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Effect of Alcohol on Diesel Engine Combustion Operating with Biodiesel-Diesel Blend at Idling Conditions

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Abstract. Biodiesel is a promising alternative fuel to run the automotive engine. However, its blends have not been properly investigated during idling as it is the main problem to run the vehicles in a big city. The purpose of this study is to evaluate the impact of alcohol additives such as butanol and ethanol on combustion parameters under idling conditions when a single cylinder diesel engine operates with diesel, diesel-biodiesel blends, and diesel biodiesel-alcohol blends. The engine combustion parameters such as peak pressure, heat release rate and ignition delay were computed. This investigation has revealed that alcohol blends with diesel and biodiesel, BU20 blend yield higher maximum peak cylinder pressure than diesel. B5 blend was found with the lowest energy release among all. B20 was slightly lower than diesel. BU20 blend was seen with the highest peak energy release where E20 blend was found advance than diesel. Among all, the blends alcohol component revealed shorter ignition delay. B5 and B20 blends were influenced by biodiesel interference and the burning fraction were found slightly slower than conventional diesel where BU20 and E20 blends was found slightly faster than diesel So, based on the result, it can be said that among the alcohol blends butanol and ethanol can be promising alternative at idling conditions and can be used without any engine modifications.

1. Introduction

Transportation system plays a significant role in developing the economy of any country in the world. Presently, the demand of transportation sectors is fulfilled by fossil fuels either gasoline or diesel. As a result, the motor industry is developing due to high demand and as well as the average consumption of energy in the transport sector is increased by 1.1% per year. It has been reported that from the year of 2010– 2040, the transportation sector has 63% share in the step up of total global liquid fuel consumption [1, 2]. Hence, day by day the fossil fuel stocks decreasing as well as the price also increasing due to the demand and limitation. Researchers trying to find out the alternative sources to replace the natural resources. Among the sources, biodiesel is considered more viable cleaner, environment-friendly and it can be replaced as a diesel fuel replacement [1, 3]. The main advantage of using biodiesel is that it can be applied in any proportion with diesel as a biodiesel-diesel blend due to its favourable properties like petro-diesel [4]. Many researchers had conducted experiments on combustion or performances using different types of biodiesel in CI engine [5]. However, limited research was found conducted on engine combustion and performance under idling condition. Recently, idling conditions is a perilous problem for the transport sectors. Idling condition means a condition when the engine run at low-rated speed with low load. Researchers found that during the idling time, the vehicles consume higher fuel consumption and release emissions than running on the road by a factor of 1.5 [6]. Further elaborated, during idling condition time, the engine did not work at peak operating temperature and for this reason, it leads to the incomplete combustion and emissions level increase with more fuel deposits in the exhaust detected. Moreover, due to some disadvantages of the biodiesel like 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 [7, 8]. Recently alcohols like butanol and ethanol with the blending of diesel and biodiesel play an important role as an alternative fuel. It was found that improvement of combustion efficiencies of diesel fuel can be achieved by the adding oxygenated fuels such as ethanol, butanol, biodiesel, and vegetable oils, due to having a complete combustion. Many studies have been conducted to evaluate engine performance and emission using palm biodiesel blends in a diesel engine at idling condition [5, 9] but very few have been conducted using a high portion of alcohol as an additive with palm biodiesel-diesel blend at idling condition.

In this study, the tri-fuel composition was used consist of diesel, palm biodiesel and butanol. Another composition of tri-fuel consists of diesel, palm oil biodiesel and ethanol blends. The aim of this research was to study the combustion analysis with the new composition fuel involving pressure, energy release rate, mass burn fractions and ignition delay under idling condition.

2. Methodology

The test was done Yanmar TF120M (2012) single cylinder CI engine which was coupled with a positive displacement gear pump (model HGP-3A-F23) dynamometer. The engine was manufactured from the year of 2012.The idling condition (1200 RPM at low load was considered in this investigation. 5% and 20% (B5 and B20) blends of palm biodiesel with the diesel and 20% of alcohols of butanol and ethanol (BU20 and E20) along with palm and diesel fuel have been used to run the engine. Also, to present the effect of idling, the engine was run at no load at low engine speed and measured data were compared with the diesel at idling condition. Figure 1 presents the labelling and arrangement of the test bed component in a schematic diagram.

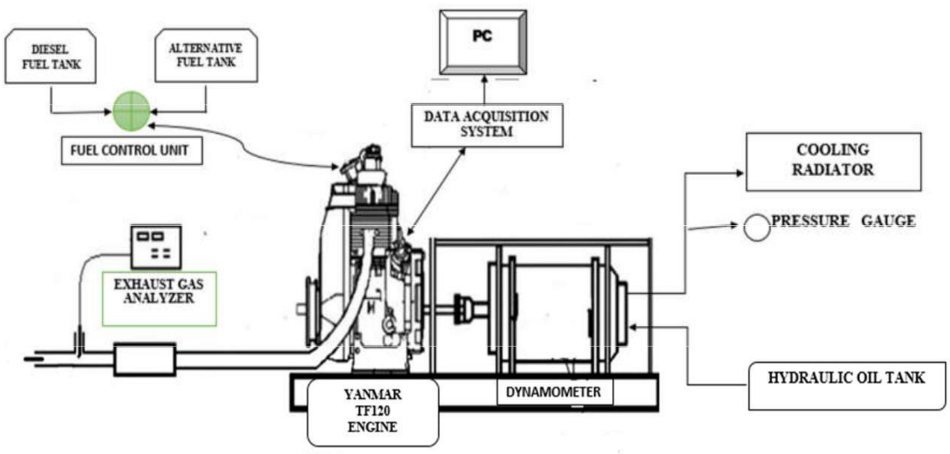

Figure 1. Schematic view of the experimental setup of engine.

Engine specification was shown in Table 1. A pressure transducer and crank angle encoder were used for combustion analysis. The relationship of the combustion pressure with that of the crank angle degree of the piston movement (pressure-crank angle degree) is provided from these two sensors. Digital data have been recorded in a computer by the using a software name TFX engineering DAQ Combustion Analyzer. The alternative fuel like palm biodiesel and the alcohol were bought from the local a market. For the blending process of Alcohol (Butanol and Ethanol) with palm and diesel, the magnetic string process was used. The basic fuel properties of diesel, biodiesel, butanol, and ethanol are shown in Table 2. The engine was run mostly at the room temperature with diesel fuel and to maintain the steady conditions at and also run for the certain time to consume the alternative fuel from the remaining experiment which was conducted carefully and repeated for 3 times. The experiment was conducted at a room temperature.

Table 1. Specifications for single cylinder engine.

Description	Specification
Engine model	TF120
Engine type	Horizontal, diesel 4 stroke
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 and ethanol [7, 10-12].

Fuel	Lower heating value (MJ/kg)	Density @20^{o}C (kg/m^3)	Viscosity @40^{o}C (MPa s)	Flash point (^{o}C)	Cetane number	Latent heat at 25^{o}C (kJ/kg)
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	582
Ethanol	26.8	788	2.6	-	5-8	904

3. Result and Discussion

3.1 The in-cylinder pressure

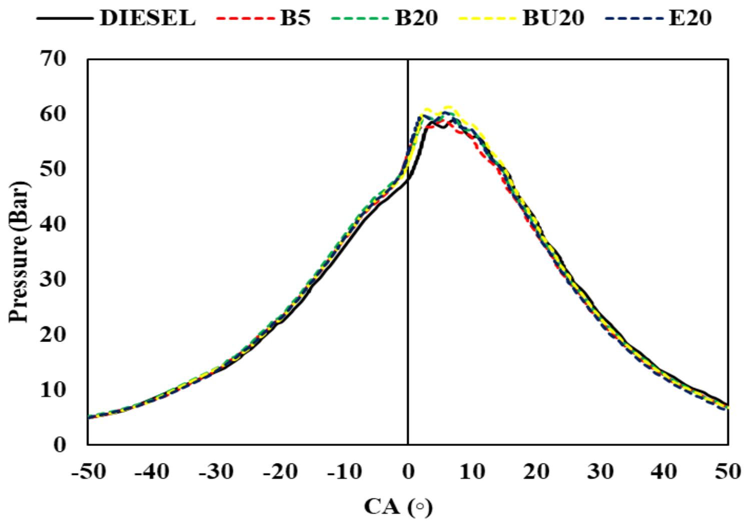

Figure 2. In-cylinder pressure vs. crank angle variation of biodiesel, biodiesel-alcohol blends compared to diesel at idling condition.

Figure 2 shows combustion pressure. Combustion peak pressure for bi-fuel category possessed almost similar reading, 59.04 for diesel, 58.08 for B5 and 60.09 for B20. Slight increment reading on peak combustion can be seen in the case of all tri-fuel blend categories, 59.80, 61.36 for E20, and BU20 respectively. Pressure graph indicated distorted fluctuation pattern at the peak which indicated slight minor engine knocking experience for all types of fuels. From Figure 2, it shows that all the biodiesel blends had slightly higher pressure than diesel. This might be happening during lower load condition as the residual gas temperature and wall temperature become low. In addition, while the injection charge becomes low, it increases the delay period and the combustion starts later. So due to the delay, the peak pressure became lower than the biodiesel blends [4]. When the engine was running at low load, residual gas temperature and wall temperature was also low. Therefore, injection charge temperatures were also significantly low, which in turns increases injection delay period. This explained why diesel fuel combustion starts later compared to biodiesel and its blends yield lower peak pressure compared to biodiesel blends. It was also found that the ethanol blends E20 had slightly lower pressure than butanol blends BU20. This might be because butanol has higher calorific value, higher density and lower latent heat of vaporization as compared to ethanol leading to a lower cooling effect that shown in table 2. This finding disagrees with the similar previous research by Lie et al. with ethanol influence in the blend yield higher peak pressure compared to the blend with butanol [12].

3.2 Heat Release Rate

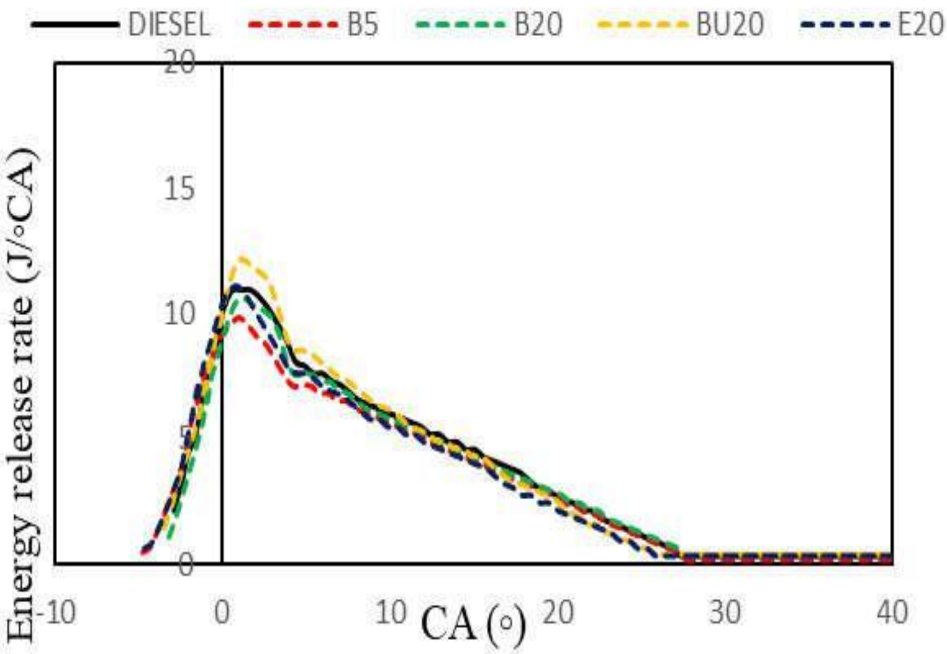

Figure 3. Energy release rate vs. crank angle variation of biodiesel, biodiesel-alcohol blends compared to diesel at idling condition.

Figure 3 illustrates the comparison of energy release rate against CA degree to see how much heat is released during the combustion and the speed of the burning with different fuel composition. The curve of energy release of all fuels maintaining the same position from top dead centre (TDC). The variation is on the peak of each fuels blend. Higher peak is an indicator for higher power thermal output [13]. Hence, higher energy release reading is more desirable. B5 blend was found with the lowest energy release among all. Slightly lower than diesel was B20. BU20 was seen with the highest peak energy release. This is an indicator of higher combustion temperature. E20 blend advanced slightly from diesel. Overall, alcohol in the blend with the lowest heating value come in second before diesel [14].

It can be seen, more energy release by B20 blend than B5 blend but conventional diesel reading still higher than both blends. With lesser diesel content, maintaining 5% biodiesel plus 20% alcohol fix the cause and boosting more energy. Alcohol influence was seen increasing the peak of energy release more than 100% diesel. To compare between the two types of alcohol, in this case, BU20 blend with Butanol beats E20 blend with ethanol. Considering the case similar to combustion pressure where butanol influence compared to ethanol influence raised up the question of why this is happening. By right, remark on oxygen content attribute should have come in handy and help the burning efficiency. But apparently, the oxygen content of ethanol which is higher than butanol did not reflect the energy release reading of BU20. This can be explained by considering the amount of energy release is subjected to the carbon oxidation state in the hydrocarbon. So, based on the ratio of hydrogen/carbon, butanol with greater H/C ratio compared to ethanol explained why more energy release of BU20 more than E20.

3.3 Ignition delay time

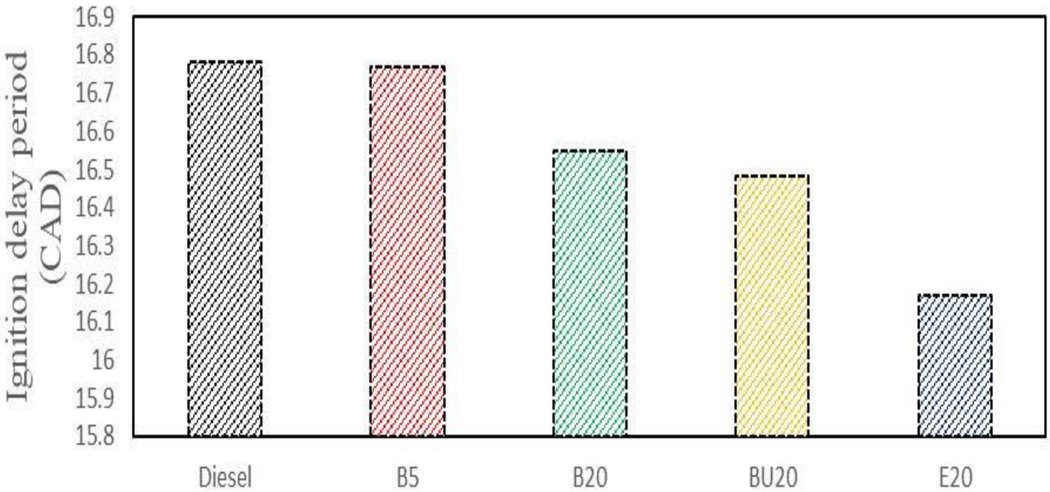

Figure 4. Ignition delay period of biodiesel, biodiesel-alcohol blends compared to diesel at idling condition.

Figure 4 illustrates the comparison of Ignition delay period of the different types of fuels under idling condition. By definition, ignition delay period is cumulated from the moment injection starts till the moment combustion actually begin to initiate [15]. It is widely accepted that volatile compound responds much faster than the rest during combustion and as a result, shorter ignition delay should be expected [16]. The result of the experiment is against the previous study by D.C. Rakopoulos et al. and M. L. Randazzo & J. R. Sodré on the statement with regards to ethanol with lower cetane number could have caused the increase of ignition delay [17] [18]. In another word, alcohol influence the blend with low cetane number would postpone the ignition more while blend under the influence of alcohol with higher cetane number eases the ignition hence shorten the duration. In this case, BU20 with butanol under higher cetane number category as compared to ethanol in the E20 blend. Furthermore, combustion pressure of E20 slightly ahead of BU20. This is an indicator that Ignition delay of E20 slightly shorter than BU20. E20 with the shortest delay period as compared to others. Potentially, shorter range ignition delay is desirable to reduce peak combustion temperature and simultaneously reduce the formation of NOx and total hydrocarbon emissions.

Agreed with Qi et al. alcohol is known as high latent heat of evaporation attribute and low cetane number which should by right increase the ignition delay period. From the increase of the ignition delay, cylinder peak pressure rise is expected [19]. M. Zöldy emphasized alcohol in tri-fuel should shorten ignition delay period prolong longer burning [20]. This assumption disagreed with M.L.Randazzo and J.R.Sodré on due to alcohol addition, ignition delay increased as a result of slow rate evaporation characteristics of alcohol [18]. Su Han Park et al. and quoted Lu et al work on ethanol blended with diesel remark; as the ratio of ethanol increased, combustion duration could be shortened but ignition delay may increase [21]. But in this experiment, with biodiesel as an additional component in the blend, yield surprising outcome on ignition delay period. All three-blended composition with alcohol component revealed shorter ignition delay as compared to blended without alcohol influence. This can be explained considering biodiesel attribute as a surfactant which may unlock alcohol hidden potential [22]. Fundamentally, the shorter the better and the peak pressure expected should be not too high. The ignition delay period is shown below in Table 3.

Table 3. The ignition delay period.

Fuel	Low load	start of injection	Start of combustion	Ignition delay(CA)
Diesel	1200	-17	-0.22	16.78
B5	1200	-17	-0.23	16.77
B20	1200	-17	-0.45	16.55
BU20	1200	-17	-0.49	16.51
E20	1200	-17	-0.78	16.22

3.4 Mass fraction Burn

Figure 5 is the amount of fuel burned during the combustion. The pattern is aligned with energy heat release pattern. The mass fraction burned of BU20 and E20 side by side has been found slightly faster than diesel. Both blends without alcohol influence burned slightly later than diesel. In one glance, the difference is not that significant. But fundamentally, MBF pattern of BU20 and E20 advance slightly is the consequences of shorter ignition delay as seen in Figure 4. In combustion cycle, this is an indicator for good energy conversion [23]. Fundamentally, MFB curve by a crank angle is to define cumulative combustion. It is good to see that there is no negative dip like typical MFB graph. theoretically, Ignition delay and combustion duration came from MBF reading. B5 and B20 influenced by biodiesel interference and the burning fraction slightly slower than conventional diesel. In another word, biodiesel slows down the burning rate while alcohol speed up the burning process.

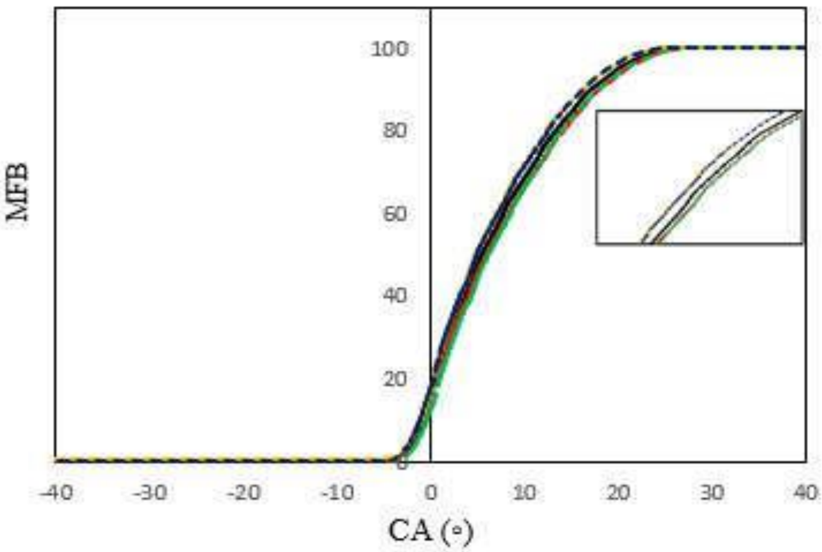

Figure 5. Mass burned fraction vs CA of biodiesel, biodiesel-alcohol blends compared to diesel at idling condition.

4. Conclusions

An experimental investigation was carried out to observe the combustion analysis of biodiesel and the alcohol blending's with diesel and biodiesel at different blending's at idling conditions. The B5 (95vol % diesel+5vol % palm biodiesel), B20 (80vol% diesel + 20 vol% palm biodiesel), BU20 (75vol% diesel + 5vol% palm biodiesel + 20vol% butanol) and, E20 (75 vol% diesel + 5vol% palm biodiesel +

20vol% ethanol) fuels were used as the test fuel at low load with 1200 rpm speeds. The main conclusions are as following below:

- The In-cylinder pressure during idling conditions for biodiesel blends and alcohol blends are a little bit higher than diesel due to lower load condition and lower the residual gas or wall temperature.
- B5 with the lowest energy release among all. Slightly lower than diesel is B20. BU20 is seen with the highest peak energy release. This is an indicator of higher combustion temperature. E20 advance slightly from diesel. Overall, alcohol in the blend with the lowest heating value come in second before diesel.
- All three-blended composition with alcohol component revealed shorter ignition delay as compared to blended without alcohol influence. This can be explained considering biodiesel attribute as a surfactant which may unlock alcohol hidden potential.
- Fundamentally, MFB curve by a crank angle is to define cumulative combustion. Theoretically, Ignition delay and combustion duration came from MBF reading. B5 and B20 influenced by biodiesel interference and the burning fraction slightly slower than conventional diesel. The mass fraction burned of BU20 and E20 side by side has been found slightly faster than diesel.

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