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EFFECT OF TECHNICAL MODIFICATIONS ON THE FUEL CONSUMPTION AND EMISSION LEVEL OF BIODIESEL-DIESEL BLENDED (B30) FUEL ENGINE

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The use of the mixed of biodiesel and diesel (BXX) will affect the performances of engines that are previously used for pure diesel. Therefore, this study was conducted to determine the appropriate technical modifications that can be applied in the B30-fueled generator set. Several modifications were carried out such as no modification (as a control), the addition of fuel preheater, the change of the injector nozzle specifications, and the combined modifications in the B30 fuel generator set. The results of the study revealed that the addition of fuel preheater reduced fuel consumption, CO emission around 20% and 7.6% respectively. In contrast, there was an increase of the output voltage by 0.7%. Moreover, the change of the injector nozzle specifications showed a decrease in fuel consumption and output voltage around 7.92% and 2.2% respectively, but increase in CO emissions by 62.3%. The combined modification showed the reduction of fuel consumption and output voltage around 12.45% and 2.6%, respectively. However, the CO emission increased around 90%. In summary, the best modification for biodiesel-diesel blended (B30) fuel engine was found in the engine with the addition of preheater modification because it gives high fuel consumption but low emission level.

Keywords: *Biodiesel, B30, Fuel Preheater, Generator Set, Nozzle Injector*

1. INTRODUCTION

The Indonesian government has suggested biodiesel fuels as a future fuel to reduce the import of fossil fuel by this country [1]. It also can be useful for enhancing the potential of palm oil industry [2]. The Ministry of Energy and Mineral Resources continues to encourage the usage of biodiesel in the form of BXX or X% biodiesel mixture in diesel oil. The government has contributed in the successful of biodiesel fuel by conducting the research about the mixing of 30% biodiesel type (B30) from vegetable fuel with pure diesel fuel. Currently, the application of B30 still concerns on the transportation sector [3], while the use of the B30 in the industry sector is still sparse. Therefore, the studies about the use of the B30 for industrial facilities such as generator set are an interesting topic to be investigated. Generator set is one of the important industrial tools to generate the electric power. The use of generator set has been widely applied in the all industries. Generator set is an electric engine that converts from mechanical energy to electrical energy by using the principle of magnetic induction. Generator set can be divided into two sets; AC and DC generators.

The previous studies about diesel engines that used biodiesel fuel have been carried out [4]. One of the physical properties of biodiesel-solar mixture that will affect the performance of generator set is viscosity. High viscosity will affect the atomization rate of the fuel. The use of B5, B10, and B20 may result in a decrease in torque and power that are generated by diesel engines [5]. The use of B30 in diesel engines power plant can increase fuel consumption [6]. Based on a study by Oyedepo et al [7], the use of B5-B20 also causes a decrease in engine power, the highest percentage of power decrease occurs during the use of B20 around 21.1%. The properties of the non-modified diesel engine use a biodiesel-diesel mixture show the reduction of engine torque,

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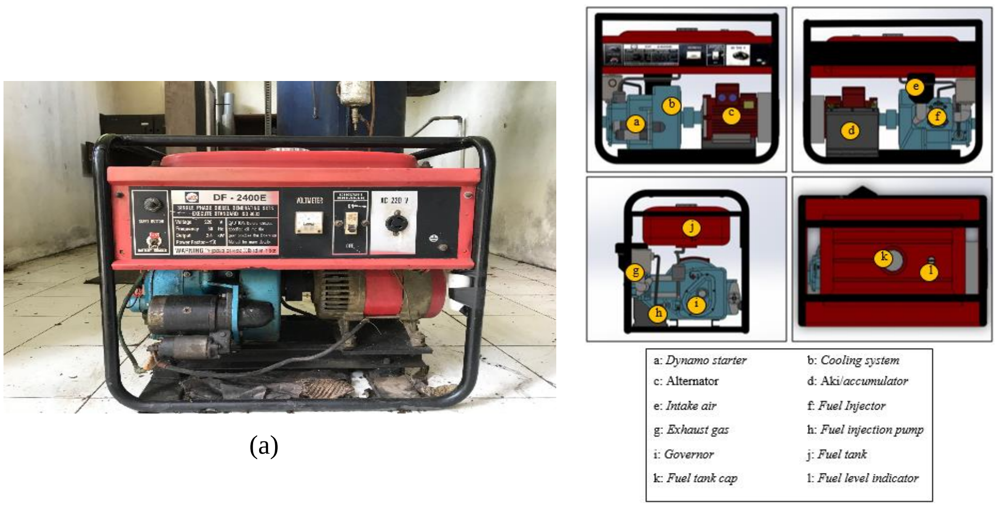
brake power, gas emissions (CO and UHC), but increase of exhaust gas temperature, brake specific fuel consumption, and NO_x and CO_2 emissions [8].

Based on outputs of those studies, we know that to produce the performance of diesel generators that are as good as diesel fuel. The generators with biodiesel fuel in higher mixtures (B30 or more) needs to be modified. Several modifications that can propose such as the addition of fuel preheater to facilitate the atomization process in combustion chamber [9], or change the specification of nozzle injectors to improve the combustion process [10]. Mekonen and Sahoo [11] assumed the use of fuel preheater in engines with biodiesel-diesel mixtures led to increase the efficiency around 8.7-14.3% as compared with other engines. In addition, the increase in CO_2 in fuel heating engines also shows that the combustion rate is better than normal engine. Sharma et al. [12] found the reduction of nozzle size by 0.08 mm can affect the fuel consumption of diesel engines. As a whole, this current study will apply several technical recommendations on B30-fueled generators. The performances of engine will be tested according to the implemented modifications. Outputs of this study hope to give technical recommendations for generator manufacturers and consumers that related to the maintenance, services of biodiesel-diesel blended (B30) fuel engine.

2. MATERIALS AND METHOD

The engine or generator that used in this study was designed by a manufacturer of diesel fuel and it was classified as AC generator set (Fig. 1). The generator was namely Vanco DF-2400E type. Furthermore, the specifications of the generator were presented in Table 2. We used four types of modifications in this study such as the engine with no modification (as a control), the engine with the addition of fuel preheater, the engine with the replacement of nozzle injector, and the engine with the combined modification. Some parameters for analyzing performance of the studied engine were fuel consumption, exhaust gas temperature, residual O_2, CO emissions, and the output voltage.



(a) (b)

Figure 1: (a) Generator type used in this study, (b) Parts of generator components.

The installing of fuel preheater component was carried out by cutting the fuel flow pipe between the fuel tank and pump injection. The fuel preheater was assembled in this position that was useful for flow the fuel directly to the pump injection without a delay. Moreover, the nozzle injectors that used in this study had a same type but they were different size. The injector nozzle varied in the diameter of the nozzle needle which directly compressed the fuel into the combustion chamber. The change of nozzle injector was carried out by removing the injector in the fuel flow block cylinder. The nozzle in the inside of the injector nut was removed and replaced with a smaller nozzle. The comparisons of nozzle injector specification were shown in Table 3. Based on Table 3, the normal condition nozzle was 0.99 mm in diameter and the modified nozzle was lower at 0.96 mm. The change of existing specifications was expected to give positive performances in the work patterns of the engine. The comparisons of these modifications were shown in the Table 4.

Table 2: The specifications of diesel engine.

Parameter	**Value**
Model	Horizontal, Air cooled, 4-stroke
Combustion System	Swirl combustion chamber
Total Cylinder	1
Bore x Stroke (mm)	75 x 75
Total displacement (L)	331
Compression Ratio	21 ± 1
Rated power (kW)	3.68
Rated speed (r/min)	2600
SFC (g/kW.h)	≤ 301.4
SLOC (g/kW.h)	≤ 4.1
Cooling System	Air-cooled
Lubricants System	Combined pressure and splashing
Starting Method	Hand cranking
Net Weight (kg)	≤ 50

Table 3: Comparison of specifications of old nozzle injector and new nozzle injector.

Specifications	**Old Nozzle injector**	**New Nozzle injector**
Outer Diameter	13.81 mm	13.76 mm
Nozzle Body Diameter	5.93 mm	5.95 mm
Nozzle End Diameter	0.99 mm	0.96 mm
Nozzle Top Diameter	2.64 mm	2.59 mm
Nozzle Hole Diameter	1.67 mm	1.99 mm

Table 4: The comparison of old nozzle injector and new nozzle injector based on engine sound and emission.

Generator Set Condition	**Observation Results**
Generator set with old nozzle injector	• Engine sound was less stable at startup, but stable when running and shut down. • No smoke at the time of running and shut off, but at startup was found slight visible plumes of white smoke.
Generator set with new nozzle injector	• Engine sound was less stable at startup, started to stabilize when running and shut down but the sound was not too loud. • No smoke at the time of running, but at startup and shut down observed dark smokes

In this study, we also calculated the efficiency analysis that converted the combustion from calorific energy into mechanical energy and then converted again into electrical energy. The performance efficiency of the engine was calculated by the formula in the Equation 1.

$$\eta_o = \frac{V \times I}{m \times LCV} \times 100\% \tag{1}$$

V represented the output voltage (volt), I represented the strength of the electric current (ampere), m stated the rate of fuel mass flow (kg/s), and LCV stated the lower calorific value (J/kg).

3. RESULTS AND DISCUSSION

3.1 Effect of engine modifications on fuel consumption

Figure 2 showed the comparison of fuel consumption in four engines with several modifications. The result of study found the lowest fuel consumption was observed at the engine with the addition of fuel preheater (1,060 ml), followed by the engine with the combined modification (1,160 ml), engine with nozzle injector replacement (1,220 ml), and engine with no modification (1,325 ml). A study by Priyanto and Sudarmanta [13] found that the increase in temperature tended to lower the viscosity of the biodiesel-diesel mixtures so that the size of droplets sprayed into the fuel chamber became smaller while the atomization became better. This process would make the fuel consumption for the combustion process greatly decreased.

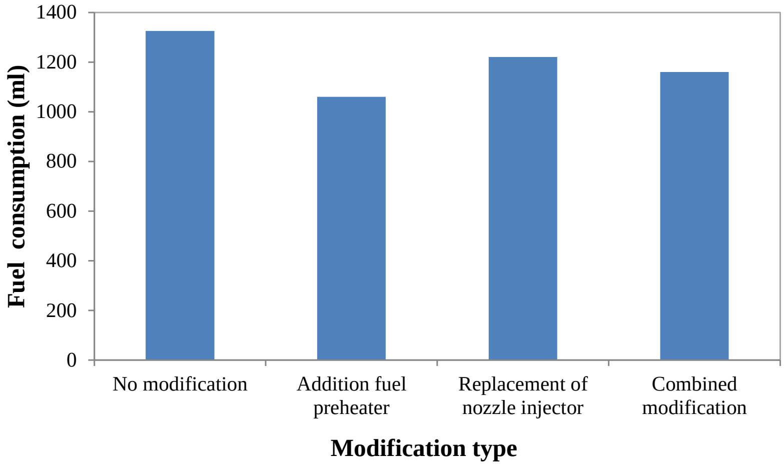


Figure 2: The fuel consumption in each engine modification.

3.2 Effect of engine modifications on CO levels

The lowest average of CO emission was shown in the engine with the addition of fuel preheater (55.83 ppm), while the highest value was shown in the engine with the combined modification (114.83 ppm). The engine with replacement of nozzle injector obtained the second higher CO emission after the engine with combined modification around 98.08 ppm. The engine with no modification showed the CO emission around 60.4 ppm (Fig. 3). Increased CO emissions in combined modification conditions by 90% compared to engine conditions without modification. This is due to the lack of air entering the combustion chamber so that the combustion becomes imperfect and the time is not enough in completing the combustion process so that the resulting CO emissions will be much more increased [14].

3.3 Effect of engine modifications on residual O_2 levels

The average of residual O_2 from the highest value was observed in the engine with the addition of fuel preheater (19.05%) and followed by the engine with the combined modification (19.01%), the engine with the replacement of nozzle injector (18.90%), and the engine with no modification (18.72%) (Fig. 4). The increase in residual O_2 might be due to the increase of temperature of the engine. When the fuel temperature raised, the self or spontaneous combustion would occur. This increase of residual O_2 levels also could be due to the poor mixture of air and fuel. Because the imperfect combustion in the engine would produce more oxygen to the air. The oxygen residual values would be low when the perfect combustion occurred [15].

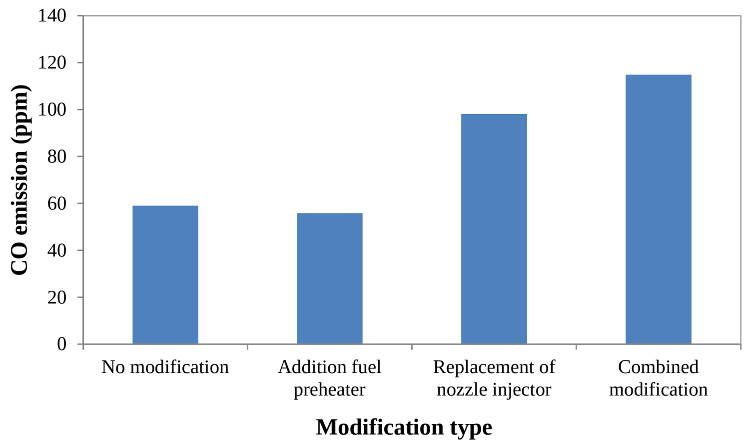


Figure 3: The CO emissions in each engine modification.

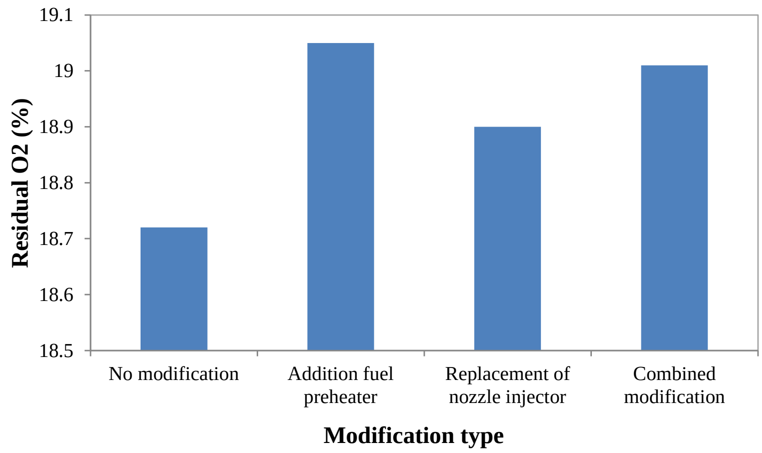


Figure 4: The residual O_2 values in each engine modification.

3.5 Effect of engine modifications on exhaust gas temperature

Based on the Figure 5, the highest exhaust gas temperature was observed in the engine with addition of fuel preheater around 145˚C. This temperature was found in the time ranging from 60 to 90 minutes. All engines with modification generally fluctuated across the time. In the engine with the replacement of nozzle injector, the highest exhaust gas temperature was at 125-130 ˚C with time between 70 and 140 minutes. In the engine with the combined modification, the highest exhaust gas temperature was shown in 135 ˚C at 135-150 minutes. While, the engine with no modification gradually increased and reached the maximum temperature at 140 ˚C (Fig. 5).

3.6 Effect of engine modifications on output voltage

The average output voltage that was produced by the engine with no modification was 237.75 volts (Fig. 6). While, the engine with addition of fuel preheater showed the output voltage value around 239.5 volts. The engines with the replacement of nozzle injector and the combined modification showed a lower output voltage values ranging from 231.5 to 232.5 volts. Based on output voltage graphs, the output voltage on the engine with the addition of fuel preheater was more stable than the engine with other modifications. The output voltage that was produced by the engine with the addition of the preheater was higher than the other engines. It was seem stable in the first 75 minutes. This condition might be due to the punctuality of combustion. The fuel would quickly splash as the temperature was close to the flash point. However, there was a simultaneous increase during 90-135 minutes and experienced a turn back in 180 minutes. This condition was affected by the velocity of rotor rotation in the engine block, where the longer the operating time would increase the torque working on the crankshaft. Torque was produced by the effect of piston movement that enlarged the power of the engine. This rotation also increased the voltage values. The engine with the combined modifications showed a fluctuation of performance profiles. This unstable output voltage might be due to an unstable combustion process and rotor rotation. The output voltage in the engine with the modified nozzle injector was found lower than the engine with no modification. This was due to the lack of fuel in the fuel chamber thus the production of energy was smaller and made the condition of the rotor rotation become unstable. The Injector nozzle sprays a combination of fuel and air into the combustion chamber. Some critical injector nozzle factors, including such hole size and geometry, have an impact on the diesel engine's combustion characteristics. Changes in the type, geometry, and size of the nozzle are certain to affect the injection parameters so that the production of mechanical energy is directly affected. Fuel/air mixing has been shown to be most effective with smaller nozzle holes. Reduced nozzle hole size, on the other hand, minimizes the level of turbulent energy generated by the engine. The optimum nozzle design would be one that burnt the most liquid fuel and left the least quantity of liquid fuel unburned throughout the combustion process. According to several researchers, fuel penetration into the combustion chamber with a smaller nozzle size for the use of fuel oil with a higher viscosity will get an adverse influence on the mixing of fuel with available air in the combustion chamber. The presence of biodiesel in the fuel causes the viscosity to rise, disrupting the atomization process and clogging the engine's rotation. There is the risk of flowability disturbance, that could lead to a blockage.

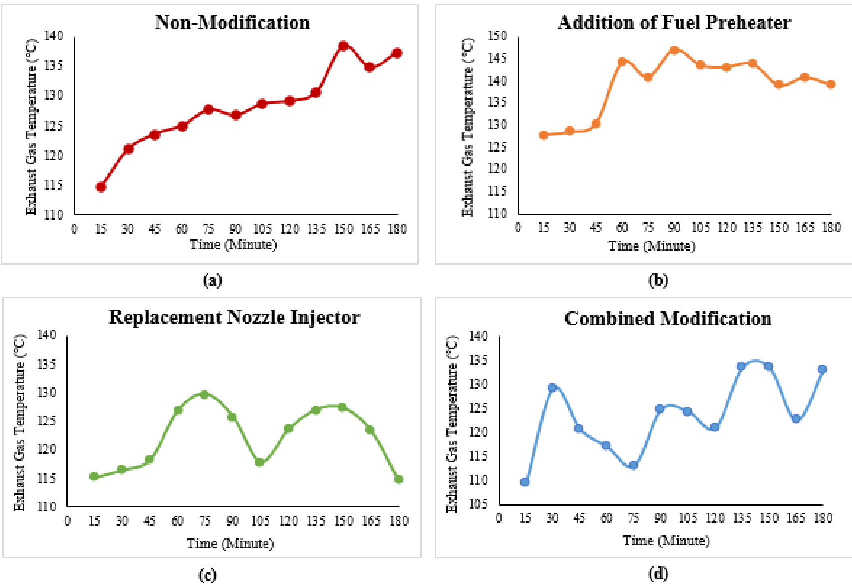


Figure 5: (a) Exhaust gas temperature in non-modification, (b) Exhaust gas temperature in addition of fuel preheater, (c) Exhaust gas temperature in replacement nozzle injector, (d) Exhaust gas temperature in combined modification

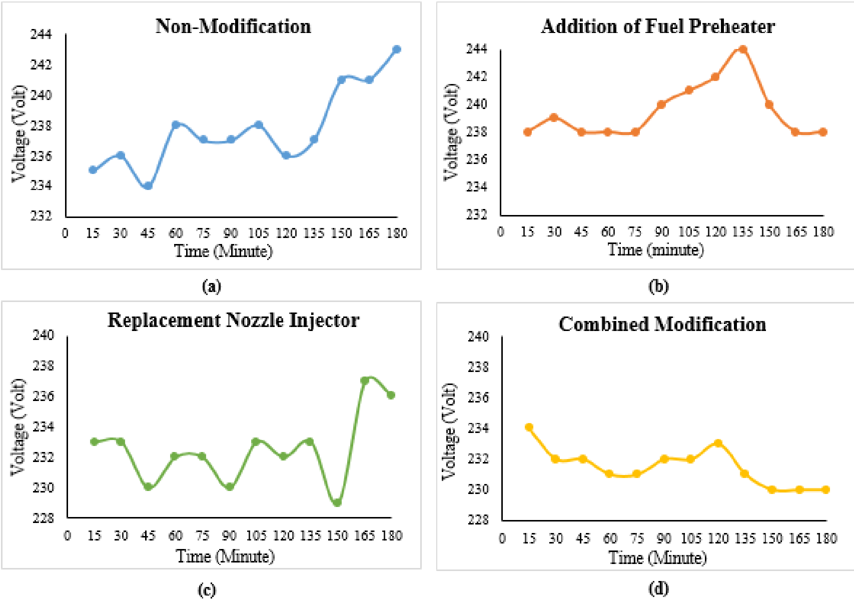


Figure 6: (a) Output voltage in non-modification, (b) Output voltage in addition of fuel preheater, (c) Output voltage in replacement nozzle injector, (d) Output voltage in combined modification

3.7 Efficiency of engine after modification

Based on the result of efficiency analysis, the engine with the addition of fuel preheater showed the highest efficiency at 41.5%. This condition proved that this modification that converted from fuel to energy in the form of output voltage was better than in other modifications. The replacement of nozzle injector had an efficiency rate around 40.2%. This value was found lower than that other modification with value of 41.1%. This indicated that the nozzle replacement must be followed by other component settings in order to improve the engine performance. The efficiency value in the engine with the combined modifications was about 40.1%, indicating the lowest efficiency value as compared with other modifications.

4. CONCLUSION

The best performance engine or generator set for B30 fuel was the engine with the addition of fuel preheater. It was because this modification had the best performance for all the studied parameters such as fuel consumption, gas emissions and output voltage. The addition of fuel preheater could improve the fuel atomization system so that the combustion process became better. The addition of the fuel preheater also reduced the fuel consumption by 20% and the output voltage profile was stable. The replacement of the injector nozzle led to instability in the output voltage. The adjustment of air supply was needed to be done for different sizes of injector nozzles. The change of nozzle size could decrease fuel consumption, while CO emissions would increase due to the poor combustion processes.

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