Effects of Injection Pressure on Combustion Behavior and Emission in Commonrail Single-Cylinder Diesel Engine Using Jatropha Methyl Ester (JME)

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Abstract

This research aimed to correlate combustion characteristic with exhaust emissions in a 4-stroke single cylinder diesel engine equipped with commonrail system. The tested fuels were neat jatropha methyl ester (JME) and ultra low sulfur diesel fuel (JIS No.2). Emission analysis was conducted in Yanmar diesel engine model NFD-***13*** having its typical injector replaced by a commonrail injector unit. Injection pressures were selected at 20 and 140 MPa with engine loads varied by indicated mean effective pressure (IMEP) from 200 to 800 kPa with an increment of 200 kPa at a low speed of 1,200 rpm. The emission results showed lower THC and CO emissions for both fuels at low injection pressure while lower diesel smoke/soot emission at high injection pressure. For best comparison, combustion characteristic was further analyzed with optical diesel engine configured to the exact same conditions (compression ratio, injection pressure and engine speed). Rate of heat release (RHR) and combustion flame were captured as a function of IMEP for both fuels. The results showed that the RHR trends of both fuels were not so different because of their similar cetane numbers. Furthermore, the combustion flame brightness being luminous could be observed for the injection pressure of 20 MPa; whereas, the blue flame was seen instead for 140 MPa. This can be the effect of diesel smoke/soot, which was abundantly detected in the case of 20 MPa.

Keywords: Jatropha Methyl Ester, Commonrail injector, Optical diesel engine, Rate of Heat Release and Combustion flame

1. Introduction

With the recent fossil fuel crisis, diesel fuel has shown the sharply increase in price over time. Together with this, diesel emissions and smoke can also cause the environmental problems. Hence, for achieving the fuel consumption economy and emission reduction, the requirement of advanced technology such as commonrail system and renewable source of energy such as biodiesel fuel have recently been taken into consideration. Biodiesel fuel is usually derived from a chemical process called "transesterification" (or alcoholysis) using vegetable oil (or animal fat), short-chain aliphatic alcohols (ethanol or methanol) and sodium hydroxide (NaOH) as catalyst [1].

This study focused on a small direct injection diesel engine (single cylinder) as it has been widely used in many agricultural activities. According to the diesel emissions and smoke number from typical single cylinder engine, a standard injector was replaced with an 8-holes commonrail injector controlled via a diesel commonrail control unit. Injection pressures were set at 20 and 140 MPa, corresponding to the jerk pump pressure [2] and commonrail pressure [3], respectively. The testing engine was fueled with diesel fuel and jatropha methyl ester (JME) at a speed about 1,200 rpm. In addition, engine loads were adjusted to have IMEP from 200 to 800 kPa by 200 kPa increment.

Another experiment to investigate combustion behavior was conducted in optical engine with the testing conditions still maintained. In this case, a high speed camera was utilized to capture the combustion process occurring in the chamber.

2. Experiments

The study has been divided into two parts. In the first part, diesel emissions and smoke were measured and recorded using an exhaust gas analyzer and a smoke meter. JME and low sulfur diesel were fed into the Yanmar diesel engine as tested fuels. The experimental schematic diagram of the first part is illustrated in Figure 1. In the second part, several combustion features were tested, recorded and analyzed via the optical diesel engine and a high speed camera. The apparatus was set up as demonstrated in Figure 2.

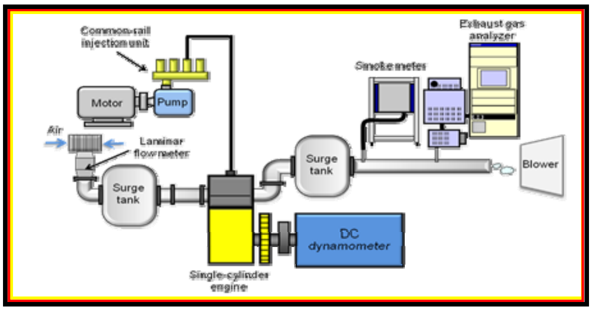


Fig. 1 Setup for Diesel Emission and Smoke Test

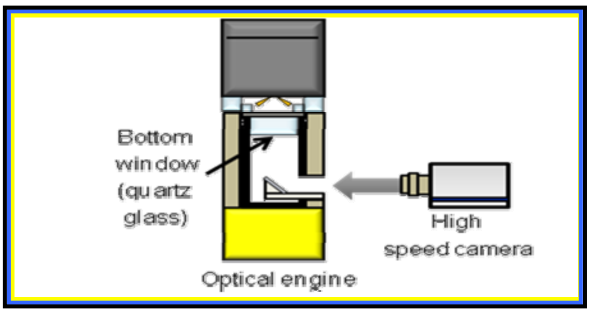


Fig. 2 Optical Engine Setup for Combustion Characteristic Test

The designed experimental conditions, testing engine specifications and tested fuel properties are shown and compared in Tables 1-4, respectively.

Table. 1. Testing Conditions of the Metal Engine

Conditions	**Details**
Testing Engines	4-Stroke Single Cylinder Diesel Engine
Engine Cooling Temperature	80°C
Injection Pressures	20 and 140 MPa.
Engine Speed	1,200 rpm (approximately)
Testing Fuels	Biodiesel (JME) and Japanese Light Diesel Oil
IMEP	200, 400, 600 and 800 kPa.
Intake Air Temperature	25±1°C
Lubricant Oil Temperature	70±5°C

Table. 2. Testing Conditions of the Optical Engine

Conditions	**Details**
Testing Engines	4-Stroke Single Cylinder Diesel Engine
Engine Cooling Temperature	90-95°C
Injection Pressures	20 and 140 MPa.
Engine Speed	1,200 rpm (approximately)
Testing Fuels	Biodiesel (JME) and Japanese Light Diesel Oil
IMEP	200, 400, 600 and 800 kPa.
Intake Air Temperature	95±1°C
Lubricant Oil Temperature	70±5°C

Table. 3. Engine Specifications (Metal and Optical Diesel Engine)

Items	**Details**
Engine Name and Model	YANMAR DIESEL, NFD-13
Engine Type	4-Stroke Single Cylinder
Bore x Stroke	92 x 96 mm.
Volume Displacement	638 cm^3
Compression Ratio	15.2 : 1
Combustion Chamber Type	Pancake Dish Type
Injection Type	Direct Injection System (DI)
Injection Equipments	Commonrail System

Table. 4. Properties of Low Sulfur Diese and JME Biodiesel

Items	**Standard Methods**	**Units**	**Diesel**	**JME**
Density (15°C)	JIS K 2249	g/cm^3	0.8833	0.827
Kinetic Viscosity (30°C)	JIS K 2283	mm^2/sec	6.14	3.831
Flash Point	JIS K 2265	°C	168.5	72.5
Cetane Number	JIS K 2280	-	55.4	56.4
Low Heating Value	JIS K 2279	J/g	42,340	43,030
Sulfur	JIS K 2541-6	mass ppm	1	9

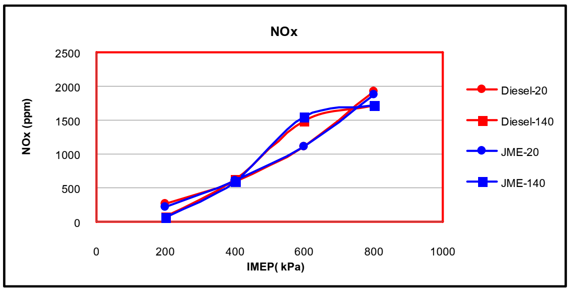
3. Results and Discussion

3.1 Diesel Emissions and Smoke

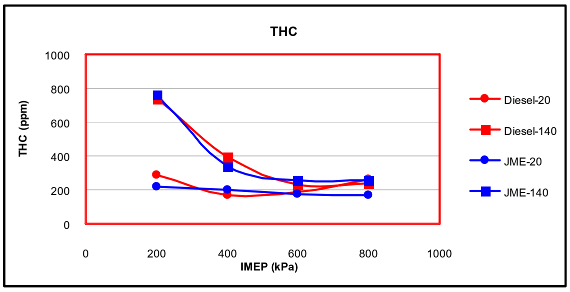
According to the emission outcomes in Fig. 3, NO_X results are not different from each other, as shown in Fig. 3(a), with the amount rapidly increased at higher IMEP. On the other hand, Figs. 3(b)-(c) show that the THC and CO emissions tend to reduce for the higher IMEP values at high injection pressure of 140 MPa for both fuels. It is obvious that increasing the injection pressure can have negative effects on both THC and CO emissions particularly in the range of lower IMEPs. Since CO emission is normally formed by incomplete combustion of the fuel [4], the imperfect combustion can be explained that excessively high injection pressure of 140 MPa could powerfully inject the fuel to penetrate through hot air and strike on chamber and/or cylinder walls. Hence, proper air-fuel mixture and combustion cannot be achieved.

For the higher loads, more complete combustion can be achieved for all situations because larger and smaller amounts of CO_2 and O_2 were observed in Fig. 3(d)-(e), respectively. Rich mixture may be clearly found at the higher IMEP range due to more O_2 is utilized for internal burning and then lesser O_2 quantity is formed as a result.

Commonrail pressure apparently showed the positive effect on diesel smoke for both fuels as illustrated in Fig. 3(f). Applying JME as alternative fuel can help improve the emission in term of black smoke especially at low injection pressure. On the contrary, the black smoke quantity trends of the typical injection pressure dramatically increases for the higher IMEP.



(a)



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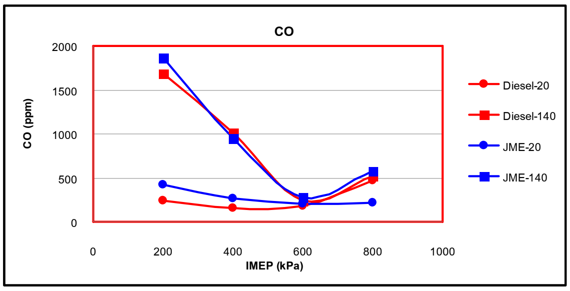

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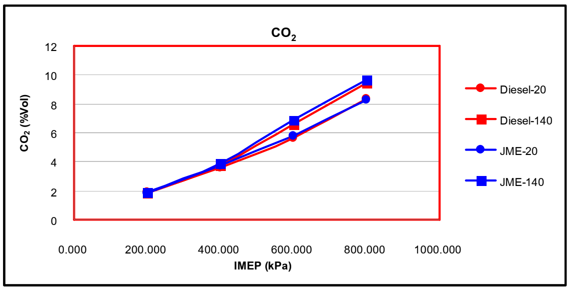
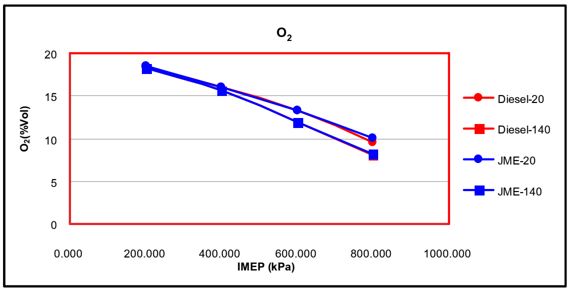
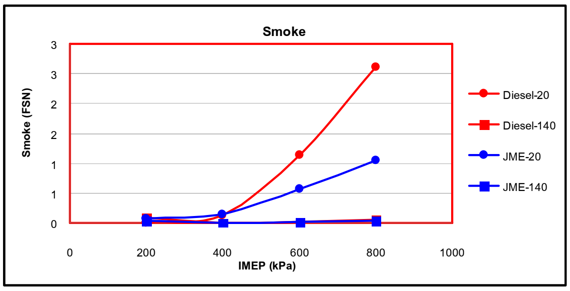


(d)



(e)



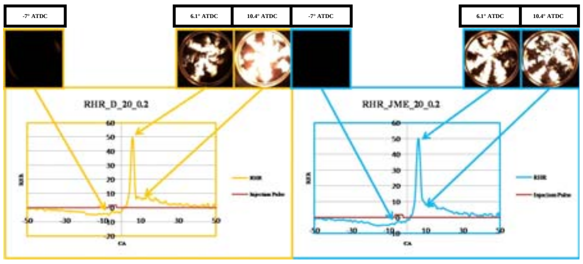
(f)

Fig. 3 Emission results of diesel and JME at injection pressure of 20 and 140 MPa: (a) NOx, (b) THC, (c) CO, (d) CO_2, (e) O_2 and (f) smoke

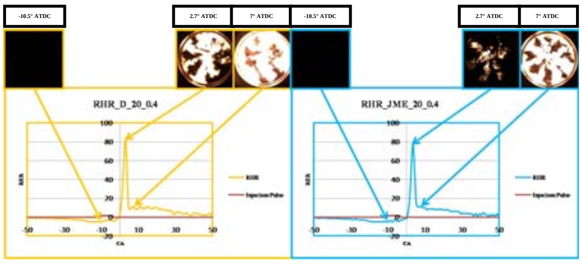
3.2 Combustion Characteristic

In support of the jerk pump pressure (20 MPa), Figs. 4(a)-(d) show that the rate of heat release (RHR) of both fuels were not distinguishly different for all engine loads (IMEP = 0.2, 0.4, 0.6 and 0.8 MPa) except slight distinction in 0.6 MPa state. This may be due to similar cetane numbers noted in the Table 4.

Diesel **JME**



(a)



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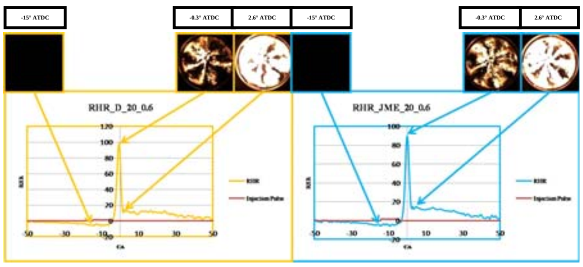

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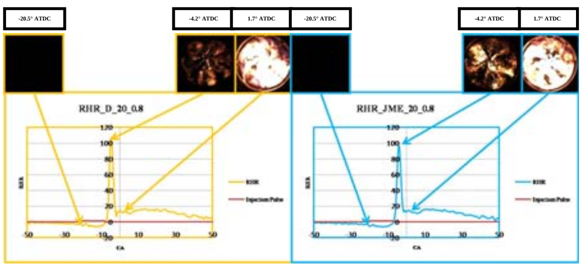
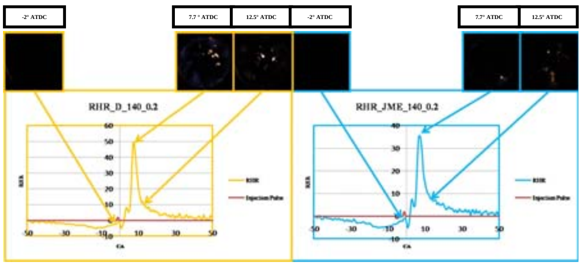


(d)

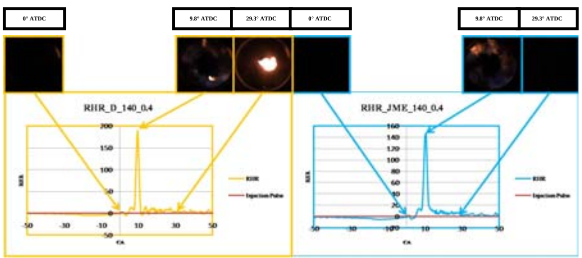
Fig. 4 Combustion Images and the Rate of Heat Release at Injection Pressure of 20 MPa for both Diesel (left, yellow color) and JME (right, blue color) at IMEP of (a) 0.2, (b) 0.4, (c) 0.6 and (d) 0.8 MPa)

In the case of the commonrail pressure (140 MPa), Figs. 5(a)-(d) show that there were some RHR dissimilarities at 0.2 and 0.4 MPa of IMEP, where diesel fuel gave higher RHR values. According to Figs. 3(b)-(c), THC and CO results were high at 140 MPa of injection pressure especially at IMEP of 0.2 and 0.4 MPa. These could be linked to the combustion images that the flame brightness was not much observed implying the incomplete combustion process.

Diesel **JME**



(a)



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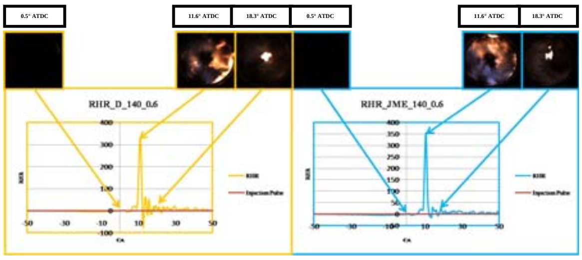
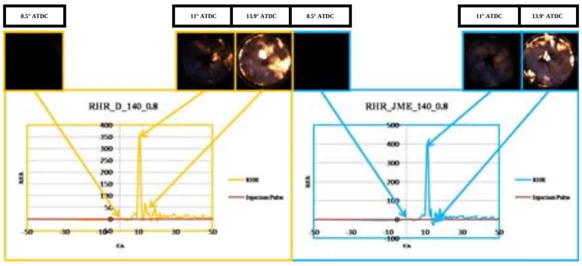


(c)



(d)

Fig. 5 Combustion Images and the Rate of Heat Release at Injection Pressure of 140 MPa for both Diesel (left, yellow color) and JME (right, blue color) at IMEP of (a) 0.2, (b) 0.4, (c) 0.6 and (d) 0.8 MPa)

As observed from combustion images of each case, the combustion flame brightness (luminous flame) of 20 MPa injection pressure was more visible compared to that of 140 MPa case showing the blue flame instead because there was more soot/smoke emitting. For the commonrail pressure of 140 MPa, it was not easy to notice the fuel spray pattern because the droplet size of fuel spray was very small. In addition, when RHR values increased, the combustion temperature should also raise and thus more NO_X emission was formed in the exhaust gas emissions.

4. Summary and Suggestion

The present study provided some preliminary information on jatropha biodiesel utilization in a small DI diesel engine with a commonrail system. The following synopsis have been analyzed and concluded from the technical data mentioned above.

NO_X emission increased as the increment of IMEP for all cases because of higher combustion temperature in the higher IMEP range. Therefore, applying the exhaust gas recirculation (EGR) system with a heat exchanger may be necessary for the high load conditions. In the EGR system, exhaust gas is recalculated back to an engine cylinder to reduce the heat of combustion resulting in NO_X formation decrease [5].

Higher amount of THC and CO emissions were seen once the injection pressure was changed from 20 to 140 MPa. However, using the commonrail pressure and JME as fuel could reduce diesel black smoke significantly.

The combustion process was more completed at higher IMEP because of observed CO_2 increase and O_2 decrease. This was confirmed from lower THC and CO emissions at higher IMEP.

When JME and diesel fuels were fed as the tested fuel, the rates of heat release (RHR) were not so different from each other because of their cetane number being resembled.

According to the smoke results, the luminous flame was observed for the injection pressure of 20 MPa as higher smoke quantity was detected; whereas, the blue flame was seen for the case of 140 MPa instead.

5. Acknowledgement

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6. References

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