine that modern can be divided into two phases. The first phase is the phase of the premix and begins after the start of injection where fuel is mixed with air and form a fuel rich burn zone during the ignition delay period. After ignition, premixed mixture quickly responds. The second phase begins when oxygen is depleted, at which combustion is changed to mode dispersion, which contains emissions at high temperatures.

Figure 3 shows the rates of heat release for different blends speed and load condition. The curve shows the heat release rates of various fuels at different speed. It was observed blended fuel produced a bit higher in heat release compare to diesel especially at higher speed. It can be found that the maximum rate of heat release in blended fuel higher than base diesel, but the pattern shows a comparable characteristic to that of diesel fuel. The premixed combustion heat release increases slightly with proportion of 2-butyl alcohol contents due to lower cetane number (Hulwan & Joshi, 2011). Higher premixed heat release rate on DBu5 and DBu10 promoted better air-fuel mixing process while slightly slower ignitions delay. Greater 2-butyl alcohol portion in the blend indeed results higher in premixed combustion rate of heat release. As discussed above, this is due to the enhanced mixing process and extended ignition delay caused by the addition of 2-butyl alcohol.

The maximum rate of heat release is delayed as 2-butyl alcohol additive increases in the blend. Furthermore, the maximum rate of heat release is reduced to below that of the diesel fuel for all 2-butyl alcohol ratios at low speed. The rate of heat release is significantly delayed for 10% 2-butyl alcohol additive with higher value of maximum rate of heat release of 1970 J/deg. at 3 deg ATDC on 3000 rpm due to the retard in the ignition timing. Furthermore, the maximum rate of heat release for blended fuel with 10% 2-butyl alcohol is slightly higher than that of base diesel at the same crank angle retard.

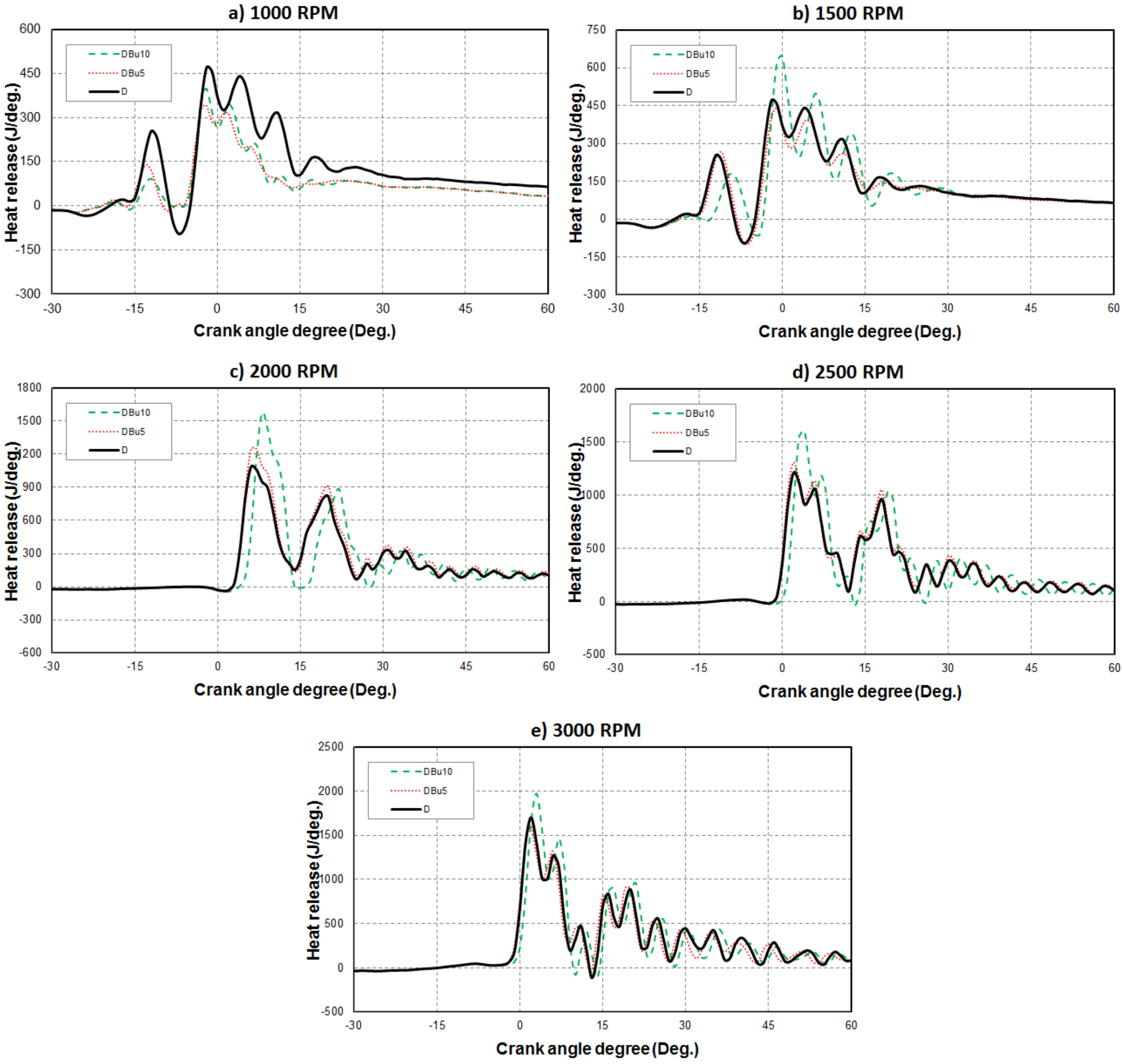
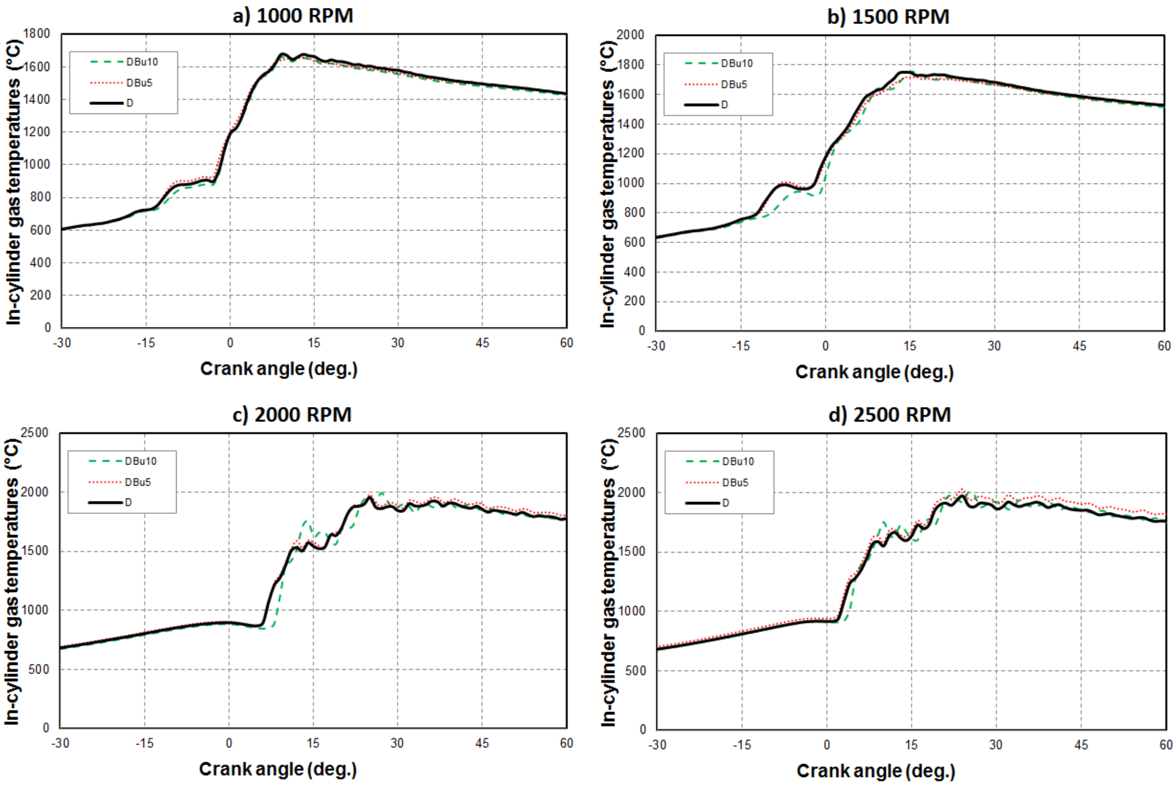


Figure 3: Heat release rate at 50% Load

In-cylinder gas temperatures

The mean cylinder gas temperature can be calculated based on the in-cylinder pressure for each crank angle degree by considering the ideal gas assumptions with a known gas temperature at reference location such as inlet gas closure. During the combustion process the in-cylinder pressure and temperature are changed simultaneously. The fuel oxygen content directly affects the combustion process and the trends of the cylinder gas temperature.

Figure 4 demonstrates the cylinder gas temperatures against the crank angle degree for diesel, DBu5 and DBu10 at various engine speeds. The fuel combustion behaviour after the peak pressure is more comparable to mineral diesel fuel. Overall, there are sudden increases in temperature tendency between -4° to 6° CAD depend on their speed. The cylinder gas temperature of blended fuel is lower that of the diesel fuel for low speed but higher at high speed. This is due to late injection leads to lower cylinder temperatures. The benefit is, there is no time available for oxidation of the emission or soot particles before opening of the exhaust valve.


a) 1000 RPM

b) 1500 RPM

c) 2000 RPM

d) 2500 RPM

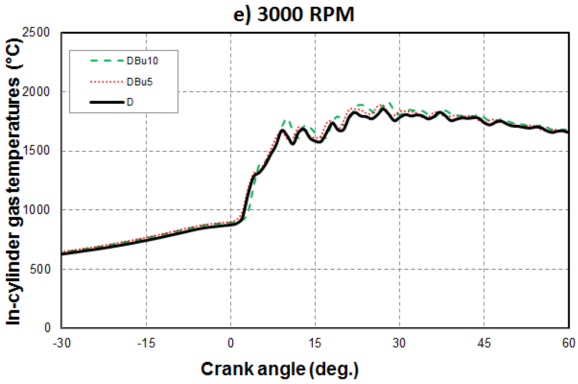


Figure 4: In-cylinder gas temperatures at 50% Load

Conclusion

Generally 2-butyl alcohol addition, in adequate quantity, in the blends of diesel, drastically improved the combustion of diesel fuel at low and middle speed. Oxygen content in 2-butyl alcohol increased up to 21.6% by means of weight ensuring the optimum combustion in the cylinder. The maximum peak pressure has reached up to 86.3 bar at 10 deg. ATDC, 3000 rpm for the DBu10, 83.7 bar for DBu5 while base diesel has 83.6 bar at 9 deg. ATDC, 3000 rpm. This difference in the peak pressure rise (4%) is due to the high oxygen content and specific heat capacities of blended fuel content 2-butyl alcohol in DBu10. The rate of heat release is significantly delayed for 10% 2-butyl alcohol additive (DBu10) due to the retard in the ignition timing. The addition of 2-butyl alcohol can considerably improve CO_2 emissions and slightly increase on NOx.

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