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Experimental evaluation of tertiary blends of water in diesel with butyl alcohol using compression ignition engine

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Abstract. Alcohols are important alternative fuel resources for diesel engines. Prominent fuels of the three types include water in diesel reduce engine temperature and NOx and alcohols with a high number of carbons. There is potential to use tertiary blends of diesel fuel, water and higher alcohols, such as butanol, in diesel engines for the purpose of increasing the use of alternative fuel and decreasing fossil fuel consumption. In this study, diesel fuel (D) was mixed with water (5%), and butanol (5% - 10%). Test fuel blends of W5DBu5 (5% of water, 5% of butanol), W5DBu10 (5% of water, 10% of butanol) and W5DBu15 (5% of water, 15% of butanol) were prepared using ultrasonic emulsifier and tested in a diesel engine. It carried engine performance and exhaust emission tests of the blends out on a four-cylinder, four-cycle diesel engine generator at a fixed load of 50% and various engine speeds from 1000 rpm to 3000 rpm. According to engine test results, brake specific fuel consumptions (BSFC) of Blended fuels decrease compared to diesel at all engine speed. As compared to diesel, W5DBu15 presented the best oxides of nitrogen (NOx) at a speed of 2000 rpm with a reduction of 34.7%.

1. Introduction

Energy is one of the key issue in the world today and into the future, where they will face critical energy problems, particularly for countries that rely on energy and export crude oil. We must utilise local resources for energy production as far as possible to solve this problem. To reduce the reliance on fossilized fuel resources, different types of alternative fuels have been used in the internal combustion engines, such as algae, biodiesel, and emulsified fuel. Alcohol fuel is among the second choice for suitable fuel substitution to diesel fuel in compression ignition engine because of their capability for ignition process and ability to form homogeneous blend with or without diesel fuel. Butanol has a hydrogen to carbon ratio compared to diesel.

Butyl alcohol or butanol is considered as a potential biofuel for road vehicle in near future [1-5]. Butanol mainly produces from agricultural feedstock such as sugar cane, potato and corn [3]. Butanol is produced through a fermentation process. During the fermentation process, by products such as 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 [6]. Butanol a higher cetane number, lower heating value, larger viscosity, a higher flashpoint and better lubricity. Butanol molecules contain alkyl and hydroxyl, that easier to blended into diesel fuel. In fact, butanol has very good intersolubility with diesel fuel without any surfactant [7].The Butanol have four isomers. Each type of isomer has distinct physical and chemical characteristics. The solubility of n-butanol and iso-butanol is quite limited to few blended diesel fuel, while sec-butanol has substantially better solubility. Tert-butanol is fully miscible with water. By owing these advantages, butanol–diesel fuel blends studies began to increase in the recent years [3, 7-9]. These physical and chemical properties indicates that butanol has the capability to overcome the disadvantage from other types of low-carbon alcohols. However, the great interest is now to use Butanol in diesel engine to reduce the dependency of diesel engine to petroleum diesel.

Modifying the fuel by adding water in diesel offers a another method to improve performance and emissions as many researchers reported in literatures [10-13]. There are several researchers reported that water in diesel can decrease NO_x and smoke simultaneously. NO_x emission reduced due to improvement of OH radicals of water [11, 12, 14, 15]. There were differences regarding the percentage ratio of different water emulsion diesel as reported in the literature. Most of the study, 10% water-diesel emulsion relied best to control the NOx emissions of the engine [16].

Data based on water in diesel and butanol suggest show that this renewable fuel is a potential use such as biodiesel used for diesel. This research aims to analyse and compare the engine performance and emission characteristics of a diesel engine operating on tertiary blends of water, diesel and butyl alcohol that could theoretically serve as an alternate fuel for future. To this point, water, diesel and butyl alcohol were mixed and W5DBu5, W5DBu10 and W5DBu15 fuels were prepared. These fuels engine emissions and performance results were compare with respect to diesel and water in diesel with butanol alcohol blends.

2. Material and methods

2.1. Description of the experimental setup

The experimental setup comprises an Isuzu 4JJ1 turbocharger, four-cylinder diesel engines as engine test bed and a data acquisition system in the control room. It equips this engine with an exhaust gas recirculation system; however, for this experimental investigation the exhaust gas recirculation mode is turn off. The layout of the engine layout and control room is shown in Figure 1 and specification of the engine is stated in the Table 1. A 150kW ECB-200F SR No. 617 from Dynalec Controls eddy-current dynamometer was used in the experiments. A mechanical shaft is used as connection between the engine and dynamometer. In order to account for that, it is very common to use speed and torque when conducting operations with the engine and dynamometer. In which, the speed of the engine could be regulated towards its required value, whilst the torque brake is calculated as the engine output. It is calculated by the Dynalec eddy current dynamometer controller. The power delivered from the engine electromechanically absorbs by dynamometer. Through the external cooling tower, the heat generated by the torque was removed.

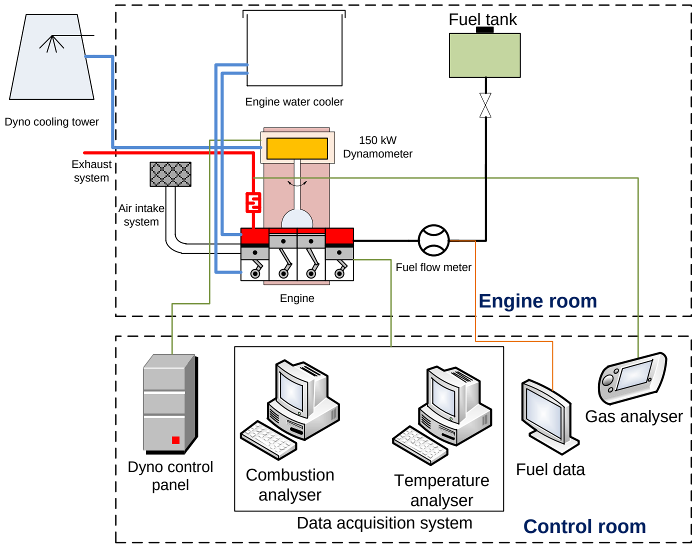

Figure 1: Schematic diagram of the experimental setup

Table 1. Specification of test engine.

Engine type	Value
Model	Isuzu 4JJ1 (Turbocharged)
Bore (mm)	95.4
Stroke (mm)	104.9
Displacement (L)	2.999 L
Firing order	1-3-4-2
Compression ratio	17.5
Max. torque (Nm/rpm)	280±5%/ 1800
Max. power (kW/rpm)	61.0±3%/ 2500
Ignition system	Direct injection

The fuel flowmeter is connected between stainless steel fuel tanks with 10 liters of capacity. The flow rate were recorded in real time to a data logger. Both inlet and outlet of the fuel rail is attached with two thermocouple respectively using K-Type thermocouple. The air from the intake box is absorbed into engine manifold. A manometer is use to measure the pressure drop during the suction process. Nevertheless, the calculated correction factors are still measured during the determination of the performance characteristics of brake power [17]. A KANE gas analyser is used to conduct the readings of the exhaust gas species such as CO, CO_2, O_2 and NO_x. To guarantee the consistency and the precision of the measurement data, the engine warn up for thirty minutes with diesel fuel. Table 2 lists the descriptions of the KANE gas analyser.

Table 2. KANE gas analyser specifications.

Specification	Description
Oxygen (O_2)	Specified Range 0-21% @ ±5% accuracy
Carbon monoxide (CO)	Specified Range 0-10% @ ±5% accuracy
Carbon dioxide (CO_2)	Specified Range 0-16% @ ±5% accuracy
Nitrogen oxides (NO_x)	Specified Range 0-5000ppm @ ±5% accuracy
(CO/CO_2) measuring principle	NDIR bench
(O_2/NO_x) measuring principle	Electro-Chemical Cells

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Table 3. Properties of diesel fuel, butanol and water and blended fuel.

Fuel Properties	Unit	Measurement	Diesel fuel	butanol	Water	W5DBu5	W5DBu10	W5DBu15
Density at 20°C	kg/m^3	ASTM D4052	837	810	998	828.5	828	827.5
Cetane number	-	ASTM D613	50	25	-	46	45	44
Kinematic Viscosity at 40°C	mm^2/s	ASTM D88	2.6	3.6	0.66	2.6	2.6	2.7
Lower Heating Value	MJ/kg	ASTM D240	43.25	33.1	-	40.64	40.20	39.75
Specific heat capacity	J/kg°C	ASTM D2766	1850	2545	4179	2001	2036	2071
Flash point	°C	ASTM D93	52	35	-	49	48	47
Oxygen	%weight		0	21.6	88.9	46.9	47.7	48.6

The tertiary mixtures were stored for 3 days at room temperature and no separation was observed. For the time being all fuel mixtures were miscible and stable. Table 3 shows the basic properties of diesel fuel, butanol and water.

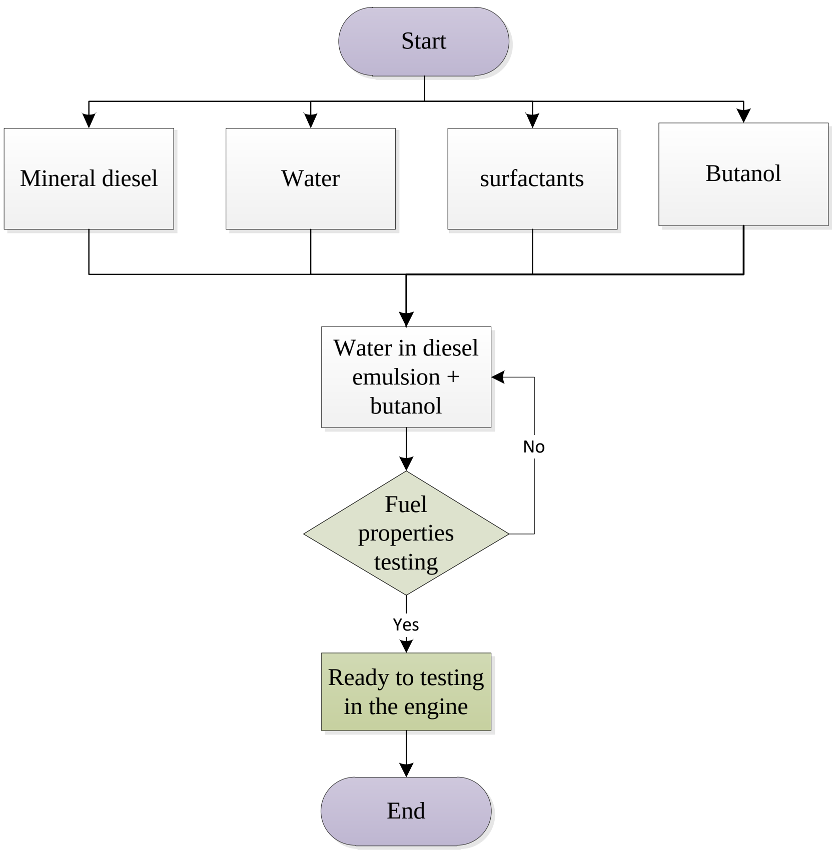

Figure 2. The preparation of diesel-water-butanol.

The preparation of water in diesel-butanol (WDBu) is depicted in figure 2. In the early stages, the percentage of surfactant in the liquid fuel WDBu studied before a final decision is made. A mechanical stirrer set at speed of 1000 rpm was used to blend the water and diesel without surfactants for 30 min.

Table 4. Details of WDBu emulsion fuels and butanol.

No	Water in Diesel-butanol fuel	Diesel (%) by vol.	Water (%) by vol.	Butanol (%) by vol.	Surfactants	
					Span 80 (%) by vol.	Tween 80 (%) by vol.
1	W5DBu5	88	5	5	1	1
2	W5DBu10	83	5	10	1	1
3	W5DBu15	78	5	15	1	1

Consequently, in order to scrutinize the steadiness under static settings, the ready fuel was kept in the tubes. It is worth noting that in less than fifteen minutes, a major parting between the water and diesel was apparent in the test tube. Therefore, it was suggested that a surfactant is needed to formulate the stable water in diesel emulsion fuel. Table 4 tabulates the details of the surfactants with a mix of Span80 and Tween80 along with its proportions. Fuel beaker and laboratory overhead paddle stirrers are employed to arrange the stable WDBu emulsion fuel in two distinct phases. As for the initial phase, the surfactants Span80 (HLB = 4.3) and Tween80 (HLB = 15) were filled in the reactor vessel with 2% volume and held at a constant speed of 1000 rpm.

The Hydrophilic-Lipophilic Balance (HLB) between the two surfactants suggests the relative intensity of the hydrophilic and lipophilic and the emulsion stability. The collective HLB value for the two surfactants is estimated using the equation [19]:

$$HLB_{AB} = [(H_A \times W_A) + (H_B \times W_B)]/(W_A \times W_B) \quad \ldots(1)$$

Where HA, HB, WA and WB represents the HLB values and weights of the two surfactants, Span80 and Tween80, respectively. It was established that a HLB value of 10 yields the most stable WDBu emulsion fuel.

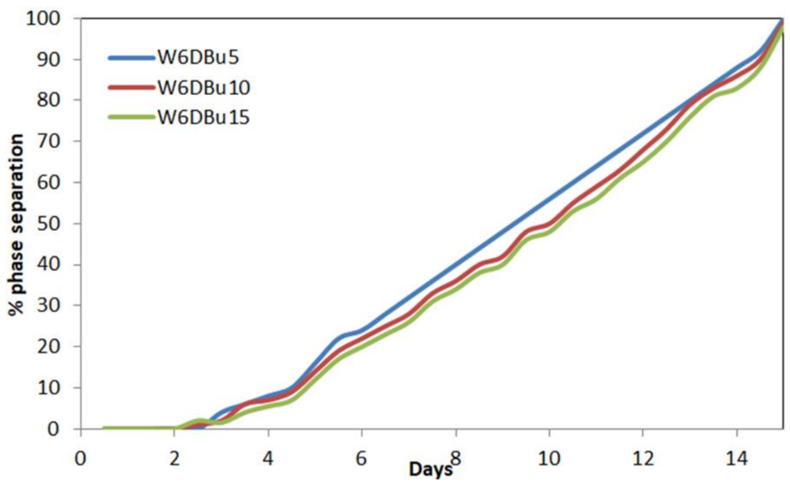

Figure 3. Percentage of phase separation index in blended emulsion fuel.

The stability of water in diesel blended emulsion achieved was a maximum of three days for WDBu fuel which had 5%, 10% and 15% of butanol. To assess the stability level of blended fuel, the fraction of the amount of water separated in the test bottle at different WDBu separate water heights from each other to observe the separation percentage index for the emulsion. Separation index measures from zero (without separation) to 100% (full separation) as shown in Figure 3. All the tested fuels were prepared of the same value of HLB percentage. WDBu was filled in the fuel beaker and it is mixed at agitation speeds of 1000 rpm with the surfactant. Simultaneously, the distilled water was dropped (percentage by volume) gradually into the fuel beaker. Thus, the resulting solution obtained from the fuel beaker is the WDBu emulsion fuel (DW5Bu5, DW5Bu10 and DW5Bu15) and had a creamy white colour as shown in Figure 4.

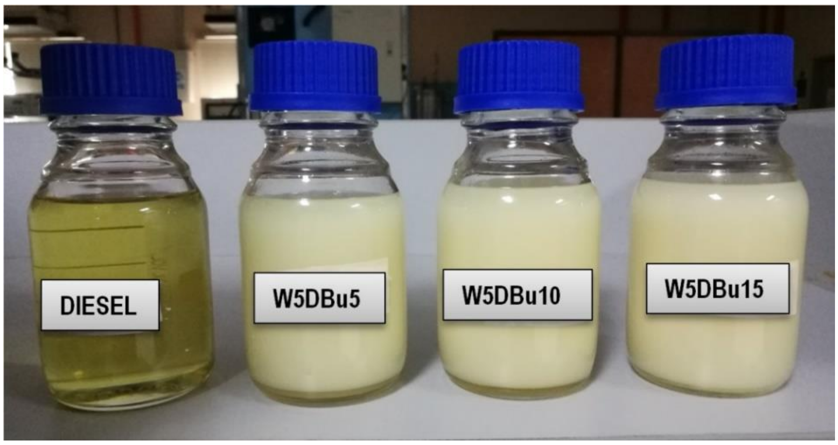

Figure 4. Photograph of Diesel, DW5Bu5, DW5Bu10 and DW5Bu15.

2.2. Testing procedure

The Isuzu 4JJ1 engine as shows on Figure 5 was used in this experiment. The engine was tested at half loads (50%) and engine speeds (1000rpm to 3000rpm) using different percentage of water in diesel 5% with butanol (5%, 10% and 15%) blends. Maximum load of 50% is considered to maintaining of longer life of engine while maximum speed of 3000 rpm was choosing just a bit higher speed after highest torque reached at 2500 rpm. Previous study had noted the W5DBu5 (water in diesel – butanol 5%), W5DBu10 (water in diesel – butanol 10%) and W5DBu15 (water in diesel - butanol 15%). At the beginning of each test, the throttle position was adjusted to give a speed of 3000 rpm at a highest dynamometer load. In the experiments, the load was decrease slowly as the engine speed decrease by 500 rpm to 1000 rpm. Initially the engine was operated with diesel fuel for the warming up process and then water in diesel fuel is gradually introduced. After the testing with water in diesel fuel, again the engine will be operated with pure diesel for the purpose of flushing and cleaning of the fueling system.

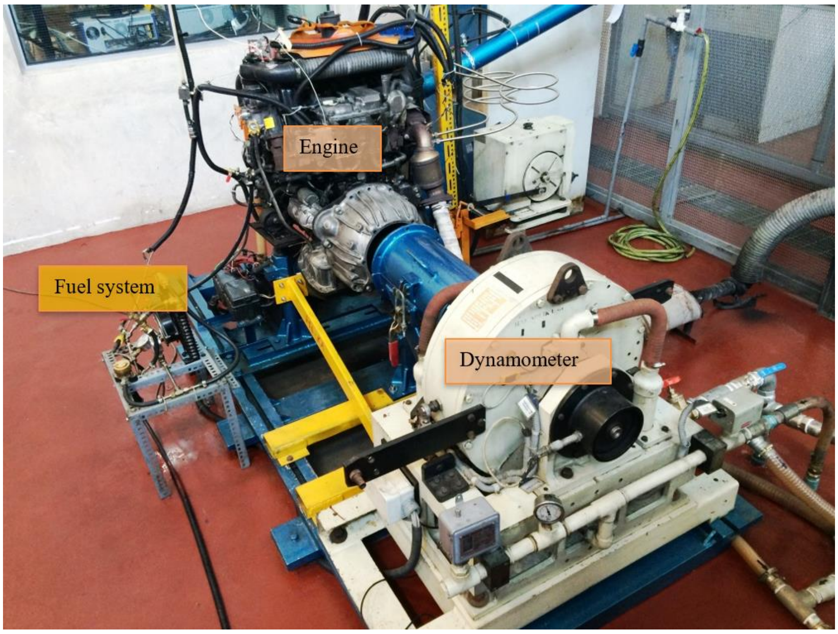

Figure 5. Engine test set-up and test instruments.

3. Experimental results

3.1 Analysis of Engine performance

Engine performance analysis is an important point to investigate the reliability of fuel used in the engine. The study presented in this part is one of the investigation to utilise Isuzu 4JJ1 turbocharged, common-rail direct injection diesel engine. It aims to contribute a clear understanding in the growing area of the engine performance with blended emulsion fuel 5% and a different percentage of butanol compared to the base diesel.

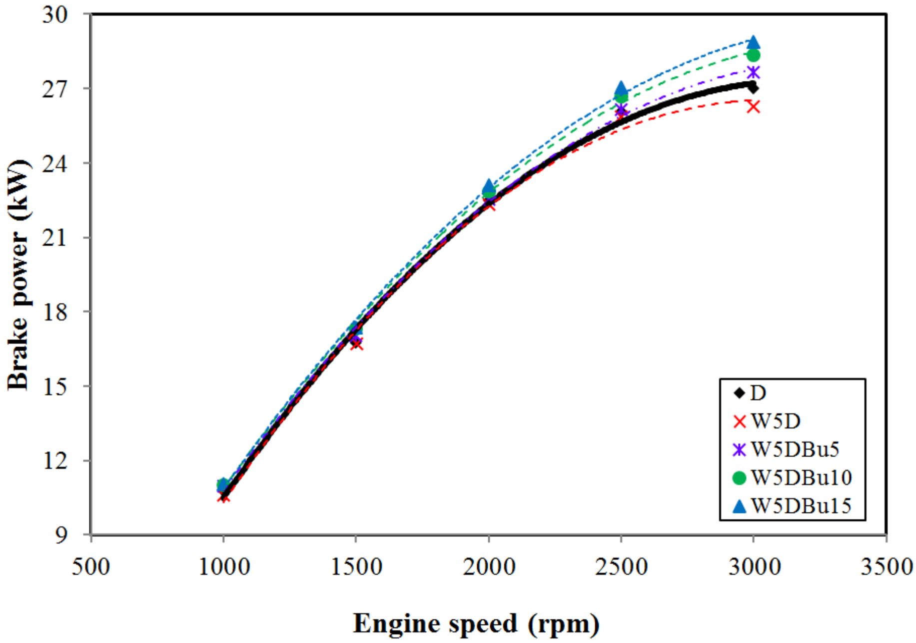

Figure 6. Experimental results of brake power at 50% load at different fuel blends and engine speeds.

Figure 6 depicts the tendency of the engine brake power against the engine speed for diesel and blended fuel W5DBu5, W5DBu10, W5DBu15 with 50% load. It could be observed, that as the brake power increases as the engine speed increases for all the tested fuels. Moreover, it is apparent that the maximum brake power was attained at 3000 rpm. Besides, W5DBu15 fuel has the best brake power compared to other tested fuels over the range. However, the uses of W5DBu5 provide the worst brake power among all fuel from the beginning to 2500 rpm. The tendency of base diesel was a decline after a speed of 2500 rpm while other blended W5DBu have same parallel pattern of graph. This is because it does not have the characteristics of oxygen as other fuels. However, the brake power of W5DBu5 is significantly produced the worst performance, especially at speeds before 2000 rpm.

The effect of different percentage of butanol as additives on brake power at higher percentage to be obvious at high additive ratio, which is higher than 3%, at different trends. This distinction can be noted in the effect of additional additives on the engine brake power with W5DBu due to the main reason to the effect of two factors, which is the effect of additives which provide adding of oxygen content to the fuel and the effect of additives on increase the fuel energy content. Moreover, the higher explosiveness of chemical additives leads to the increasing of the mixing velocity of air and fuel mixture which improves increases the combustion efficiency [5].

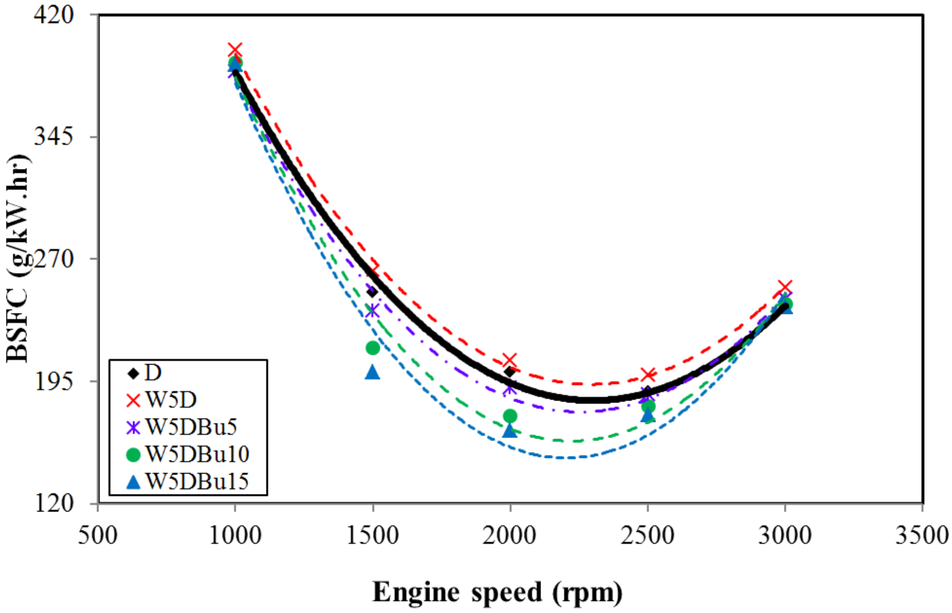

Figure 7. Experimental results of BSFC at 50% load at different fuel blends and engine speeds.

The BSFC is represented as the unit power output mass fuel consumption of the engine and its relationship to fuel viscosity, density, cetane number and heating value [17, 20]. Figure 7 shows the comparisons of BSFC as a function of engine speed for the fuel blends. BSFC of binary blends were higher than that of diesel at all engine speed. Base on the graphs in, the obvious observation that clearly to be described is the contradiction trends amounts of BSFC over the engine speed range for all types of fuels tested with low percentage of load compares to the others load test. This result illustrates the basic theory of combustions, where at low speeds, the heat loss occur to the combustion chamber is respectively larger than that at high speed, thus causing in lesser combustion efficiency [21] and it also has been proven by [22] with the same results.

Among of all the fuel samples, the W5DBu5 fuel shows a comparable result to the base diesel fuel with not much difference in percentage of BSFC. However, when the Butanol fraction is added up to 10% into the sample, the results show a significant different of percentage decrease for BSFC within the range of engine speed. The similar results also shared by the previous researcher which conclude that the lower calorific value of the butanol compared to that for the base diesel fuel will increase in specific fuel consumption [23]. This effect does not follow when the emulsion diesel is added up with 15% of butanol fraction in volume. With the increment volume in butanol percentage to 15% (operating at low load), the engine consumed a significant large number of fuels to be the highest of all

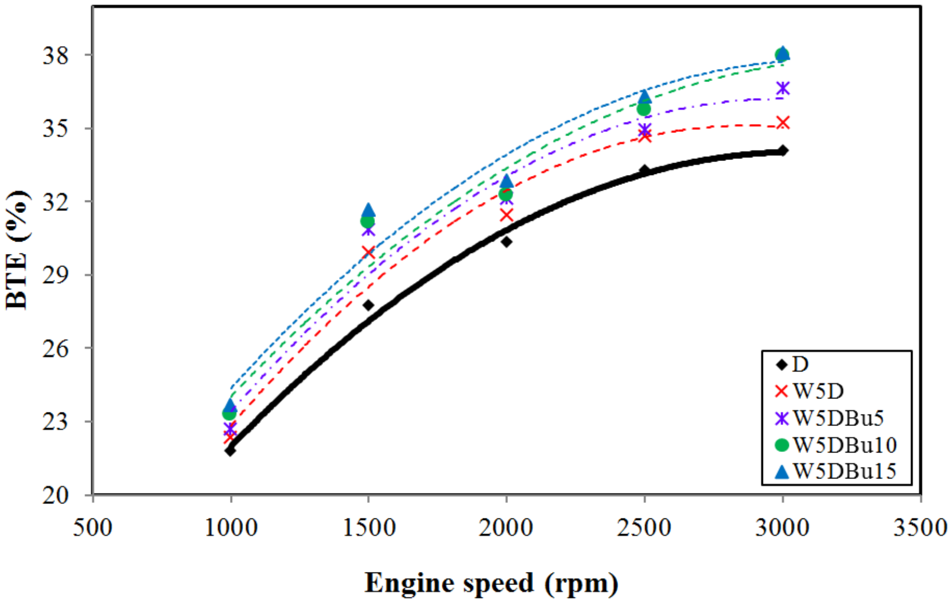

Figure 8. Experimental results of BTE at 50% load at different fuel blends and engine speeds.

Brake thermal efficiency is basically and inverse of the heating value and brake specific fuel consumption. As BSFC increases, it reduces with regard to load [4, 17]. Figure 8 illustrates the trend of the engine brake thermal efficiency against the engine speed for diesel and blended fuel with butanol additive for different ratios (5%, 10% and 10%) at 50% load condition. The brake thermal efficiency of the blended fuel W5DBu at different butanol percentage are higher than base diesel throughout engine speeds and rises with the increasing of butanol ratio. At this load condition, W5DBu15 produce best thermal efficiency. The BTE at 3000 rpm are 33.6%, 36.6%, 37.5% and 38% for 0%, 5%, 10% and 15% butanol ratios, respectively. The increasing in values is proportionate to the increase percentage of Butanol (in volume) of the blends. The reason behind this situation relies on the specific heat capacity value of each fuel blend as compared to the base diesel, which can be referred to Table 3. That the specific heat capacity value is the primary function as directly to the increasing in brake thermal efficiency is being the answer to the stated situation [24].

3.2 Analysis of Engine Emission

Figure 9 shows the nitrogen oxides (NO_x) engine emissions for the base diesel fuel and the various percentages of the butanol in its blends with emulsion diesel fuel. Based on the result the NO_x produced by the water-diesel-butanol blends are slightly lower than those for the corresponding base diesel fuel. In other word, the increase in proportion of butanol in blend ratio will reduce more NOx emission. This might be credited to the lower temperature effect from the butanol that has lower calorific value and higher heat of evaporation. It also helped by water containing in fuel to reduce temperature more. The higher percentages of NO_x reduction delicate over one side, i.e.; depending on the engine specific and its working conditions [25]. Theoretically, lower cylinder pressure in the combustion will reduce the exhaust temperature. Thus, lower NOx in blended fuel. NOx levels in blended fuel were slightly lower than the base diesel fuels because of its lower energy densities, causing lower peak of combustion temperatures.

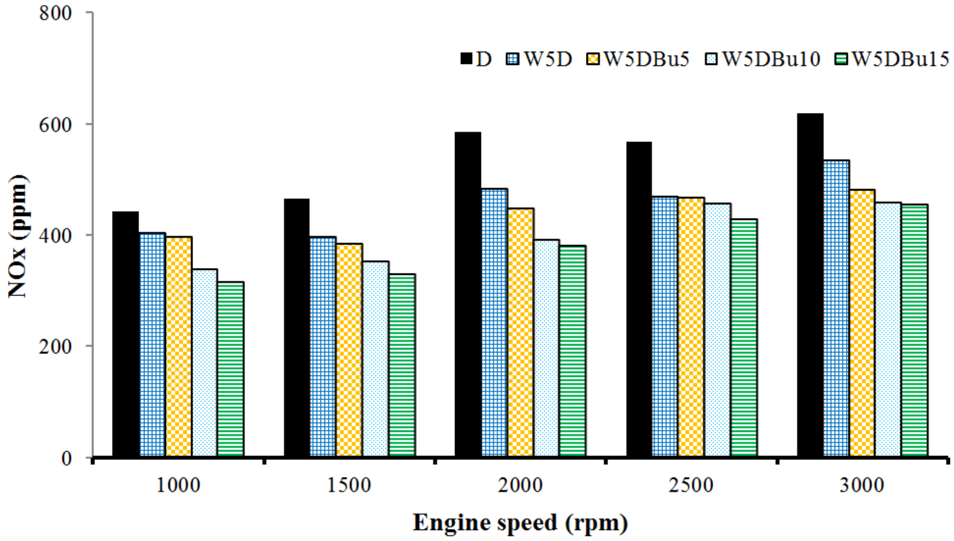

Figure 9. Experimental results of NOx at 50% load at different fuel blends and engine speeds.

Figure 10 shows the graph of carbon monoxide (CO) exhaust emissions for different fuel blends and engine speeds at 50% load. Based on the Figure 9 it can be seen that CO yield by the 2-butanol–emulsion diesel fuel blends is normally lower than that for the base diesel fuel. The reduction rate of CO emission was higher in the bigger engine load conditions. However, for all speed and load, CO value produced by all fuel not over 5%. Definitively, the emitted CO follows the same behavior as the NOx tendency. CO trend is most probably disappear at high speed because of the engine behaviour that operated in the leaner mixture conditions [26]

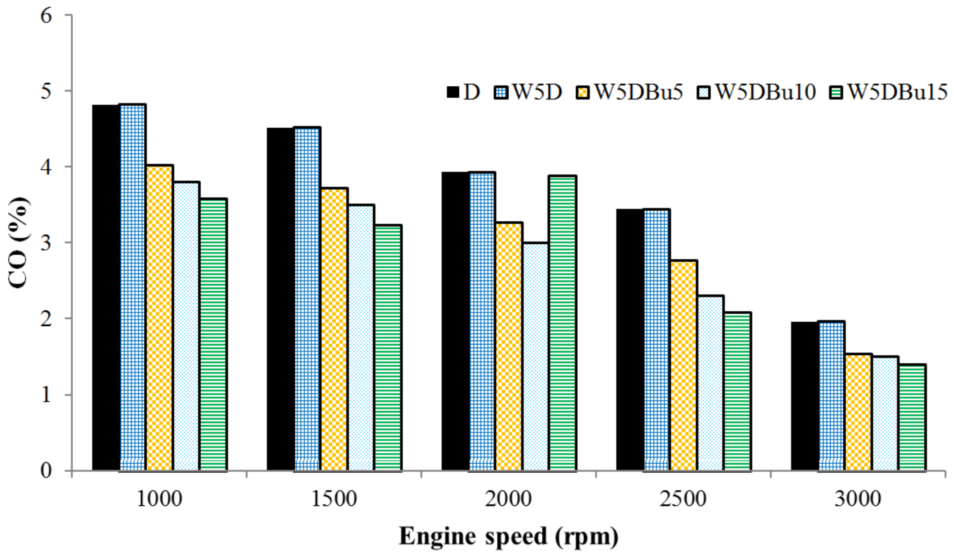

Figure 10. Experimental results of CO 50% load at different fuel blends and engine speeds.

Figure 11 shows the variation of CO2 at 50% load at different fuel blends and engine speeds. It is noted from the experimental results that blended fuel W5DBu15 yield higher CO_2 emission by 8.6% with respect to the base diesel at 3000 rpm. This is mainly due to reason of oxygen content which emerged to reacts with unburned carbon atoms in blended W5DBu15 during the combustion and increases the formation of CO_2. Higher CO_2 in engine exhaust emissions shows the complete combustion of fuel. There has been agreement on this with [27] which discovers an increase in CO_2 emission with fueled by water in diesel with butanol compared to the base diesel.

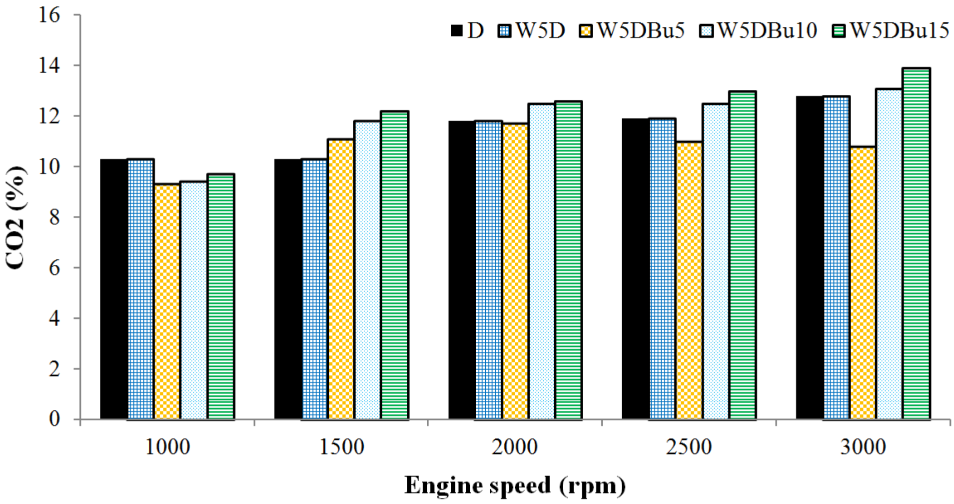

Figure 11. Experimental results of CO_2 at 50% load at different fuel blends and engine speeds.

4. Conclusion

In this study water in diesel-butanol tertiary blends was used to study the effects of important operating parameters of performance and emission such as brake power, BSFC, BTE, CO, CO_2 and NOx on compression ignition engine. Based on the consequences of this revision the following decision can be drawn.

1. The diesel engine operated smoothly with W5DBu5, W5DBu10 and W5DBu15 with no engine modification.
2. The brake power rises with the higher engine speed for all the tested fuels and the maximum brake power attained at 3000 rpm.
3. BSFCs slightly decreased for W5DBu5, W5DBu10 and W5DBu15 respectively by 4.6% to 20.8% compared to that of diesel.
4. The increasing in values of BTE are proportionately to the increase percentage of Butanol (in volume) of the blends at 50% load of engine.
5. The NO_x produced by the water-diesel-butanol blends are slightly lower than those for the corresponding base diesel fuel. In other word, the increase in proportion of butanol in blend ratio will reduce more NOx emission.
6. Throughout this study, it seems reasonable to suggest that W5DBu5, W5DBu10 and W5DBu15 can be used as alternatives to diesel fuel at the expense of their insufficient fuel reduced.

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Nomenclature
WDBu water in diesel -butanol (butanol emulsion fuel) blend
BSFC brake specific fuel consumption
BTE brake thermal efficiency
bP brake power
bT brake torque
CO carbon monoxide
NOx nitrogen oxide
CI compression ignition