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Effect of Diethyl Ether (DEE) on Performances and Smoke Emission of Direct Injection Diesel Engine Fueled by Diesel and Jatropha Oil Blends with Cold EGR System

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Abstract. A widely use of diesel engines increases the scarcity of fossil fuels and air pollution. Jatropha was proved potentially to be used as alternative diesel fuel. However, adding jatropha to diesel fuel increases smoke emissions due to higher their viscosity than diesel fuel. Therefore diethyl ether is substituted into a mixture of diesel and jatropha fuel to solve the problem. However, the use of diethyl ether may have an impact on diesel engine performance. Therefore, the purpose of this study is to evaluate the effect of the addition of diethyl ether on thermal efficiency, exhaust gas temperature and smoke emissions from diesel engines. This study used Isuzu 4JB1 engine equipped with EGR system. The diethyl ether composition in the mixed fuel was varied at 5, 10 and 15% of the total fuel volume. Jatropha in this mixed fuel was set at only 10%. Based on the experimental results, the use of DJ10DEE15 fuel showed the highest increase of 16% in hot EGR systems compared to those without EGR and cold EGR using D100 fuel at full engine load. In addition, the use of DJ10DEE15 fuel with cold EGR system resulted in 8% reduction of exhaust gas temperature compared to the use of D100 fuel at full engine load, while smoke opacity was decreased to 33%.

Keywords: diethyl ether (DEE), thermal efficiency, exhaust gas, temperature, smoke opacity, EGR system, diesel engine

1. Introduction

Diesel engines are widely used compared to gasoline engines due to their reliability and higher thermal efficiency. Diesel engines are the main drivers of transportation, agriculture, heavy equipment, industry, etc. Compression Ignition is a combustion system on a diesel engine. This system allows the achievement of high initial pressure prior to combustion. This will increase the thermal efficiency of diesel engines [1]. In addition, the advantage of diesel engines is due to the flexibility of the type of fuel used. This is because the combustion that occurs in the combustion chamber does not require control of sparks. The fuel is often used as a substitute such as a palm oil, coconut oil, jatropha oil, etc. Jatropha oil is an alternative fuel derived from non-food ingredients through the esterification process of vegetable oil [2]. Jatropha oil is often used as a mixture of diesel fuel especially in the use of diesel engines [3]. However, it results in higher smoke emissions and lower performance compared to pure diesel [4].
According to Syaiful et al. (2013) [5] that the use of low purity methanol as a mixture of diesel fuel can reduce the smoke emissions of diesel engines. In addition, the addition of diethyl ether also results in decreased soot emissions and increased thermal efficiency produced by diesel engines [6]. This results were also found in Syaiful’s et al study, (2017) [7]. High oxygen content in diethyl ether (DEE) supports combustion oxidation processes that can result in increased thermal efficiency and decreased soot emissions produced by diesel engines [8]. However, the higher percentage of alcohol in diesel and jatropha fuel blends leads to an increase in NOx emissions [9].

EGR (Exhaust Gas Recirculation) is one of the methods for reducing the high emission of NOx produced by diesel engine due to high temperature in the combustion chamber [10]. EGR is a method to circulate the percentage of the exhaust gas into the intake manifold which then mixes with the fresh air into the combustion chamber [11]. The high NOx emissions on diesel engines can be reduced by using EGR because EGR results the reduction of air concentration in the combustion chamber effects to the reduce of the temperature inside the combustion chamber. The EGR method is classified to become the hot and cold EGR. Hot EGR, is a method for circulating a portion of the exhaust gas into the combustion chamber without the use of heat exchanger. Meanwhile, cold EGR is the method for circulating a portion of exhaust gas into the combustion chamber through heat exchanger media [12].

Based on some aforementioned studies, this work focuses to investigate the effect of DEE on the performance and smoke emission of diesel engine fueled by diesel and jatropha oil blends. The test was performed using a direct injection 4JB1 diesel engine equipped with an EGR system. Hot and cold EGR systems were investigated to evaluate their effects on the performance and smoke emission of diesel engines.

2. Experimental Set-up

The fuel blends used in this research were diesel, jatropha and diethyl ether. Diesel fuel produced by PT. Pertamina, Tbk. Diethyl ether (DEE) with a purity level of 75.22% and jatropha obtained from the market. The main characteristics of the fuel are shown in Table I. The percentage of the jatropha volume was 10% by total volume of fuel. While the percentage of DEE volumes tested were 5, 10 and 15% called DJ10DEE5, DJ10DEE10, DJ10EE15, respectively. D100 (neat diesel fuel) and DJ10 (Diesel and 10% jatropha oil blend) were applied for the comparison.

| No | Properties | Diesel | Jatropha | DEE |
|----|------------|--------|----------|-----|
| 1  | Cetane Number | 48     | 41.8     | 126.49 |
| 2  | Water Content (％%) | 0.05   | 3.16     | 1.8  |
| 3  | Viscosity (at 40°C (mPa.s)) | 2.0-5.0 | 3.23 | 0.22 |
| 4  | Heating Value (MJ/kg) | 45.21  | 37.97    | 33.89 |
| 5  | Fire Point (°C) | 60     | 198      | 45   |
| 6  | Oxygen Content (％) | -      | 10.9     | 21.6 |
Experiments were conducted with Isuzu 4JB1 diesel engine direct injection 4 cylinders. The blended diesel, jatropha and DEE fuels were prepared with the certain percentage before the experiment begins. Due to the high polarity of the DEE making it difficult to blend with diesel, a mixer (23) was used to obtain a homogeneous fuel blend. The location of the mixer was placed higher than the engine so that the fuel blend flowed into an fuel injector (3) through a valve (22) and a burette (21) based on the principle of gravity and assisted by a fuel pump (18) installed on the engine. A burette (21) was used to measure the fuel consumptions, in which each 30 ml fuel volume was calculated their time. Afterward the fuel was sprayed into the combustion chamber using the fuel injector.

A tachometer (17) was used to monitor the engine speed which was detected by a proximity sensor. A dynamometer (2) was applied for measuring a brake torque produced by the diesel engine. This was performed by coupling the engine shaft with the dynamometer shaft. Engine load was varied. Engine load was varied from 25% to full load from the load capability achieved by the engine by changing the flow rate of water flowing into the dynamometer. Water was drained from a water tank pumped by a water pump (5) into the dynamometer. The magnitude of the incurred torque was read by a strain load sensor mounted on the torque arm in the dynamometer then informed on the load display (16).

Experiments were performed on a fixed engine speed of 2500 rpm with a variation of the fuel blend concentrations. Some of the exhaust gases were either directly recirculated (Hot EGR) or cooled by a heat exchanger (Cold EGR) (19). The magnitude of EGR percentage leading to the intake manifold (8) for mixing with fresh air was varied by 12.8, 14.1, 15.3 and 16.5% through an inlet valve opening (24). In each variation, the test was done three times and the value of uncertainty data in percent taken from the test results.

In order to measure the temperature, K type thermocouples were installed in the exhaust manifold, EGR inlet, EGR outlet and in intake manifold and an engine block in where the measurement results were informed by the thermocouple display (11-15). To measure the air mass flow rate and EGR rate, orifice plates were applied by U manometer 1 (27) and U manometer 2 (26) mounted on the intake manifold and on the EGR input channel. As for measuring smoke emissions, smoke meter (OTC 495) (20) coupled with a gas analyzer display (25) was applied.
3. Results and Discussion

A. Brake Thermal Efficiency (BTE)
Brake Thermal Efficiency (BTE) increases as the load increases. The use of diesel, jatropha and DEE fuel blends yields an increase in the value of BTE. This is due to the low viscosity of the DEE which makes it easier to atomize and refine the fuel spray pattern [13]. Thus, it increases the combustion rate due to better injection [14]. In addition, the high oxygen content in DEE supports complete combustion resulting in the increase of thermal efficiency [6]. In other studies were observed that the oxygen content, calorific value, and viscosity influences the thermal efficiency. If the oxygen content is high, the combustion efficiency increases leading to higher thermal efficiency. Conversely, lower calorific value and high viscosity results in reducing thermal efficiency [15].

By comparing Figures 2 to 4, the use of EGR system slightly increases the thermal efficiency of diesel engines. This is probably because the amount of oxygen in the EGR from the burning process of biodiesel fuel is put back into the combustion chamber resulting in an increase in thermal efficiency. The use of the hot EGR system resulted in higher increase in the thermal efficiency than that of cold EGR system. This is caused by the low temperature of the combustion chamber for the cold EGR system because the exhaust gas of EGR is cooled by the exchanger prior to entering the combustion chamber [1].

![Figure 2. Brake thermal efficiency for engine load variations and different fuel blend percentages without EGR system](image_url)

Figure 2 shows the thermal efficiency increases as the load increases. The use of a fuel blend results in an increase in the thermal efficiency compared to the neat diesel (D100). It may be caused by excess oxygen in the combustion chamber promoting the rate of carbon oxidation leading to an efficient combustion process [16, 17]. The results are observed that DJ10DEE5 expresses the highest BTE than other fuel blends for all variation of engine loads. The highest increase of BTE is found for DJ10DEE5 fuel by 26% of D100 at 75% engine load. This investigation also shows a decrease in BTE by increasing the percentage of DEE for all engine loads. At full engine load, BTE drops 12.2% by increasing the percentage of DEE up to 10%. This is probably due to the low heat release rate in the premixed combustion process phase at a high percentage of DEE [18].

Figure 3 shows the brake thermal efficiency (BTE) for various fuels in a hot EGR system. Figure 3 illustrated that BTE increases as the load increases. The use of DEE as a fuel additive results in an increase in BTE compared to the D100 except for DJ10 in which BTE reduces 3% in all engine loads.
The highest BTE increase is found for DJ10DEE15 fuel by 26% at 75% engine load, whereas the lowest BTE increase is observed for DJ10DEE10 fuel by 3% at 75% engine load. Figure 4 illustrates BTE for various fuels in cold EGR systems. By comparing Figure 4 with Figures 2 and 3, a similar trend is observed in which the BTE increases as the load increases. The addition of DEE additives to the jatropha-fuel diesel blend increases BTE for overall machine loads compared to the use of D100. The highest BTE increase was obtained on DJ10DEE10 fuel by 26% with 25% machine loading, while the lowest BTE increase was obtained on DJ10 fuel by 4% with 100% machine loading.

![Figure 3](image3.png)

**Figure 3.** Brake thermal efficiency for engine load variations and different fuel blend percentages hot EGR system

![Figure 4](image4.png)

**Figure 4.** Brake thermal efficiency for engine load variations and different fuel blend percentages without EGR system
B. Exhaust Gas Temperature (EGT)

Figure 5. Exhaust Gas Temperature for engine load variations and different fuel blend percentages without EGR system

Figure 6. Exhaust Gas Temperature for engine load variations and different fuel blend percentages hot EGR system

Figure 5 to 7 is a presentation of Exhaust Gas Temperature (EGT) test results using blended diesel, jatropha and DEE fuels with hot and cold EGR systems. EGT increases as load increases. The use of diesel, jatropha and DEE blended fuels results in a decrease in EGT compared to D100. This is because the low heat value of the DEE results in a decrease in the temperature of the combustion chamber, resulting in a decrease in EGT [13]. In addition, the use of the EGR system also results in EGT declining because EGR reduces the amount of fresh air entering the combustion chamber, so the amount of oxygen...
for burning becomes reduced as it is replaced by flue gas. This decrease in oxygen leads to incomplete combustion so that the temperature in the combustion chamber decreases and eventually the temperature of the exhaust gases will decrease as well (Vinod, 2012).

Figure 6 is an EGT presentation for a variety of fuels using a hot EGR system. Figure 6 shows that EGT increases when the engine load increases. The addition of DEE in the fuel mixture results in a lower EGT than D100. This is due to the low heating value of the fuel mixture and the reduced supply of oxygen in the combustion chamber, resulting in a decrease in EGT. The highest EGT decrease was obtained on DJ10DEE15 fuel by 2% with 100% machine loading, while the lowest EGT drop was obtained on DJ10DEE10 fuel by 1% with 50% machine loading.

Figure 7 is an EGT exposure for a variety of fuels using cold EGR systems. EGT increases as engine load increases. The use of a cold EGR system with a variety of fuels showed a sharper EGT reduction compared to the hot EGR system and without EGR. The highest EGT drop was obtained on 11% DJ10DEE15 fuel with 25% machine loading, while the lowest EGT loading was obtained on DJ10 fuel of 1% with 25% machine loading.

C. Smoke Opacity
Smoke opacity increases with increasing load. This happens because of increased fuel injected into the combustion chamber with increased loads that allow increasing carbon that is not oxidized by incomplete combustion [5]. The addition of 10% jatropha in diesel fuel causes increased smoke opacity. This is due to the decrease of injection quality due to high viscosity in jatropha [4]. However, the addition of DEE in the fuel mixture results in a decrease in smoke opacity. The higher the DEE content, the smoke opacity decreases. This is due to the low viscosity in DEE improving the fuel injection quality so as to reduce soot formation due to the reduction of unburnt fuel [19]. In addition, the decrease in smoke opacity is also due to the high oxygen and cetane number content in DEE that support the fuel oxidation process in the combustion chamber [20]. Tendency decrease smoke opacity due to DEE content also occurs in research Srihari S et al. 2017.

Figure 8 presents smoke opacity for various fuel variations without the EGR system. Figure 8 shows an increase in smoke opacity as engine load increases. The addition of 10% jatropha on diesel fuel causes an increase in smoke opacity of 3% in each machine loading. However, the addition of DEE in a mixture
of diesel and jatropha fuels causes a decrease in smoke opacity. The highest smoke opacity drop was obtained at 50% DJ10DEE15 fuel with 25% engine loading, while the highest smoke opacity drop occurred on DJ10DEE5 fuel by 19% with 75% machine loading. Figure 8 presents smoke opacity for various fuel variations without the EGR system. Figure 8 shows an increase in smoke opacity as engine load increases. The addition of 10% jatropha on diesel fuel causes an increase in smoke opacity of 3% in each machine loading. However, the addition of DEE in a mixture of diesel and jatropha fuels causes a decrease in smoke opacity. The highest smoke opacity drop was obtained at 50% DJ10DEE15 fuel with 25% engine loading, while the highest smoke opacity drop occurred on DJ10DEE5 fuel by 19% with 75% machine loading.

Figure 9 represents smoke opacity exposure for a variety of fuels with a hot EGR system. Figure 9 produces the same tendency as Fig. 8. Addition of 10% jatropha on diesel fuel causes smoke opacity to increase by 11%. This is due to the decrease in burning quality due to jatropha content. However, the addition of DEE in mixed diesel and jatropha fuels results in a decrease in smoke opacity. This is because the low viscosity and high cetane number in DEE improve the combustion quality so smoke opacity decreases. The highest smoke opacity decrease was obtained on 19% DJ10DEE15 fuel with 25% engine loading, while the lowest smoke opacity drop was obtained on DJ10DEE5 fuel by 3% with 75% machine loading.

Figure 10 is a smoke opacity presentation for a variety of fuels with a hot EGR system. Figure 10 shows the same tendencies as Figures 8 and 9. The addition of 10% jatropha in diesel fuel leads to an increase of smoke opacity of 3% in each machine loading. However, the presence of DEE concentrations in the fuel mixture causes a decrease in smoke opacity. The higher the concentration of DEE, the smoke opacity decreases. The highest smoke opacity drop was obtained on 55% DJ10DEE15 fuel with 25% engine loading, while the highest smoke opacity drop was obtained at 23% DJ10DEE5 fuel with 100% machine loading.

![Figure 8](image.png)

**Figure 8.** Smoke Opacity for engine load variations and different fuel blend percentages without EGR system
Figure 9. Smoke Opacity for engine load variations and different fuel blend percentages hot EGR system

Figure 10. Smoke Opacity for engine load variations and different fuel blend percentages hot EGR system

4. Conclusion
Based on the description that has been submitted, it can be concluded as follows:
1. Addition of DEE produces positive impact to improve the thermal efficiency of a diesel engine. The highest increase in thermal efficiency was obtained on DJ10DEE10 fuel by 26% compared to D100. This increase in thermal efficiency occurs at 25% machine loading with a hot EGR system.
2. While on the exhaust side of temperature gas, the use of diesel, jatropha and DEE mixed fuels results in decreased EGT, both with EGR systems and without EGR. The highest decrease occurred on DJ10DEE15 fuel by 11% compared to D100. This happens when using a cold EGR system.
While the lowest decrease occurs when using fuel DJ10DEE10 of 1% when using a hot EGR system.

3. In addition, the addition of DEE also causes the smoke opacity to decreasing. The highest smoke opacity decrease was obtained on DJ10DEE15 fuel by 55% compared to D100. This occurs when the loading of a 25% machine with a hot EGR system. While the lowest decrease occurred on a DJ10DEE10 fuel of 3% at 50% load when using hot EGR system.

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