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Experimental investigation of the impact of using alcohol-biodiesel-diesel blending fuel on combustion of single cylinder CI engine

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Abstract. The effect of alcohol addition has been experimentally investgated in the current study by blending it with diesel and palm based biodiesel on the combustion of a compression ignition engine. The experiment was run by single-cylinder, naturally aspirated, direct injection, four-stroke diesel engine. Based on the pressure-crank angle data collected from the pressure transducer and crank angle encoder, the combustion analysis such as incylinder pressure, in-cylinder temperature, energy release rate, cumulative energy release and ignition delay are analysed. In this comparative study, the effects of alcohols namely butanol BU20 (20% butanol addition on the commercially available diesel biodiesel emulsion) is compared and evaluated with pure diesel (D100). The results revealed that the the ignition delay for BU20 is longer as compared to that of D100 in all engine speeds and loads compared. Besides, the incylinder temperatures were rudecued with the butanol addition. The energy release rate for BU20 was higher than that for diesel, whereas the peak positions concerning the energy release rate for BU20 was discovered at 2400 rpm. Therefore addition of butanol will have positive role on the NOx emissions and stability of the engine due to its higher latent heat of vaporization.

1. Introduction

Compression Ignition (CI) engine is the most widely used internal combustion engine in the transport sector nowadays. Usually, CI engine compared to spark ignition (SI) engine produces higher thermal efficiency due to higher compression ratio and the higher carbon content of the fuel [1]. However, regarding on the environmental pollutions from internal combustion (IC) engines triggered by environmental concern. Unfortunately, the pollution emitted by the CI engine regularly producing higher nitrogen oxides (NOx) and soot and other emissions. In order to meet the environmental concern the renewable and alternative fuels in internal combustion engine has been enhanced recently due to continuously decreasing the crude oil reserves, growing rapidly the costs of the fossil oil fuels and restrictions on exhaust emissions.

Among the renewable fuel, biodiesel is the most used and promising alternative fuel in CI engines.The advantages of biodiesel as compared to diesel fuel are such as the negligible sulfur and aromatic content. Moreover, higher flash point and lubricity added some advantages. Their disadvantages are the lower calorific value, the higher viscosity, the higher pour point and volatility, the hygroscopic tendency, and the lower oxidation stability [2]. The majority of the researchers agrees that biodiesel reduces the emissions like particulate matter (PM), unburnt total hydrocarbons (THC) and carbon monoxide (CO) emissions than diesel [1-3]. Currently, vegetable oils, waste cooking oils, and animal fats are mainly used as biodiesel feedstocks. Nevertheless, the limitation of supply of these feedstocks restricts further growth and extension of biodiesel production [3].

Moreover, due to some disadvantages of the biodiesel like the high viscosity, lower volatility and sometimes high emissions, researchers are in search of some additives such as alcohols added to the biodiesel fuel to improve these fuel properties [4-6]. Alcohols like methanol, ethanol and butanol can be used with diesel-biodiesel blends in CI engine in different percentages as clean additives. Although most of these alcohols are immiscible with the diesel fuel, they are miscible with the biodiesel. Therefore, diesel-biodiesel-alcohols can be used within certain limitations of alcohols concentration without miscibility problems [4]. Among the alcohols, butano has higher heating values, viscosity, cetane number and lower latent heat of vaporization as compared to other alcohols like methanol and ethanol and that makes butanol the optimum additive in the diesel engines [4, 5].

Tse et al have investigated the blend of diesel-biodiesel-ethanol in CI engine for the combustion characteristics and particulate matter emissions. They have used 4-cylinder naturally-aspirated direct-injection diesel engine at a steady state speed of 1800 rev/min by varying the engine load. They have reported a shorter delay period as compared to the pure diesel [7]. A review work on the blend of diesel,biodiesel and ethanol on the feasibility in view of the property, safety, stability, combustion and material compatibility is conducted by Shahir et al. [8]. They have reported that upto 20% biodiesel and 5% ethanol can be blended for better combustion in diesel engine. However, the review barely touched the details of the combustion phenomenon. Labeckas et al. [9] have investigated the effect of blend of diesel-biodiesel-ethanol on the combustion, performance and emission in a direct injection CI engine. They have reported that, addition of oxygenated fuels affected the delay period through the oxygen content. Unlike to the literature on the combustion of diesel-biodiesel-ethanol or diesel-biodiesel-methanol blends in a diesel engine, there are few studies done in the combustion of butanol with diesel-biodiesel blends. Thus the aim of this study is to investigate the effects butanol-palm biodiesel-diesel blends on the combustion of a diesel engine and compare with petrodiesel fuel.

2. Methodology

The experiment was conducted with a naturally aspirated water-cooled single-cylinder direct injection diesel engine was used to conduct the test at the engine test laboratory of the faculty of Automotive Engineering Center at University Malaysia Pahang. The schematic view of the experimental setup of the engine is seen in Figure1. The specifications of the engine is presented in Table 1. A pressure transducer and crank angle encoder were used to analyze the combustion characteristics. The engine was coupled with a positive displacement gear pump (model HGP-3A-F23) and it was used as a dynamometer. The data were recorded by the TFX Engineering DAQ system, which resided of the in-cylinder pressure sensor, and crank angle sensor. The K-type thermocouples were used to measure the ambient temperature and the exhaust gas temperature which is connected to Pico thermocouple data logger.

The engine was run at different speeds ranging from 1200 to 2400 rpm and engine load of 75%. The hydraulic dynamometer was calibrated for the engine load. The fuel used in the investigation are D100 (100% diesel by volume) and BU20 (80% of the commercially available biodiesel blended diesel (95% diesel and 5% biodiesel) and 20% butanol by vol.). The alternative fuel (palm biodiesel) and the alcohol additive (butanol) were blended to the diesel fuel through stirring on a magnetic stirring plate and the properties of tested fuel are shown in Table 2. First, the engine was run using diesel fuel and carried out until the engine is in steady state condition. For every new experiment, the engine was run for sufficient time to consume the remaining fuel from the earlier experiment and was conducted very carefully and repeated for three times.

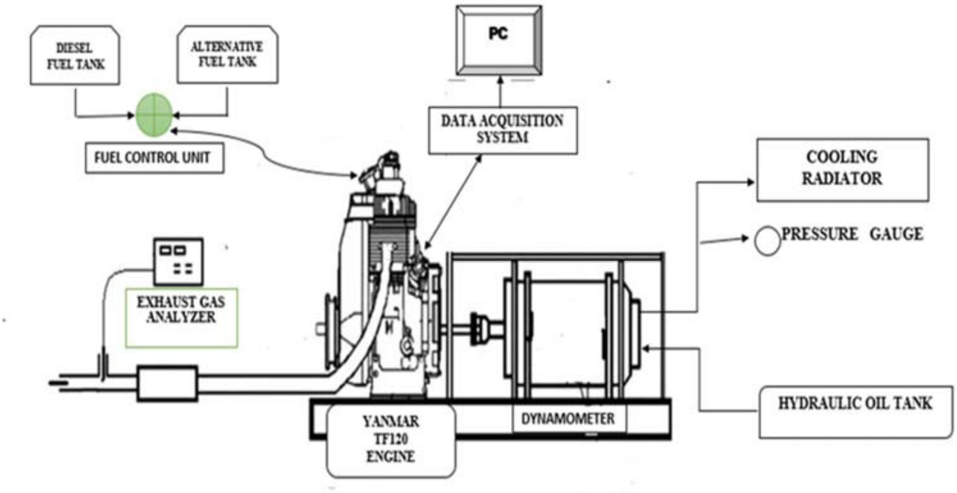

Figure 1. Schematic view of the experimental setup of engine

Table 1 Specifications for diesel engine

Description	Specification
Engine model	TF120
Engine type	Horizontal, diesel 4 stroke cycle
Combustion system	Direct injection
Number of cylinders	1
Bore x Stroke (mm)	92 x 96
Displacement (L)	0.638
Compression ratio	17.7
Continuous output (HP)	10.5 HP at 2400 RPM
Rated output (HP)	12 HP at 2400 RPM
Cooling system	Water cooled (radiator type)

Table 2 Basic fuel properties for diesel, biodiesel and butanol

Fuel	Lower heating value (MJ/kg)	Density@20°C (kg/m3)	Viscosity@40°C (mPa s)	Flash point(°C)	Cetane number
Diesel	45.28	853.8	2.6	93	54.6
Biodiesel(PME)	41.3	867	4.53	165	67
Butanol	33.1	808	2.63	35	25

3. Results and discussion

3.1 The incylinder pressure

Alcohol, as fuels in internal combustion engines, was discovered to have a decisive influence on combustion chamber despite of the lower energy value. Moreover, alcohol, as fuels, is oxygenated fuels that permit complete combustion. Also, they offer higher volumetric efficiency in naturally-aspirated engines due to their high latent heat of evaporation. When utilizing butanol blends with diesel biodiesel, the in-cylinder temperature, and the maximum in-cylinder pressures has dropped slightly. Figure 2 illustrates the differences of in-cylinder pressures for D100 and BU20 at and 75% engine loads at five different speeds (1200 to 2400 with intervals of 300 rpm). Besides, all the first cycles presented diesel biodiesel butanol blends (BU20), while the other presented pure diesel (D100). The combustion characteristics, is strongly associated to in-cylinder pressure. The incylinder pressure of diesel was slightly higher than that of BU20 at almost all the engine speeds. Moreover, the in-cylinder pressure is found to increase as the speed of the engine increases. Other than that, the variantion in the in-cylinder temperature with D100 and BU20 are presented in Figure 3. The in-cylinder temperatures with pure diesel D100 is recorded to be higher than that of for BU20 at all engine speeds.This is attributed to the moisture content in butanol blends [10], higher oxygen content in the combustion [4] and its higher latent heat of vaporization. Moreover, the in-cylinder temperature increased with the increase for all speeds. More over in 2400 rpm, the butanol blends slightly increased due to the increased higher temparure. Nevertheless, the maximum in-cylinder temperature detected for the BU20 was at 75% and 2400 rpm engine load. Similar results were also achieved for diesel engine with alcohol (oxygenated fuels) [11, 12].

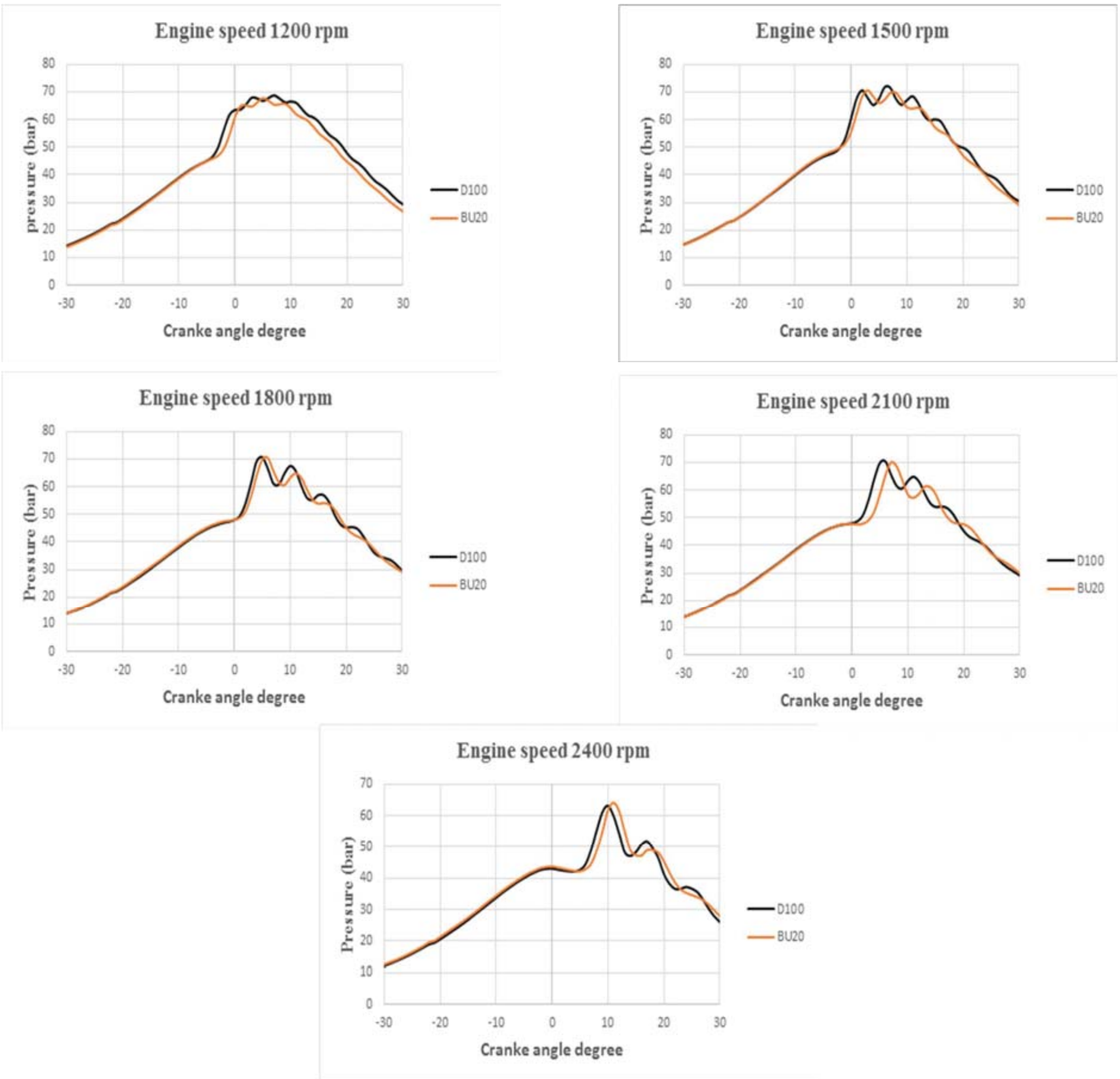

Figure 2. The differences of in-cylinder pressure for D100 and BU20 at defferent engine speeds

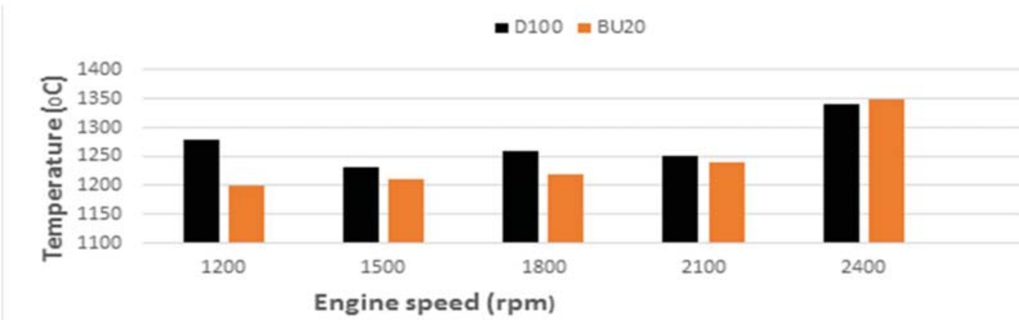

Figure 3. In-cylinder temperatures for D100 and BU20 at defferent engine.

3.2 Energy release rate and Cumulative energy release

The release energy analysis computes how much heat would have to be added to the cylinder contents, in order to produce the observed pressure variations [13]. The net energy release calculations were taken from the measured cylinder pressure by utilizing the first law of thermodynamics applicable to the closed part of the engine cycle [14]. The equation (Eq.1) for calculating energy release rate (dQ/dı) is given below.

$$\frac{l\,l}{l\,l} = \frac{l}{l\,l\,l}\, l\, \frac{l\,l}{l\,l} + \frac{l}{l\,l\,l}\, l\, \frac{l\,l}{l\,l} + \frac{l\,l\,l\,l}{l\,l} \quad (1)$$

where, *k* is specific heat ratio, *Q* is the crank angle, *p* is cylinder pressure, and *V* is volume and θ is crank angle degree. Figure 4 shows that the differences of energy release rates for BU20 and diesel fuels at five engine speeds. It is observed that the energy release rates increased as the engine speeds both diesel and butanol blends oil increased. The energy release rate for diesel fuel started to increase earlier from that of butnol blends at all engine speeds, except at 1500 rpm. Moreover, Figure 3 shows the variation of energy release rate with crank angle for D100 and BU20. The combustion is much slowed in case of diesel–biodiesel–butanol blended fuel and the instantaneous heat release rate which occurs almost at the beginning of the combustion is much higher. The main attribute to this phenomenon is due to the lower cetane number of the blended fuel as compared to the D100. This has instigated for the sudden ignition of the collected fuel during the longer ignition delay period resulting in higher sudden energy release rate thereby the ignition delay of diesel was shorter than that of BU20. Furthermore, the peak positions for energy release rate of BU20 were higher than those of diesel. In fact, the single boiling point of BU20 is one of the main reasons for the increase in energy release. Moreover, the oxygen content in alcohol played a main role in enhancing combustion, and more amount of fuel was burnt in the areas close to TDC [15, 16]. However, the highest peak energy release rate for BU20 was noted at 75% engine load and 2400 pm, which was 29 (J/CA). The energy release rate mostly depended on ignition delay, cetane number, and injection timings [17].

The cumulative energy release rate was calculated by using equation ,as given in Eq. (2).

$$l\;l\,l\,l\;\;l\,l\,l\,l\,l\,l\,l = l \frac{l\,l}{l\,l} = l \frac{l}{l\,l\,l}\, l\, \frac{l\,l}{l\,l} + \frac{l}{l\,l\,l}\, l\, \frac{l\,l}{l\,l} + \frac{l\,l\,l\,l}{l\,l} \quad (2)$$

As a result, the cumulative energy release exhibited a slight increase with BU20 compared to pure diesel D100.

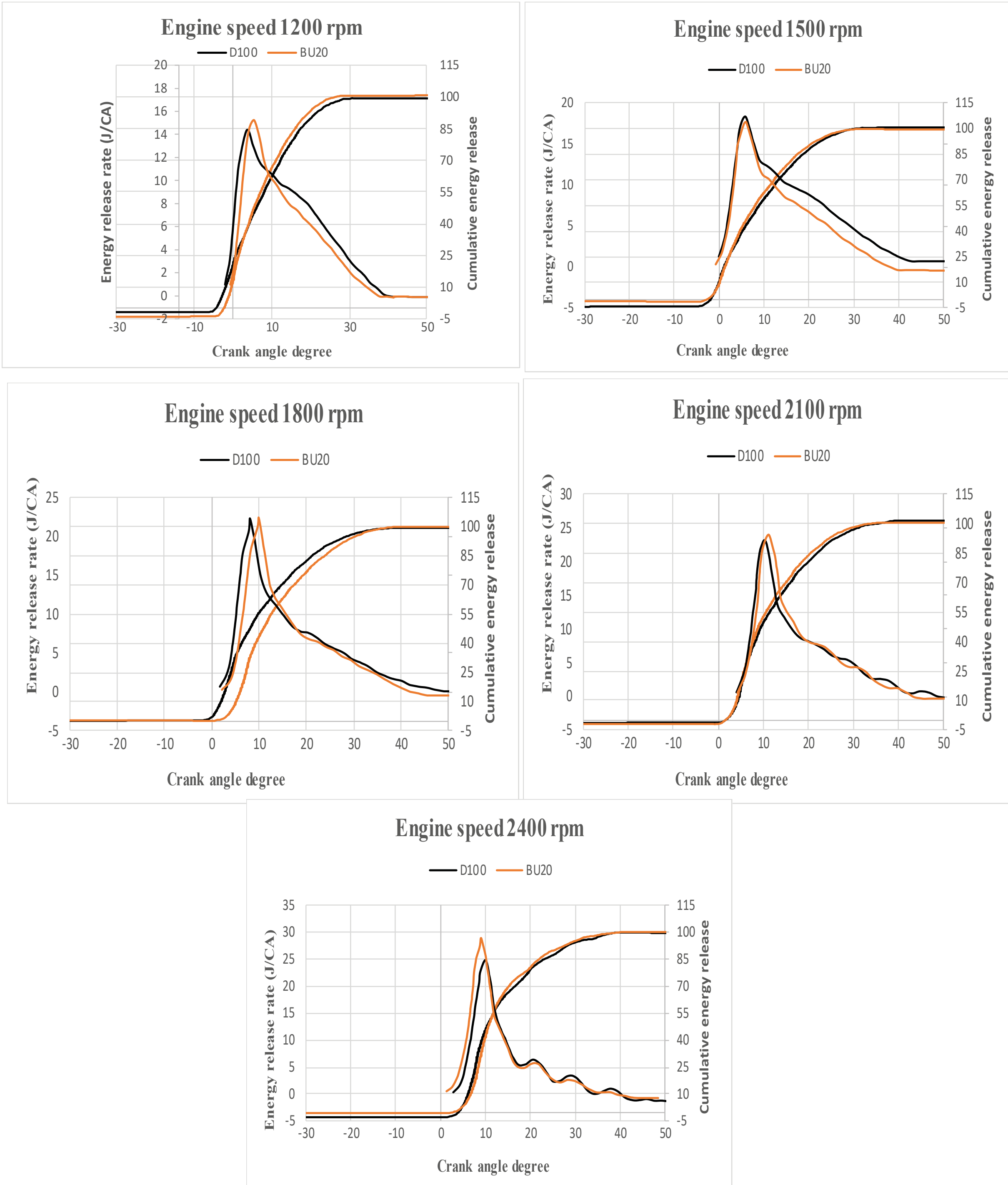

Figure 4. Energy release rate and cumulative energy release for D100 and BU20 at five engine speeds.

3.3 Ignition delay

Ignition delay is a significant factor in the combustion of compression ignition engine. The ignition delayis known as the time between the start of injection and the start of combustion [18, 19]. In this study, the ignition delaywas converted from angle to time (MS) via Eq. 3:

$$\text{ııı ıı} = \frac{\text{ı ı}}{\text{ı .ı}\frac{\text{ı ıı}}{\text{ı ı}}\text{ı .}\frac{\text{ııı}}{\text{ııı}}} * 1000 \tag{3}$$

Next, Table 3 presents the difference of ignition delay for pure diesel and BU20 at two five engine speeds ranging from 1200-2400 rpm. Figure 5 shows the ignition delay of D100 and BU20 at different speeds as well. The fact that butanol has higher latent heat of vaporization, it was evident that the increment in ignition delay with BU20 as the result of the latent heat of vaporization. Furthermore, the phenomenon can be attributed to the lower cetane number of the blend than that of diesel. On the other hand, Senthilkumar et al [17] suggested that the cooling effect generated by the vaporization for longer ignition delay period of alcohol blended fuels.

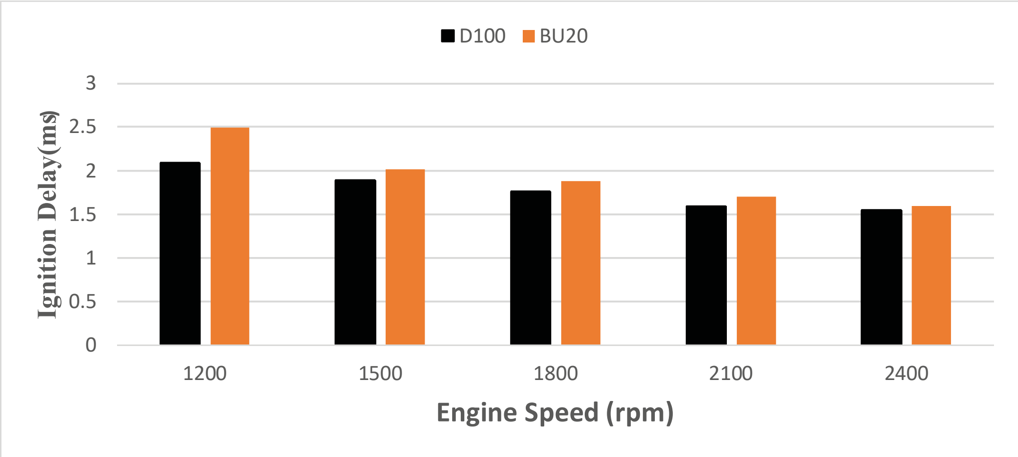

Fig.5. Ignition delay of D100 and BU20 at five engine speeds

Table 3 Ignition delay of D100 and BU20 at different speeds and loads.

Fuel	75% load	start of injection	Start of combustion	ignition delay(CA)	ignition delay(MS)
	1200	-17	-1.94	15.06	2.06
	1500	-17	0	17	1.88
Diesel	1800	-17	2.03	19.03	1.76
	2100	-17	3.08	20.08	1.59
	2400	-17	5.3	22.41	1.54
	1200	-17	0.95	17.95	2.06
	1500	-17	1.12	18.12	1.88
BU20	1800	-17	3.28	20.28	1.76
	2100	-17	4.5	21.5	1.59
	2400	-17	6.05	23.05	1.54

4. Conclusion

The combustion of CI engine was run by diesel-biodiesel-butanol blends BU20 compared with pure diesel D100. From the results obtained from the outlined study, the following conclusins were drawn.

- In-cylinder pressures and temperatures decreased slightly with the use of diesel-biodiesel-butanol blends. This might be attributed to the oxygen and the moisture contents of butanol blends. But at 2400 rpm the BU20 slightly increased thn D100 due to its high temperature.
- The energy release rate for BU20 was higher than that for diesel, whereas the peak positions concerning the energy release rate for BU20 was discovered at 2400 rpm.
- Due to higher latent heat of vaporization and low cetane number for BU20 than pure diesel, the ignition delay is observed to be longer at all speeds and loads with BU20.

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