Performance of HSDI diesel-engine generator using the blend of B5, n-butanol and ethanol as increased to 20%

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Abstract. B5, diesel mixed with 5% biodiesel, is currently being developed to replace diesel, but there was lower engine performance. To improve the B5 properties, the addition of oxygenated additive is a better method. This research aims to study the performance of a high-speed direct injection (HSDI) diesel-engine generator at speed 3,000 rpm and different loads by using B5 blended to n-butanol and ethanol as increased to 20%. Results show that the use of B5-butanol-ethanol blends decreased engine performance as increasing ethanol; however, the release of nitric oxide, carbon monoxide, and black smoke was remarkably reduced as compared with B5. However, the use of B5 blended to 5% n-butanol, and 5% ethanol increased the electrical power to 0.33%, while electrical efficiency was added to 1.13%, and SFC was similar to B5. Therefore, this ratio can be applied with the diesel engines in the future.

1 Introduction

Electricity is mainly generated from a power plant and sometimes producing from an engine-generator station for agriculture, facility, subsistence, etc. Energy sources are reducing continuously, resulting in the extremely price of primary fuels. Moreover, the innumerable release of carbon dioxide (CO_2) and particulate matter, particularly black smoke which had a diameter of less than 2.5 microns (PM2.5), from the electrical stations, especially diesel-engine generators, is increasing continuously and causing the destruction of the environment and human health. Ethanol and biodiesel become an alternative fuel attractive in blending with diesel since oxygen (O_2) content within both oils could decrease the diesel-engine emissions [1, 2].

Prior studies on the diesel-biodiesel-ethanol blends were indicating that the mixture of diesel, biodiesel, and ethanol by using emulsification is the best because there was highly homogeneous as depended on proportion, purity, temperature, and solubility [2-4]. Ethanol could not be mixed more than 10% because of stratification time happening quickly [4-6]. And the use of diesel blending to biodiesel and anhydrous ethanol, which should not more than 10%, was lower engine power than diesel but the exhaust gas emissions, especially carbon monoxide (CO) and black smoke were decreased [7-15].

To increase the homogeneity, some researches [2-5] used emulsifiers, such as n-butanol, ethyl acetate, propanol, etc., in blending to diesel and ethanol. Use of 5% butanol, which was normal butanol or n-butanol, mixed with diesel and anhydrous ethanol could improve engine performance, and diesel could be blended to 25% anhydrous ethanol by high homogeneity, and lower thermal efficiency leading to the increase of fuel consumption [5]. Prior studies on the diesel-biodiesel-anhydrous ethanol blends by adding n-butanol for HSDI diesel engines had some parts. B5, which was diesel mixed with 5% palm methyl ester (PME), is currently replaced the conventional diesel in Thailand. Still, this research has developed the B5 as produced from using 5% palm ethyl ester (PEE) to replace the use of PME in the future. This research aims to study the fuel properties and performance of an HSDI diesel-engine generator using the B5, the 95%w diesel blended to 5%w PEE, mixed with n-butanol and anhydrous ethanol as increased to 20% comparing to B5 by testing at a constant speed 3,000 rpm and loads.

2 Methodology

2.1 Fuel preparation

Substances consist of D, B5, anhydrous ethanol (99.9%w), and n-butanol (99.5%w). For the sequence of the mixture, n-butanol (Bu) was used at 5%w in all proportions, and B5 was blended to ethanol (E) by increasing to 5, 10, 15, and 20%w, while terms were shown as B5E5Bu5, B5E10Bu5, B5E15Bu5, and B5E20Bu5 respectively. In the emulsion process, the electromagnetic machine and the mechanical stirrer were applied in the controlling mixture at 800 rpm, and the blending temperature was fixed at 30 ^{o}C as studied from the phase diagram in Reference [4]. Next, there were investigating physical properties, such as fuel density, kinematic viscosity, and lower heating value (LHV), under various ASTM procedures, as shown in Table 1.

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Table 1. Fuel properties.

Items	Density (kg/m^3)	Viscosity (cst)	LHV (MJ/kg)	Separated time
ASTM	D1298	D445	D240	-
D	830	3.26	44.57	-
B5	836	3.32	43.40	Not
B5E5Bu5	809	3.06	42.03	Not
B5E10Bu5	803	3.01	41.87	25 (days)
B5E15Bu5	797	2.78	40.99	16 (days)
B5E20Bu5	790	2.55	39.98	11 (days)

Fuel properties' results of B5 blended to ethanol from 5 to 20%w and 5%w n-butanol as compared with B5 under various ASTM procedures showing that fuel density was decreased from 3.23 to 5.50%, kinematic viscosity was reduced from 7.83 to 23.19%, and LHV was decreased from 3.15 to 7.88%. Moreover, this research found that B5E5Bu5 had not been separated for 2 months. As compared with Reference [1], B5E5Bu5 could be applied as an alternative fuel with diesel engines in the future because some properties, especially viscosity and density, were within the scope of standard diesel as determined by the Department of Energy Business, Thailand.

2.2 Engine performance test

The experiments were carried out on an HSDI diesel-engine generator [Model, Mitsuki: 5GF-ME; cylinder, 1 cyl; capacity, 0.406 L; power (max.), 5 kW_{ele} @ 3,000 rpm; compression ratio, 17.5:1], while the schematic of the experimental setup is shown in Fig. 1.

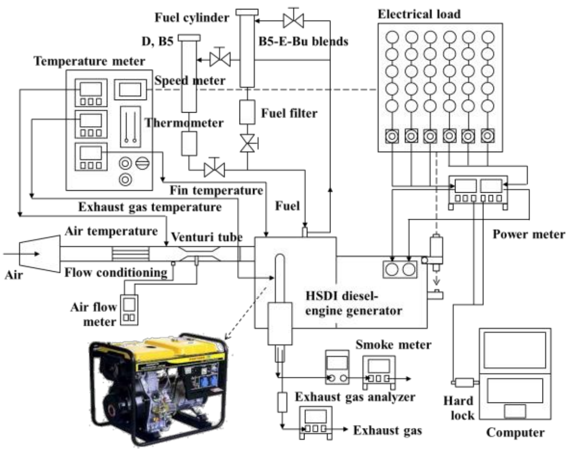

Fig. 1. Schematic of the experimental setup.

This generator was connected with the light-bulb panel, which had several bulbs, for increasing electrical loads. At the same time, a power meter was applied in measuring the electrical power by processing on a computer. Engine temperatures, such as coolant, air, and exhaust gas, were investigated by using the K-type thermocouple and the temperature meters. The air flow rate was measured from a venturi tube and an air flow meter. Fuel consumption was calculated from the amount of fuel 20 ml within a fuel cylinder per time. Finally, there were the installation of Cosber: KWQ-5 automotive emission analyzer and Cosber: KYD-6 opacimeter to measure the CO and NO levels and the black-smoke intensity, respectively.

For investigating the engine performance from using these oils, this generator was firstly warmed up about 15 minutes. After engine operation was stable, the surrounding temperature was controlled at 30±3 °C, and the coolant temperature was set at 90±5 °C. All experiments were started up by using diesel (D). Speed was controlled at 3,000±50 rpm. Electrical loads were started from 20% and later 40%, 60%, 80% and 100% respectively. Fuel volume was fixed at 20 ml to record the change of time. Parameters, such as electrical power, air flow rate, fuel consumption, temperatures, and emissions, were recorded. Next, the B5 and the B5-ethanol-butanol blends (B5-E-Bu blends), such as B5E5Bu5, B5E10Bu5, B5E15Bu5, and B5E20Bu5, were tested respectively, as using the same condition with diesel test. Finally, all parameters from using D, B5, and B5-E-Bu blends were calculated in the engine-performance parameters. Particularly, thermal efficiency as calculated in case of electrical efficiency, which was the ratio of electrical power to the sum of fuel consumption and calorific value, and specific fuel consumption as studied from the ratio of fuel consumption to electrical power. All period of the engine test was between 100 hours, and results were repeated by more than 5 times [3].

3 Results and discussion

3.1 Electrical power

Fig. 2 indicates that the electrical power is increased as increasing loads, while the use of B5-E-Bu blends at the electrical load from 20 to 80% gave the electrical power similar to D and B5.

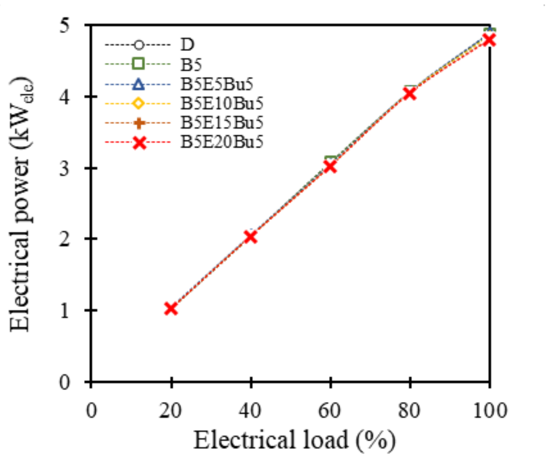

Fig. 2. Electrical power at different loads.

However, the use of B5-E-Bu blends at full load (100%), showing that electrical power as generated from using these oils changing. Especially, B5 mixed with 5% n-butanol and 20% ethanol (B5E20Bu5) had lower electrical power than B5 as reduced to 1.75%. This result is consistent with literature reviews [1-6]. Because B5 was typically higher heating value than ethanol, ethanol, as added to 20% mixing with B5 and n-butanol, resulted in a highly lower calorific value than B5 (Table 1), leading to the decrease of electrical power. Contrarily, this research is focusing on the change of electrical power from using B5 mixed with 5% n-butanol and 5% ethanol (B5E5Bu5), as found that electrical power was increased to 0.33% as compared with B5. For adding the generating electricity, this research discusses that mixing 5% n-butanol with B5 and 5% ethanol resulted in the complete combustion leading to the addition of energy release in diesel-engine combustion processes. As a result, the net engine power was increased, leading to the addition of output engine power as converted into electrical power.

3.2 Electrical efficiency

Fig. 3 on the left side shows that electrical efficiency (EE) is increased until 80% load, while the use of full load has a decrease of this efficiency due to increased heat loss and mechanical frictions [2]. This research found that two main points are interesting. First, B5E5Bu5 had higher EE than B5 as added to 1.13% at 80% load. This result is hypothesized by mixing 5% n-butanol with B5, and 5% ethanol led to a rapid ignition timing resulting in a reduced ignition delay. As a result, energy release in periods of diesel-engine combustion processes was increased, leading to an increase in thermal efficiency [4-6].

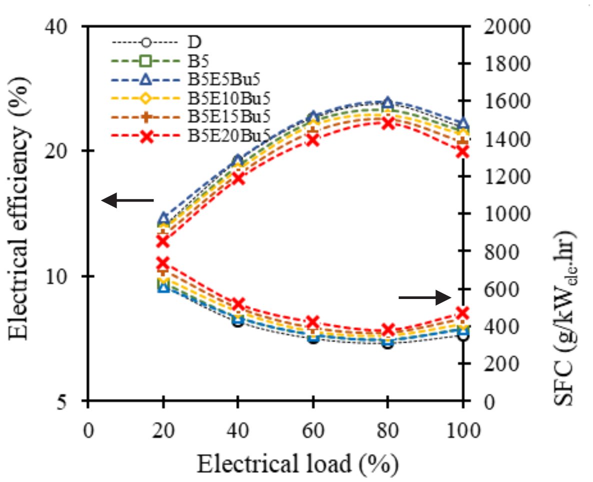

Fig. 3. Electrical efficiency and SFC.

Another reason is discussed by adding ethanol from 10 to 20% as mixed with B5 and n-butanol resulted in the decrease of EE, as reduced from 0.64 to 1.72% at 80% load compared with B5. Results were in the same direction of literature reviews [2-4] since n-butanol and ethanol had lower calorific value than B5 as blended to n-butanol and ethanol, adding from 10 to 20% (B5E10Bu5 to B5E20Bu5) resulted to the high reduction of heating value. As a result, the use of B5E10Bu5 to B5E20Bu5 had, respectively, higher fuel consumption and input fuel energy than B5 as producing electricity equally. For applying the B5-E-Bu blends as replaced to B5 with diesel-engine generators in the future, this research recommends that B5E5Bu5 is the best.

3.3 Specific fuel consumption

Fig. 3 on the right side shows that the specific fuel consumption (SFC) is decreased as increasing load until to 80%, and there is the increase of SFC at full load because of the rise in fuel consumption coming from the energy loss within the engine systems [2]. Similarly, the results of SFC have two interesting issues. First, SFC from using B5E5Bu5 was similar to B5 as hypothesized by B5E5Bu5 had the start of combustion rapidly leading to the decrease of ignition delay and complete combustion than B5. As a result, there was an increase in energy release in the combustion processes of the diesel engine. Although B5E5Bu5 had lower calorific value and higher fuel consumption than B5, they were only slightly [4-6]. For using B5E10Bu5 to B5E20Bu5, SFC was increased with the increase of ethanol as added from 6.32 to 16.47% at 80% load compared with B5. The results of this engine test had the same tendency as the previous researches [2-4]. Because the addition of ethanol from 10 to 20% as blending to B5 and n-butanol led to the decrease of heating value (Table 1) respectively, the electricity generation from using these oils equalled to using B5 resulting to higher fuel consumption.

3.4 Exhaust gas temperature

Fig. 4 on the left side shows the level of exhaust gas temperature (EGT) increasing with the increase of loads. For using the mixture of B5, n-butanol and ethanol adding from 5 to 20% as compared with B5, EGT was reduced from 13.98 to 32.95 °C at 80% load. These results have the opposite effect on References [2, 3].

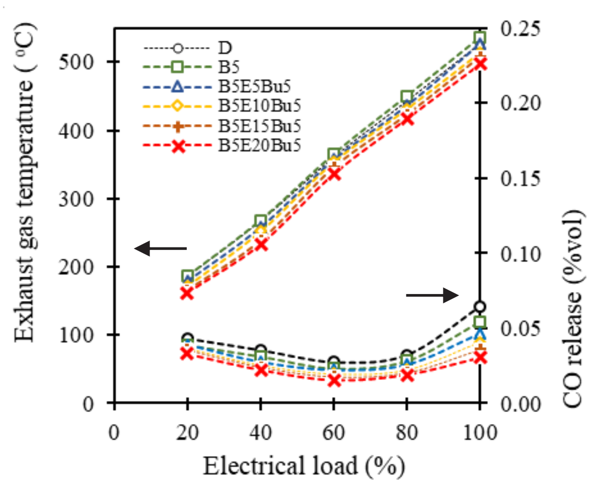

Fig. 4. Exhaust gas temperature and release of CO.

For the reasons of decreasing EGT from using these oils, firstly explained by this research used the primary substrate, which was B5 as produced from 95% diesel and 5% palm ethyl ester. Usually, the mixing ethyl ester with diesel led to the increase of burning temperature in premixed and mixing controlled combustion resulting in the increase of EGT as explained in [11-14]. Contrarily, the addition of n-butanol and ethanol up to 20% led to the change of diesel-engine combustion characteristics. Since ethanol and n-butanol had higher latent heat of vaporization than B5, B5 mixed with n-butanol and ethanol adding to 20% as injected into the combustion chamber resulted to the start of combustion quickly at a lower gas temperature which caused to the decrease of burning temperature in the cylinder. As a result, the burning temperature in mixing controlled combustion period was decreased [4-6]. Another reason is discussed by the addition of n-butanol and ethanol was to increase the O_2 content, resulting in the highly complete combustion in the premixed combustion phase leading to the duration of this period increased. As a result, the duration of mixing controlled combustion was decreased leading to the end of combustion before the end of power stroke while the exhaust valve was opened resulting to the decrease of EGT [4-6].

3.5 Carbon monoxide release

Fig. 4 on the right side indicates that the increase of load from 20 to 60% leads to the reduction of carbon monoxide (CO) emission, while CO level is increased as adding load from 80 to 100% because of increasing electricity generation causing to the increase of fuel consumption and the decrease of air-fuel ratio [2]. Use of B5-E-Bu blends comparing with B5 showing that CO release was decreased as increasing loads and ethanol percentages. For investigating at 80% load, CO level was reduced from 8.77 to 31.58% while these results were in the same direction of literature reviews [4-6] because of adding ethanol causing to the reduction of ignition delay from burning reactant by using high O_2 content resulting to the increasing products, particularly CO_2. Moreover, the use of B5 has higher CO release than the use of B5 mixed with n-butanol and ethanol as increased from 5 to 20%, because the B5 was produced from the 5% palm ethyl ester resulting to the increase of burning rate in mixing controlled combustion phase leading to the addition of CO level [11-14]. Therefore, the increase of O_2 content from mixing n-butanol and ethanol, which increasing until 20%, with B5 resulted in the complete combustion. O_2 element within these oils was mainly reacted with one carbon atom within these oils becoming to CO_2 [4-6].

3.6 Nitric oxide release

Fig. 5 on the left side shows that release of nitric oxide (NO) is increased, as the electrical load is added from 20 to 80%. However, the level of NO is decreased at full load because there was an increase of CO level as explained in Section 3.5. Use of B5 blended to n-butanol and ethanol as increased from 5 to 20% resulted in the decrease of NO level, as the electrical load was increased. For measuring the NO release at 80% load, NO level was reduced from 1.85 to 17.50% as compared with B5. These results are consistent with previous researches [4-6] while two interesting issues are illustrating the decrease of NO emission.

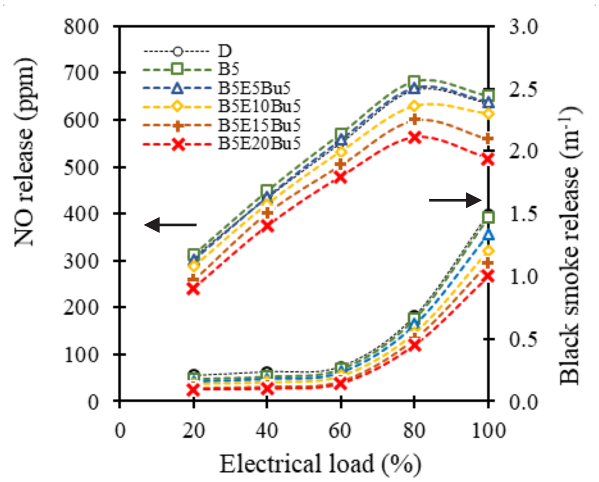

Fig. 5. NO level and release of black smoke.

First, ethanol and n-butanol had higher latent heat of vaporization after being injected into the combustion chamber, causing the start of combustion quickly at a lower gas temperature in the cylinder. As a result, the burning temperature in periods of diesel-engine combustion processes was decreased, resulting in less NO formation. In addition, ethanol and n-butanol were lower calorific value than B5 leading to the reduction of the heating value of the B5-E-Bu blends, which caused lower combustion temperature than B5. Another reason is explained from NO formation came from increasing the oxygen concentration in during the combustion processes of diesel engine, but the addition of ethanol concentration as mixing with B5 and n-butanol led to the complete combustion. As a result, O_2 element within these oils was mainly reacted with one carbon atom becoming to CO_2 as discussed in Section 3.5.

3.7 Black smoke release

Fig. 5 on the right indicates that the intensity of black smoke is increased as adding load, while the use of B5-E-Bu blends leads to the decrease of black-smoke intensity as reduced from 7.06 to 31.92% at 80% load compared with B5. Results of black-smoke intensity could conclude that the use of B5 mixed with n-butanol and ethanol as adding to 20% reduced the black smoke release, while the results of this engine test have the same tendency as previous researches [2-6]. Reason of black smoke level was decreased as using the B5-E-Bu blends, firstly confirmed from decreasing of CO level as shown in Section 3.5. Next, the use of B5 as compared with diesel resulted in the level of black smoke decreased because B5 had the O_2 element leading to complete combustion in mixing controlled combustion period [11-15]. For mixing n-butanol and ethanol, as increasing to 20%, with diesel, literature reviews [4-6] ensures that there was the increase of O_2 content leading to the ratio of carbon to hydrogen (C/H ratio) of D-E-Bu blends decreased resulting to the reduction of black smoke formation in the exhaust gas. Therefore, the use of B5 blended to n-butanol and ethanol as adding to 20% leading to the lower C/H ratio and higher O_2 content than B5. High O_2 element from using the B5-E-Bu blends had improved better combustion efficiency in mixing controlled combustion phase resulting in a higher reduction of black smoke release than B5.

4 Conclusions

From investigating the fuel properties and performance of HSDI diesel-engine generator by using B5-E-Bu blends as compared with B5 at 3,000 rpm and different loads. The main results are concluded in the following items :

(1) Physical properties of B5-E-Bu blends were lower than B5, but B5E5Bu5 had some properties, particularly viscosity and density, which was within the scope of standard diesel as determined by the Energy Business Department, Thailand. B5E5Bu5 had higher homogeneity. For applying as an alternative fuel with the diesel engines in the future, this research suggests that B5E5Bu5 should be used.

(2) Electricity generation from using the B5-E-Bu blends is similar to B5 while the electrical load was increased from 20 to 80%, but the ability to generate electricity at full load showing clearly that the use of B5E20Bu5 had lower electrical power. Contrarily, the use of B5E5Bu5 gave higher electrical power than B5.

(3) Electrical efficiency from using B5E5Bu5 was higher than B5 to 1.13%, but the use of B5E20Bu5 was decreased to 1.72%. Contrarily, SFC from using B5E5Bu5 was similar to B5, but the use of B5E20Bu5 resulted in an increase of SFC highly. Therefore, the choice of the right mixture between B5, n-butanol and ethanol as the replacement to B5 in the future recommends that B5E5Bu5 is the best because of better engine performance.

(4) Results of exhaust-gas emissions shows that the use of B5 mixed with n-butanol and increasing ethanol up to 20% as compared with B5 led to the decrease of exhaust gas temperature and pollutants, particularly CO, NO, and black smoke levels. Reasons resulting to the reduction of pollutants are explained by ethanol and n-butanol had higher latent heat of vaporization, lower C/H ratio, and higher O_2 content leading to the decrease of pollutants.

(5) The results of the present study provide the ideas for further study improvement. The injection and combustion characteristics and other emissions, such as CO_2 and unburned hydrocarbon, from using the B5-E-Bu blends as compared with B5 must be studied. While this investigating indicating that B5E5Bu5 was the best, the study of the wears of the engine from the use of B5E5Bu5 as compared with B5 in the long term should be studied.

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