Influence of Fuel Design based on the Cetane Number for Diesel Combustion
(Influence of Ethanol Blending to Jatropha FAME)

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Abstract

A feasibility study was conducted on the fuel design based on the cetane number. The fuel cetane number shows ignitability, and then ignitability changes diesel combustion such as ignition delay or premixed combustion. In addition, ethanol is known as fuel having lower cetane number. Therefore, blending ethanol to fuel can design the fuel; also diesel combustion can be designed by ethanol blending ratio. On the other hand, the Bio Diesel Fuel especially fatty acid methyl ester (FAME) made by transesterification of vegetable oil and methanol is anticipated as the sustainable renewable energy. However, the FAME made from edible oil is competed with food. Therefore, the Jatropha attracts expectation as the raw material for FAME because it unfits to eat. Although Jatropha FAME can solve the food conflict issue, it will be needed to reduce its exhaust emissions such as Nitrogen Oxides (NOx) and Particle Matter (PM). Consequently, this study was made on improving combustion and exhaust emission of Jatropha FAME by blending ethanol from fuel design perspective. Ethanol blending ratios were selected 10%, 20% and 30% in volume, and then the density and kinematic viscosity of all FAME fuels were measured. It can be seen that the ethanol blending can improve the properties of FAME. Finally, all FAME fuels were burned in a conventional 320-cc diesel engine. It is found that neat FAME and ethanol blended FAME has different trends. Particularly, ethanol 30% fuel has long ignition delay, and then its diffusion combustion seems to be disappeared. Although the Brake Specific Fuel Consumption of ethanol 30% fuel is slightly higher than neat FAME, NOx and PM in the exhaust gas are confirmed to be reduced significantly.

Keywords: bio diesel fuel, Jatropha, FAME, ethanol blending, cetane number, fuel design

1 Introduction

The bio diesel fuels (BDF) are expected as the sustainable renewable energy. In addition, they are in the spotlight as feasibility alternative fuel because they are considered the fuel solving the global warming because of “Carbon Neutral”. Particularly, Fatty Acid Methyl Ester (FAME) which is made by transesterification of vegetable oil and alcohol is anticipated, since it has good engine performance and low exhaust emissions [1-5]. However, the most of FAME are concerned the food conflict issue, due to they are made from edible oil. According to this context, FAME made from Jatropha oil has been more anticipated, lately [6].

Jatropha is deciduous shrub native to South America. It is known as grow up with the poor soil, and make high yield coefficient. Also, it is told that the expressed oil amount is three times as large as rapeseed. Moreover, Jatropha contains the phorbol ester and therefore unfits to eat. This phorbol ester is the tumor promoter, but it is removed by neutralizing process of crude Jatropha oil. Thus, Jatropha FAME can use as the safe fuel. It is declared with the research by the Japan national institute of advanced industrial science and technology (AIST) [7]. In addition, AIST has made Jatropha FAME pilot plant in Thailand with Thailand national science and technology development agency [8]. Therefore, Jatropha FAME attracts expectation as the feasibility alternative fuel in Asia.

Jatropha FAME has high practicability as mentioned above, moreover Jatropha FAME can reduce carbon dioxide (CO_2), because of “Carbon Neutral”. However, its exhaust emission such as nitrogen oxides (NOx) and particulate matter (PM) will be needed to reduce. Consequently, this study was made on improving combustion and exhaust emission of Jatropha FAME by blending ethanol from fuel design viewpoint, since ethanol can be made from plant and it has lower cetane number. This lower cetane number changes diesel combustion such as ignition delay or premixed combustion, therefore emission reduction can be expected. In this paper, experimental study was made on Jatropha FAME and ethanol blended fuels. This paper describes the influence of fuel design based on fuel cetane number.

2 Properties of test fuels

In this study, the properties of test fuels were investigated before the engine performance test in order to confirm the change of characteristics by ethanol blending. The ethanol blending ratios were selected 10%, 20% and 30% in volume, and then each fuel were named JME+E10, JME+E20 and JME+E30 respectively. Furthermore, gas oil (JIS #2) and neat Jatropha FAME were measured for the reference. This neat Jatropha FAME is shown as JME in the figures and tables.

Figure 1 gives the measured density and kinematic viscosity of test fuels. Density was measured by the float test, and viscosity was measured by using the viscometer (A&D; VM-10A-L). In addition, **Table 1** shows difference of the properties comparing gas oil and JME.

From this figure, it can be seen that the density and kinematic viscosity decreases with the ethanol blending ratio. Besides, it is found that JME and gas oil has difference but ethanol blended fuels are similar to gas oil. Density of JME is 880[kg/m^3(@293K)] but JME+E30 is improved to around 850[kg/m^3(@293K)]. Especially, kinematic viscosity is very close to gas oil. Kinematic viscosity of JME is 5.6[mm^2/s(@303K)] but JME+E30 is improved to around 2.8[mm^2/s(@303K)]. Although this result is naturally since ethanol has lower kinematic viscosity, close property is very important because it causes a similar fuel spray characteristics. If the density or kinematic viscosity is higher, fuel spray will run long distance. Then fuel spray hits the cylinder wall, and then fuel cannot burn because of cool wall. On the contrary, if the density or kinematic viscosity is lower, fuel spray will stay near the injector; this means fuel spray will stay center of combustion chamber. Then most of fuel leads to incomplete combustion, because of lack of oxygen. Consequently, blending ethanol makes close fuel property, therefore blending ethanol improves the fuel spray and combustion of JME; in other words, by blending ethanol can optimize the fuel design of property. Furthermore, diesel engines are needed the enough lubrication with the fuels for the fuel pump and fuel injector. This similar kinematic viscosity makes good lubrication inside of them, and it will not be broken them with respect to kinematic viscosity.

Table 1 Properties of gas oil and JME

	Gas Oil (JIS #2)	JME
Density [kg/m^3(@303K)]	816	872
Kinematic Viscosity [mm^2/s(@303K)]	1.86	4.28
Lower Calorific Value [kJ/kg]	42990	37130
HFRR [µm]	440	224
Pour Point [K]	265.5	275.5
Cloud Point [K]	-	275

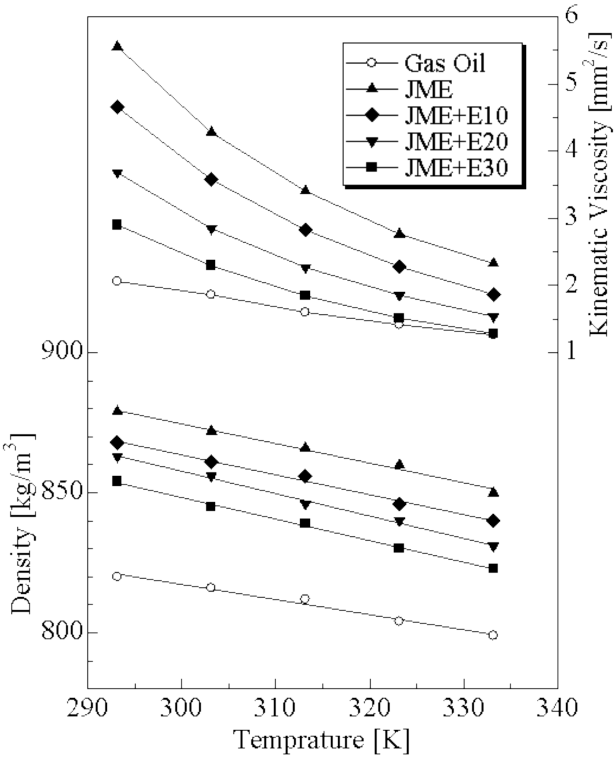

Fig. 1 Density and kinematic viscosity

Table 1 presents properties comparing JME and gas oil. There are some differences, HFRR (High Frequency Reciprocating Rig) of JME is better than gas oil but lower calorific value and pour point are worse. HFRR is a lubrication factor which means the lower is the better, therefore it can be said that JME has good lubrication. Moreover, kinematic viscosity of JME is also well as mentioned above, and then fuel pump and injector will not be broken. However, lower calorific value of JME is smaller than gas oil. Also, pour point of JME is higher than gas oil. Therefore, JME must be considered that there is a problem the use of cold winter. However, fuel consumption of JME does not need to concern because JME can be considered "Carbon Neutral".

3 Engine performance test

3.1 Experimental apparatus and method

The engine performance test was carried out in order to declare the influence of ethanol blending to Jatropha FAME for diesel combustion and exhaust emission characteristics. **Figure 2** presents the engine performance test apparatus. The engine used in this study was air- cooled single cylinder direct injection diesel engine. The engine specifications are shown in Table 2. Then, the experiment was performed under the following conditions:

The engine was set five step loads by the dynamometer. These loads were selected up to the continuous output of the test engine. The pressure and temperature also the amount of intake air, cylinder

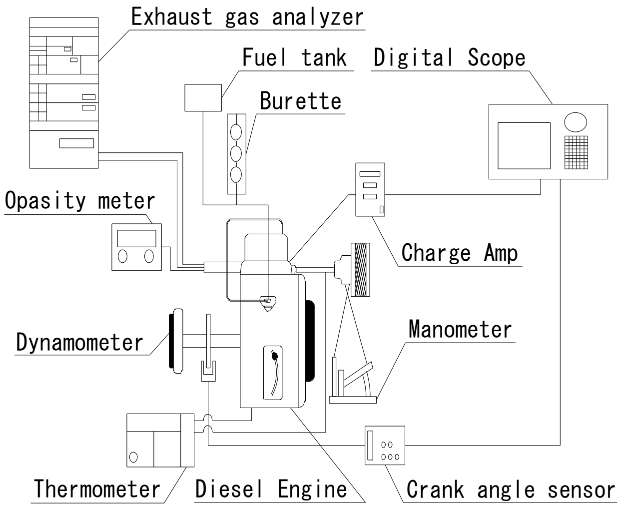

Fig. 2 Experimental apparatus

Table 2 Engine specifications

Model	YANMAR L70V
Displacement Volume	320 [cc]
Compression Ratio	21.1
Continuous Power	4.3 [kW]@3600rpm
Maximum Power	4.8 [kW]@3600rpm
Combustion Chamber	Direct Injection
Fuel Pump	Plunger type
Fuel Injection Timing	BTDC16 [deg]
Injection Pressure	19.6 [MPa]

pressure and crank angle, exhaust gas temperature, they were measured and recorded with the data logger. Exhaust gas was sampled directly from the exhaust pipe in order to measure the PM precisely by the opacity meter (HORIBA; MEXA-600SW). Also, exhaust emissions such as oxygen (O_2), carbon monoxide (CO), CO_2, total hydro carbon (THC) and NOx were precisely measured from directly sampled exhaust gas by using the exhaust gas analyzer (HORIBA; MEXA-9100D). In addition, engine performance such as brake specific fuel consumption (BSFC) was investigated. The all of measurements was precisely measured at each five step loads while the steady state condition at 3000 rpm. Finally, combustion of each fuels were analyzed from recorded cylinder pressure and crank angle.

3.2 Results and discussions

Figure 3 gives the engine performance test results of each fuel. The equivalence ratio is set on the horizontal axis because each fuel has different stoichiometric correct amount of air, exhaust emissions and BSFC are on the vertical axes in this figure. In addition, the cylinder pressure and heat release rate at the highest load are shown in **Fig. 4**. The crank angle is set on the horizontal axis, cylinder pressure and heat release rate are on the vertical axes in this figure.

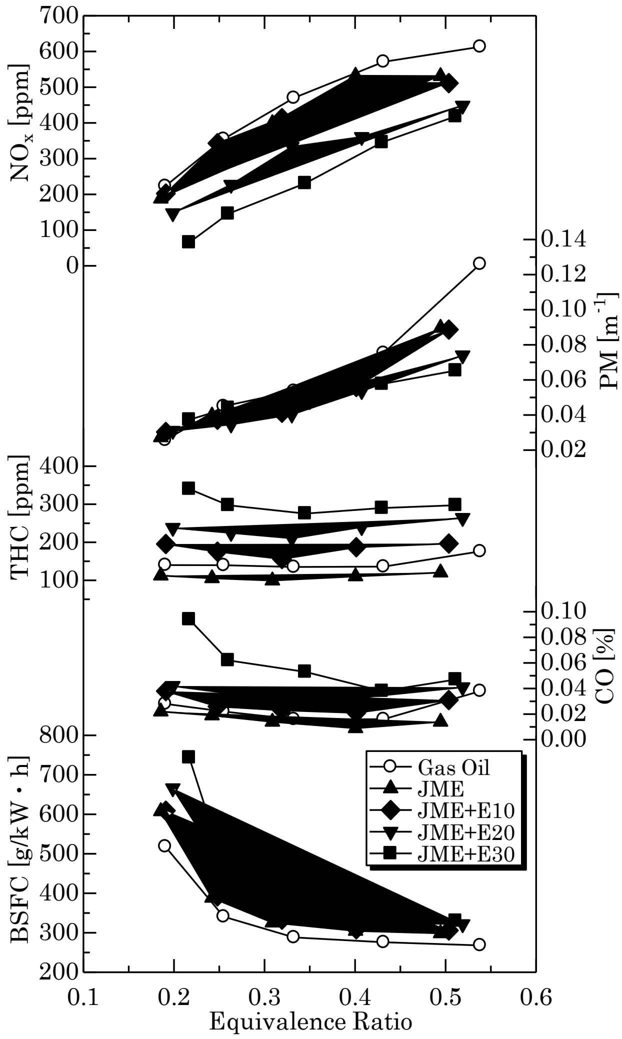

Fig. 3 Engine performance test results

From **Fig. 3**, it can be seen that NOx emission trends of ethanol blended fuels are different from JME, and they are confirmed to be reduced with the ethanol blending ratio. This reduction can be said from long ignition delay. From **Fig. 4**, it can be found that ignition delay of JME is shorter but ethanol blended fuels of it is got longer and longer by the ethanol blending ratio. Ethanol has lower cetane number as mentioned above, therefore lower cetane number fuel makes longer ignition delay. Then, longer ignition delay makes higher premixed combustion period, since amount of injected fuel during the longer ignition delay increases and they are burned in the premixed combustion period. The higher premixed combustion causes generally much NOx [9], but NOx of ethanol blended fuels are little. Therefore, this longer ignition delay can be considered that it is too long to increase NOx because ignition timing is retarded behind the top dead center. Consequently, combustion pressure is restrained lower and it makes combustion temperature lower, then NOx is reduced.

Moreover, this very long ignition delay can be considered that long ignition delay homogenizes premixed fuel-air mixture. Besides, it can be considered

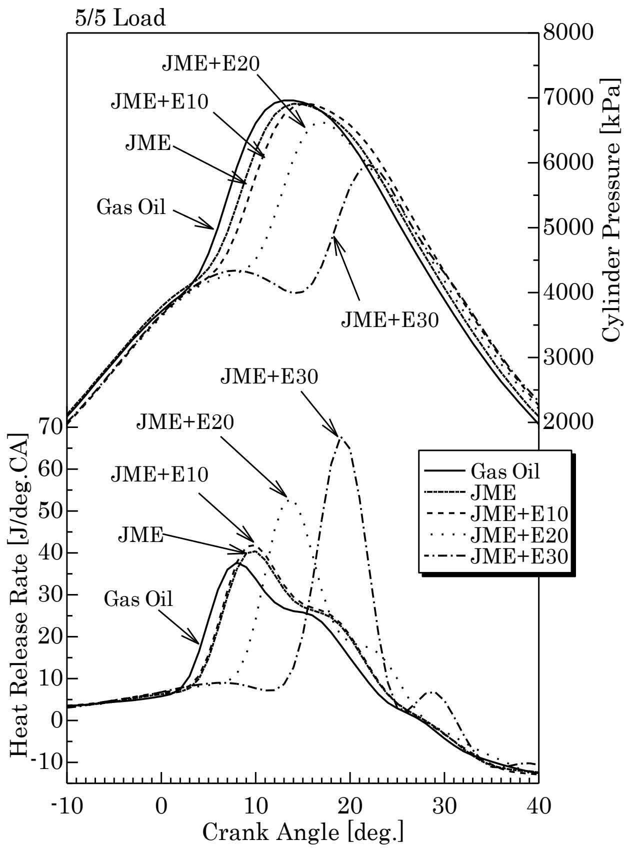

Fig. 4 Cylinder pressure and heat release rate

that the micro explosion effect is taken place during the ignition delay period. Ethanol in the fuel spray begins to boil faster than JME, since the boiling point of ethanol is lower than that of JME; boiling point of ethanol is about 350[K] but boiling point of JME is over 473[K] [10]. Accordingly, rich area especially the center of combustion chamber is dispersed into the whole combustion chamber. This rich area means the fuel-air mixture which contains much fuel more than stoichiometric correct amount of air. Diesel engines make heterogeneity fuel-air mixture in the combustion chamber because diesel engines make fuel-air mixture by the direct injection. Therefore, there are many rich areas and lean areas. Then, this rich area makes high temperature, and then thermal NO is increases, moreover rich area also makes prompt NO, therefore NOx is increased with the rich area. Hence, this dispersed rich area causes NOx reduction; in brief the micro explosion effect makes NOx reduction. In other words, fuel design such as changing cetane number or mixing different boiling point fuel makes NOx reduction.

From **Fig. 3**, it can be seen that PM emission of JME and ethanol blended fuels are confirmed to be reduced lower than that of gas oil. Ethanol blended fuels are reduced lower as ethanol blending ratio. This cause can be considered that influence of oxygenated fuel and lower cetane number fuel. Jatropha oil has oxygen inside the molecules, due to its component is oleic acid and linoleic acid mainly. Accordingly, JME can be considered the oxygenated fuel, and ethanol also has oxygen inside the molecules. Therefore, there is the supporting combustion action from oxygenated fuel. In addition, ethanol is also lower cetane number fuel. Lower cetane number fuel makes longer ignition delay as mentioned above. Also, longer ignition delay makes higher and longer premixed combustion period, consequently the diffusion combustion period is disappeared.

Diesel combustion is continued from premixed combustion to diffusion combustion. From **Fig. 4**, the first peak of heat release rate means premixed combustion period, then second one is diffusion combustion period. From **Fig. 4**, it can be seen that JME has diffusion combustion period, but diffusion combustion period of ethanol blended fuels are smaller by ethanol blending ratio. Particularly, diffusion combustion period of JME+E30 is confirmed to be disappeared. The longer ignition delay leads higher and longer premixed combustion period. Then, longer premixed combustion period leads smaller and shorter diffusion combustion period. If the end of premixed combustion period is retarded after finishing the fuel injection, diffusion combustion will not be exist. This diffusion combustion period makes PM in a word, since diffusion combustion period is prone to incomplete combustion. Therefore, smaller or disappeared diffusion combustion period leads to PM reduction; this is to say that longer ignition delay makes PM reduction. Moreover, micro explosion effect accelerates complete combustion since it atomizes fuel spray and it disperses the rich area. In addition, there is supporting combustion action from oxygenated fuel as described above. Consequently, PM is significantly reduced by the oxygenated fuel and the low cetane fuel. In other words, fuel design such as changing cetane number or mixing oxygenated fuel can make PM reduction.

NOx and PM emissions of ethanol blended fuels are reduced lower than JME, but THC and CO emissions of them are increased. However, these incomplete combustion gases can oxidize lightly by the catalyst. Therefore, they will not be problem but BSFC has to be considered. From **Fig. 3**, it can be seen that BSFC of ethanol blended fuels are slightly higher than JME. This can be considered that small lower calorific value and long ignition delay. Ethanol has small lower calorific value, therefore BSFC of ethanol blended fuels be worse. Furthermore, ethanol blended fuels have long ignition delay, and then combustion starts behind the top dead center. For that reason, BSFC of ethanol blended fuels are slightly higher. However, all of FAME fuels in this study do not have to think about CO_2 because ethanol can be made from plant. Equally, BSFC of these fuels do not need to apprehend because of "Carbon Neutral".

Thus, fuel design which changing cetane number and mixing different boiling point fuel or oxygenated fuel can change the diesel combustion and exhaust emissions. Particularly, fuel design based on lower cetane number leads to worse BSFC but "Carbon Neutral" can be considered in case of BDF. Therefore it can be said that fuel design of BDF based on cetane number can reduce the exhaust emissions.

4 Conclusions

In this paper, the experimental study was made on improving combustion and exhaust emission of Jatropha FAME by blending ethanol from fuel design perspective. The fuel properties were measured before the engine performance test. Then, Jatropha FAME and ethanol blended fuels were burned in a conventional diesel engine in order to declare the influence of them for diesel combustion and exhaust emission characteristics. The main conclusions can be summarized as follows:

1) JME and gas oil has different properties but ethanol blended fuels are similar to gas oil. Particularly, kinematic viscosity is very close to gas oil. In other words blending ethanol can optimize the fuel design.
2) NOx emissions of ethanol blended fuels are reduced lower than that of JME. This reduction seems to be from long ignition delay and micro explosion effect; in brief it is from fuel design such as changing cetane number or mixing different boiling point fuel.
3) PM emissions of ethanol blended fuels are drastically reduced by disappeared diffusion combustion and oxygenated fuel; in other words, fuel design such as changing cetane number or mixing oxygenated fuel makes PM reduction significantly.
4) Although THC and CO emissions are increased by blending ethanol, however they do not have to apprehend due to they can oxidize lightly by the catalyst.
5) Fuel design based on lower cetane number leads to worse BSFC but "Carbon Neutral" can be considered in case of BDF, therefore it can be said that fuel design of BDF based on cetane number can reduce the exhaust emissions.

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