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Research Paper

The Effect of Ethanol on Brake Torque, Brake Specific Fuel Consumption, Smoke Opacity, and Exhaust Gas Temperature of Diesel Engine 4JB1 Fueled by Diesel-Jatropha Oil

Syarifudin[1], **Faqih Fatkhurrozak**[1], **Firman Lukman Sanjaya**[1], **Eflita Yohana**[2], **Syaiful**[2], **Agus Wibowo**[3]

[1]Department of Mechanical Engineering, Politeknik Harapan Bersama, 52147, Indonesia
[2]Department of Mechanical Engineering, Universitas Diponegoro, 50275, Indonesia
[3]Department of Mechanical Engineering, Universitas Pancasakti, 52122, Indonesia

masudinsyarif88@gmail.com

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Abstract

The growth of diesel vehicles has consequences for the consumption of diesel oil. Therefore, using Jatropha as an alternative fuel reduces dependence on diesel oil and it does not interfere with food availability. However, the high viscosity of jatropha oil makes the fuel pump work harder. In addition, the low calorific value reduces the quality of the fuel which creates unique problems. Ethanol, with its low viscosity and high oxygen content, is expected to be effective in reducing jatropha problems for diesel engines. Therefore, this study aims to evaluate the addition of ethanol to the brake torque, brake-specific fuel consumption, exhaust gas temperature, and smoke opacity. The 4JB1 diesel engine with an EGR was tested on a 10% (DJ10) and 20% (DJ20) diesel-jatropha mixture. The experimental results showed that brake torque increased by 1.51% in the DJ10 application, brake specific fuel consumption decreased by 7.05%, exhaust gas temperature decreased by 0.67%, and smoke opacity increased by 25.91%. While in the DJ20 application, brake torque increased by 3.19%, brake-specific fuel consumption decreased by 30.08%, exhaust gas temperature decreased by 0.67%, and smoke opacity increased by 69.03%.

Keywords: Jatropha; Ethanol; Brake torque; Fuel consumption; Opacity

1. Introduction

Alternative fuels and air pollution are two highly emotional global issues [1]. Alternative fuels are obligated as the main solution to reduce reliance on fossil fuels [2]. In addition, the air pollution due to the use of diesel fuel also increasing accordingly [3]. The main player in the exploitation of diesel fuel is the combustion ignition engine (ICE), which is widely used to supply logistics, passenger transport, plantation cargo, agriculture, and manufacturing industry operations [4]. According to the Central Statistics Agency (BPS), the number of combustion ignition vehicles increased to 133.617,012 in 2019. In comparison to 2017, this volume increased by 12.36 percent. This trend continues, in combination with the community's population and economic growth. This phenomenon contributes to greater reliance on fossil fuels [5], [6]. Due to the obvious smoke emissions from motorized vehicles, this dependence leads to an increase in air pollution which affects the environment and human health [7], [8].

Biodiesel was developed as an alternative fuel to reduce the dependency on fossil fuel diesel [9]. Biodiesel derived from non-food materials is a top priority in the development of renewable fuels. Jatropha biodiesel has been proven to be a fuel for ICE engines [10]. The jatropha plant, which cannot be consumed, provides the base for biodiesel. Jatropha oil has a cetane number of 41.8, which really is exactly equivalent to diesel fuel but high viscosity makes the fuel pump and injector work harder [10], [11]. Furthermore, when compares to diesel fuel, the use of jatropha biodiesel results in poorer engine power and emission [12]. According to Fatkhurrozak et al [13] a 30% jatropha-fueled direct-injection engine emits 33% more smoke and takes up 33% more fuel than a non-jatropha-fueled engine. The high viscosity of jatropha increases the work of the pump, significantly reducing injection quality. According to Pradelle et al., [14] a high biodiesel content brings down fuel efficiency. The low calorific value of biodiesel generates non-optimal combustion, resulting in greater fuel consumption.

Ethanol is an alcohol that has the potential to reduce emissions and overdependence on diesel engine fuel [15]. Ethanol has a viscosity of 1.07 mm2/s, which is lower than that of jatropha oil. The high viscosity of jatropha oil might well be reduced by ethanol. Another property is that ethanol has a very high oxygen content (21.6%) [14]. These properties complete the requirements for a diesel engine's combustion. According to Fatkhurrozak [13], applying ethanol to jatropha oil enhances the diesel engine's efficiency. Ethanol's low viscosity optimizes fuel combustion and output power [16]. The output power increases with the concentration of ethanol and makes it possible to reduce fuel consumption [17].

Based on the literature review above, this study hypothesizes that ethanol has beneficial properties. The correlation between brake torque, brake specific fuel consumption, exhaust gas temperature, and smoke opacity of diesel engines is the subject of research. Cold EGR has been used in diesel engines to increase air mass by circulating exhaust fumes.

2. Methods

The test was carried out in the laboratorium Thermofluida of Universitas Diponegoro Semarang, Indonesia. To get data on brake torque, brake specific fuel consumption, exhaust gas temperature and smoke opacity, the 4JB1 diesel engine (**Figure 1**) was tested with a constant rotation of 2500 rpm. The specifications of the 4JB1 diesel engine are listed in **Table 1**.

Figure 1. Diesel engine type 4JB1

Table 1. Engine 4JB1 Spesification

Engine Specifications	Description
Type motor	Diesel, OHV, Vertical in-line, Direct injection, 4JB1
Number of cylinders	4 cylinder
Bore x Stroke	93x102mm
Engine capacity	2771cc
Maximum power	70/3000 (HP/rpm)
Compression ratio	18.21:1

Jatropha oil and pure ethanol were obtained from a commercial shop in Semarang-Indonesia. The fuels were tested with various processes (**Table 2**). The composition of jatropha was 10% and 20%. Jatropha concentration of 30% resulted in poor performance and emissions [12], [13], while the concentration of ethanol is only 10%. According to Milna et al. [18], 10% ethanol concentration (E10) is proven to produce better engine performance than E50. The properties of the fuel used are presented in **Table 3**.

Table 2. Fuel composition

No	Fuel experimental	Code	Fuel composition (ml)		
			Pure Diesel (D)	Jatropha (J)	Ethanol (E)
1	Pure Diesel	D100	1000		
2	Diesel 90%+Jatropha 10%	DJ10	900	100	
3	Diesel 80%+Jatropha 20%	DJ20	800	200	
4	Diesel 80%+Jatropha 10%+Ethanol 10%	DJ10E	800	100	100
5	Diesel 70%+Jatropha 20%+Ethanol 10%	DJ20E	700	200	100

Table 3. Fuel propertis Diesel [19], Jatropha [12], and Ethanol [16]

No	Fuel Propertis	Fuel composition (ml)		
		Diesel	Jatropha	Ethanol
1	Viscosity at 40 °C (mm²/s)	2-5	3.23	1.07
2	Cetane number	48	41.8	15
3	Heating value (MJ/kg)	45.21	37.97	27
4	Flash point (°C)	60	198	17
5	Oxygen content (%)	-	10.9	34.8

The prepared fuel was tested with the schematic in Figure 2. The fuel is accommodated in the fuel mixer (1) so that it is homogeneously mixed. The volume of fuel is controlled through the valve (2) and passed into the burette (3) before flowing to the injector (12). While the air enters through the suction channel (5). The exhaust duct (16) is fitted with a cold type exhaust gas recirculation (EGR) system (11) which is controlled via the EGR valve (4). The exhaust duct is installed with a stick (15) on the gas analyzer Stargass 898 (14) and a display (13) is installed so that it reads smoke opacity.

The output power of the 4JB1 diesel engine is installed with a brake fluid type Land and Sea dynamometer (8) so that the loading can be read on the Display (6). The 4JB1 (7) diesel engine operates at a constant speed of 2500rpm. Brake torque observations are carried out by applying a load using water supplied by the pump (19) from the water tank (17). The circulation of water to the dynamometer is controlled through the valve (20),(10). The circulation of water leaving the dynamometer is controlled through the outlet valve (9). To maintain the engine cooling system, water is channeled and controlled through the valve (18).

To obtain brake torque data for the 4JB1 diesel engine, the equation $T = F\ x\ b$ is used. Brake Torque indicates a measure of the engine's ability to do work [20]. The fuel flow rate to perform engine operation is measured as a component of the calculation of brake specific fuel consumption (BSFC) using the equation $BSFC = \frac{mf}{P}$. According to Utomo [21], the BSFC measurement takes into account the fuel flow rate ($\dot{m}_f$) per unit power (kg/kw.hour). The use of the EGR system in diesel engines affects the quality of combustion [22]. To determine the effect of the EGR system, the smoke density was observed through the gas analyzer display and the exhaust gas temperature (EGT) indicator which was measured through the thermocouple.

3. Result and Discussion

3.1. *Brake Torque*

Figure 3 illustrates the results of a brake torque test performed with a brake fluid dynomite dynamometer on a direct injection diesel engine without and with an EGR system using a mixture of jatropha- ethanol-diesel fuel. The brake torque of a diesel engine greatly increases as the engine load increases. The use of diesel-jatropha (DJ) fuel

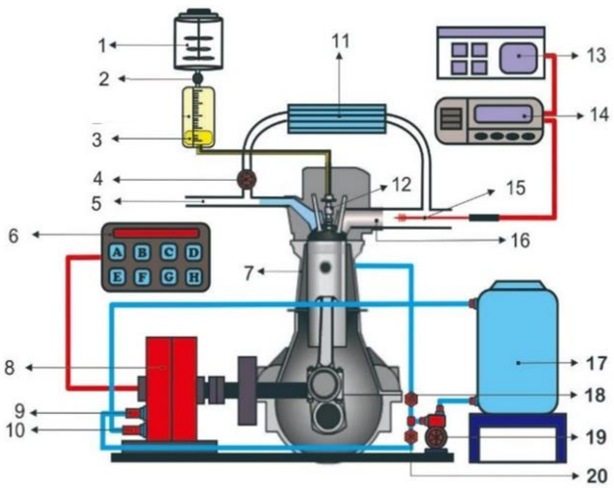
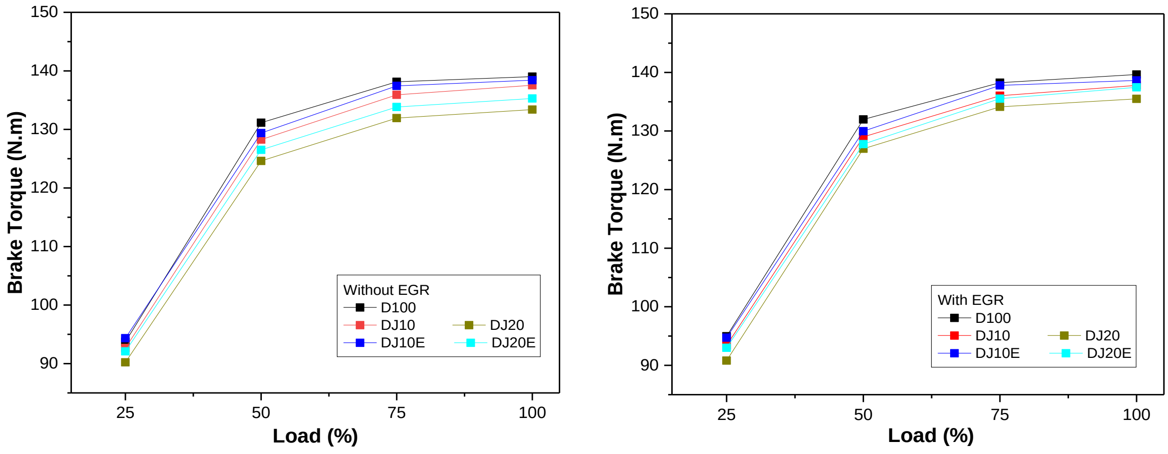


Figure 2. Schematic of the experiment setup



(a) (b)

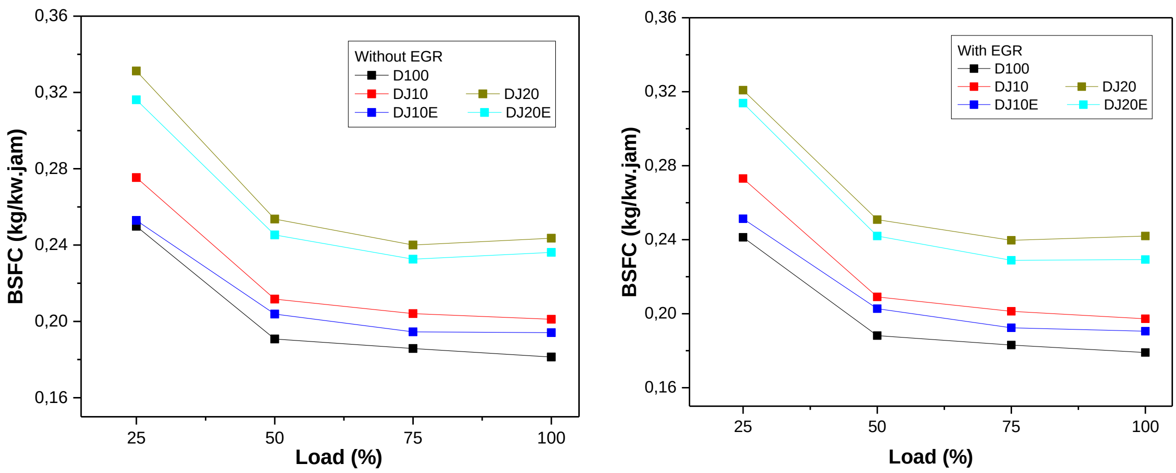
Figure 3. Brake torque direct injection diesel engine fueled by a mixture of diesel-jatropha-ethanol: (a) without EGR, and (b) with EGR.

resulted in a decrease in the brake torque when compared to fuel without jatropha (D100). The primary factors for the decrease in brake torque value are jatropha's low calorific value and high viscosity [9], [12], [23]. The actual value of the brake torque test results for diesel engines without and with EGR mechanisms using diesel-jatropa 10% (DJ10) fuel decreased by 2.21 and 2.26%, respectively. Meanwhile, the actualization of the DJ20 test results started falling to 4.98 and 4.37%, respectively.

When ethanol was added, the results are different. The addition of ethanol to diesel-jatropha fuel cuts down the brake torque of the smaller diesel-jatropha engine. The DJ10E's brake torque reduction is only 1.35% without EGR and 1.51% with the EGR system unlocked. Meanwhile, the addition of DJ20 fuel, ethanol, brings down the decrease in brake torque value by 3.54% and 3.19% when the EGR system is active. The oxygen content and high-octane number of ethanol are predicted to be the main factors underlying this tendency. This property is believed to enhance combustion quality, leading to a rise in piston momentum pushing the power stroke [17], [24].

3.2. Brake Spesific Fuel Consumption (BSFC)

Figure 4 shows the calculation results of the brake specific consumption (BSFC) of a direct injection diesel engine operated by a jatropha and ethanol diesel mixture. The BSFC of a diesel engine tends to decrease as the percentage of engine loading increases. Diesel engines with and without the diesel-jatropha (DJ) EGR system have a greater BSFC value than the D100. The high vis-



(a) (b)

Figure 4. Brake spesific fuel consumption direct injection diesel engine fueled by a mixture of diesel-jatropha-ethanol: (a) without EGR, and (b) with EGR

cosity of jatropha makes the injection task more difficult, leading to a rise in fuel supply, which generates the color of the smoke to darken due to the large amounts of unburned fuel [4], [23]. The use of DJ10 fuel results in a 10.90% increase in BSFC and a 13.18% goes up when the EGR mode is activated.

The implementation of ethanol improves the quality of diesel-jatropha fuel. Ethanol concentration has the potential to hinder the rate of increase in BSFC. The viscosity of ethanol is 1.07 mm^2/s and it has a high oxygen content of 34.8%. These properties are known to play a role in lowering the increasing value of BSFC [2], [17]. The BSFC increase in the DJ10E fuel is only 7.05% and 7.73% when the EGR device is switched on. When using DJ20E fuel, BSFC increased by 30.26 %, and 30.08% when the EGR system was active.

3.3. Exhaust Gas Temperature (EGT)

Figure 5 shows the results of measuring the exhaust gas temperature (EGT) of a direct injection diesel engine fueled by a jatropha-ethanol diesel mixture. A diesel engine's EGT always emerges as the percentage of load rises. The EGT of diesel-jatropha and diesel-jatropha-ethanol engines differs greatly. The EGT of the diesel-jatropa (DJ) diesel engine was below than that of the D100. When the EGR system was initiated, EGT on fuel with 10% jatropa content (DJ10) decreased by 5.35 and 6.25% respectively. While the DJ20's fuel consumption drops significantly to 8.03% and 8.22% when the EGR device is activated. This is due to jatropha's lower heating value and higher viscosity than pure diesel [2].

When ethanol is added, the results improve. The EGT of diesel engines continues to fall, but not significantly. When the EGR system was activated, the addition of 10% ethanol (DJ10E) decreased by 0.67 and 0.92%, respectively. EGR decreased by only 3.42% when using DJ20E fuel and 3.62% when EGR was activated. Ethanol's high oxygen properties and low viscosity improve fuel injection quality, reducing pump work, improving fuel oxidation quality, and increasing the brake torque of diesel engines [12], [13]. Ethanol's high quality properties have the tendency to lower the EGT of diesel engines.

3.4. Smoke opacity

Figure 6 presents the smoke opacity of a direct injection diesel engine operating on a jatropha/ethanol mixture as measured by the Stargass 898 gas analyzer. The smoke opacity of a diesel engine increases with the percentage of engine loading. The diesel-jatropha (DJ) diesel engine has a higher smoke opacity than the D100. The high viscosity of jatropha increases the volume of the fuel particulate matter, causing the fuel oxidation process to be less efficient [10], [12], and rising the smoke opacity of diesel engines. When the EGR mode is activated, the smoke opacity of diesel fuel jatropha 10% (DJ10) increases to 34.37% and 43.60%. Meanwhile, with a 20% jatropa content, smoke opacity increased to 71.63% and 78.67% when the EGR system was operated.

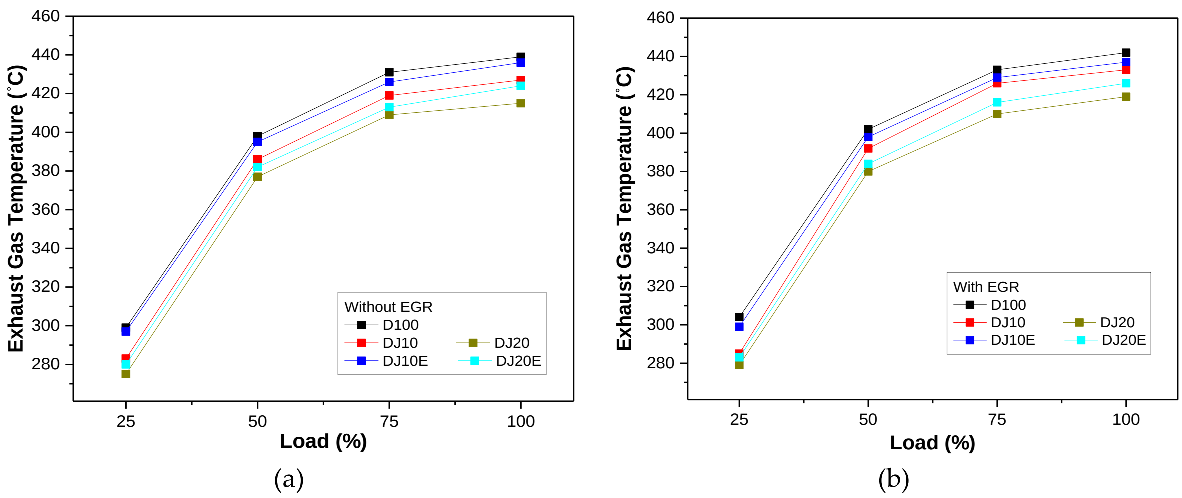


Figure 5. Exhaust Gas Temperature direct injection diesel engine fueled by a mixture of diesel-jatropha-ethanol: (a) without EGR, and (b) with EGR.

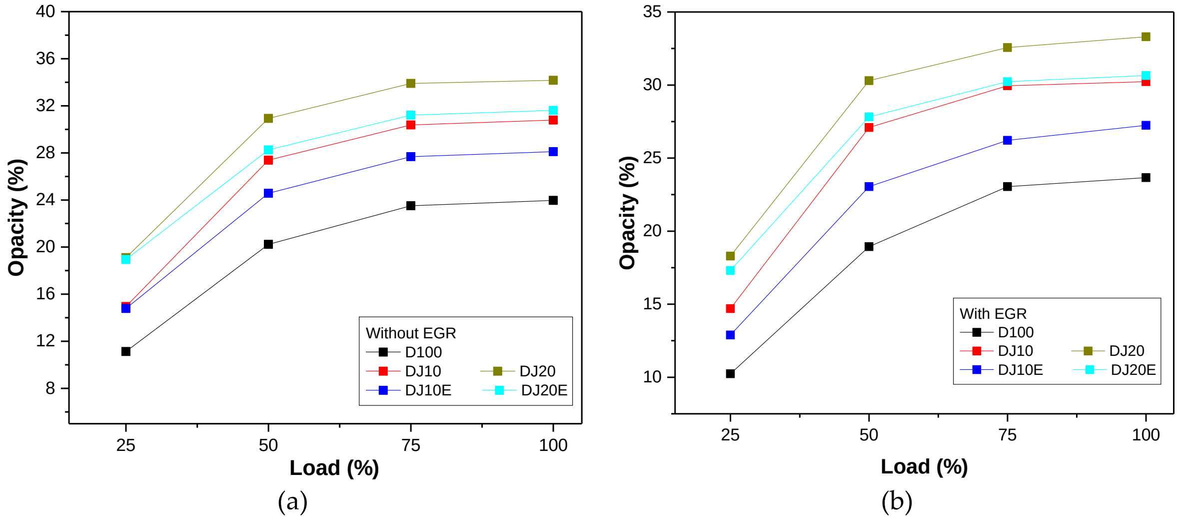


Figure 6. Smoke opacity direct injection diesel engine fueled by a mixture of diesel-jatropha-ethanol: (a) without EGR, and (b) with EGR.

Different results were achieved once evaluating the smoke opacity of a diesel engine that use diesel-jatropha fuel with ethanol addition. The increase in smoke opacity measured by the gas analyzer is lower than it would be in the absence of ethanol. The increase in smoke opacity in the DJ10E fuel is only 32.84% and 25.91%the EGR system is started. When using DJ20E fuel, the smoke opacity increases by only 70.18%and by 69.03% when the EGR mode is activated. Ethanol's high-octane number and low viscosity lead to better fuel quality and combustion quality [5], [25].

4. Conclusion

The use of jatropha-containing fuel reduces brake torque, increases EGT, significantly reduces BSFC, and raises smoke opacity. The addition of ethanol to diesel-jatropha fuel lessens the decrease in brake torque, the decrease in EGT, the improvement in BSFC, and the enhancement in smoke opacity. The Brake Torque drop on DJ10E fuel is only 1.51%, and the EGT drop is only 0.67%. The BSFC increase is only 7.05%, and the smoke opacity increase is only 25.91%. The use of DJ20E fuel results in a 3.19% decrease in brake torque, a 3.42% decrease in EGT, a 30.08% increase in BSFC, and a 69.03% increase in smoke opacity.

Author's Declaration

Authors' contributions and responsibilities

The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation and discussion of results. The authors read and approved the final manuscript.

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The authors declare no competing interest.

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