Combustion Analysis of Jatropha Oil in Pre-combustion Chamber Type Compression Ignition Engine*

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Abstract

Recently, alternative fuels are actively studied all over the world. The main reasons are the depletion of crude oil, soaring oil prices and the global warming problem. Biomass fuel is one of the most up and coming alternative fuels from the viewpoint of carbon neutrality. The problem with biomass fuel is that it creates competition between food and fuel. Thus, the authors considered Jatropha which is a non-food plant. Its seed contains phorbol ester which is toxic and thus is inedible. The combustion analysis of Jatropha oil mixed with Marine diesel oil was studied. A 4-stroke pre-combustion chamber type compression ignition engine was used because of its ability to handle inferior fuels. Increasing the mixture ratio of Jatropha oil resulted in reduced NOx emissions and a decreasing tendency of smoke opacity. Each fuel showed an approximately equal value of thermal efficiency. The results show that in a pre-combustion chamber type compression ignition engine, Jatropha oil and blended fuel can be used as an alternative fuel to MDO.

1. Introduction

Recently, alternative fuels are studied all over the world. The main reasons are the following three. The first is regarding the crude oil dryness problem. The oil company in Britain reported that the reserve-production ratio of the oil of recoverable reserves of the field of after ages of 2006 is 40.5 years. It is evident that crude oil is a limited resource. The second is soaring oil prices. After 2003, the crude oil value of the transaction was in increasing, and marked the highest value of 147 dollars in July, 2008. It is thought that there are various factors in an increase in the price of crude oil. Especially, it is enumerated that consumption in countries where economic development such as BRICs is remarkable increases rapidly. Last but not least, the global warming problem. The carbon dioxide emission is the first greenhouse gas. Crude oil contains most of the carbon dioxide emission source in the world. Therefore alternate fuels actively studied.

The biomass fuel is one of the most up and coming alternative fuels of the carbon-neutral. The carbon-neutral is a way of thinking that the carbon dioxide of the biomass fuel is not counted for new carbon dioxide. In addition, the biomass fuel can be easily reproduced, because it is made from crops.

In countries of EU of Germany and France, BDF (Bio Diesel Fuel) made from the rapeseed oil is chiefly manufactured. The production of BDF in Europe was 0.85 million ton in 2000 and was 4.5 million ton in 2006. The government of EU is obligating the use of BDF of 5.75% for the diesel fuel in 2010, it aims using the vegetable oil of 12.75 million tons for the BDF production. In Japan, it is aimed to introduce 500,000KL of the biomass fuel for transportation in the Kyoto Protocol accomplishment of a goal plan by 2010.

However, the biomass fuel has the problem of the competition of the fuel and food. Prices of cooking oils such as the rapeseed oil, the soybean oil, and the palm oil have risen to compete with the biomass fuel in recent years.

Then, we paid attention to the Jatropha which is a nonfood plant. The Jatropha is produced widely in subtropics in the world and grows up in the dry land and the Jatropha oil has the toxic, so it doesn't have the problem of the competition of the fuel and food.

Recently, the BDF esterified of the Jatropha oil was studied the combustion analysis in the direct injection type compression ignition engine by Miyamoto et al. [1]. The cost of BDF is higher than the Jatropha oil, and the product of BDF produces the glycerin waste. The processing of the glycerin waste is very difficult. Then, the Jatropha oil was studied the combustion analysis in the direct injection type

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compression ignition engine by Narayana et al. [2]. But, in the direct injection type compression ignition engine, the Jatropha oil case, the combustion efficiency becomes lower and the thermal efficiency is constricted.

In this present study, the use of the Jatropha oil is tried in the pre-combustion chamber type compression ignition engine which is better than the direct injection type at combustion of inferior oil.

2. Experimental device and method

2.1 Test Fuel

The Jatropha comes from the spurge family. It is a slightly elevated tree which shed its leaves in the dry season. It reaches the greatest harvest in five years and can maintain the greatest harvest for further 25 years. The oil content of a Jatropha seed is about 30%. For example, it is 5 times that of the soybean oil, and 3 times of the rapeseed oil. It can not be eaten because the seed contains phorbol ester which has toxic. The Chinese government and a European and American large company finance the Jatropha oil, and it is researched and developed as the new biomass fuel crops. Jatropha is produced widely in subtropics in the world and grows up in the dry land. Therefore it does not need the

felling of the tropical rain forest by the increase of the volume of production. However, Jatropha is unsuitable for the cultivation in cold districts to hibernate in Japan in winter. The Jatropha oil of the biomass fuel contains the oxygen content of about 10w%. Table 1 shows the fatty acid composition of the Jatropha oil. The chief ingredient of the Jatropha oil is oleic acid and linoleic acid of the unsaturated fatty acid.

It is easy to be oxidized and a melting point is low as a characteristic, and soot is easy to occur so that there is much double bond of the carbon with the fuel of the hydrocarbon system. Table 2 shows fuel comparison between Marine Diesel Oil and the Jatropha oil. Total calorific value for the Jatropha oil is lower by around 10% in comparison with MDO. The cetane index of the Jatropha oil is a reference value because it was not measurable by the distillation test accurately. In general, it is a little higher than MDO and between 50 to 60.

2.2 Combustion analysis

Table 3 shows the engine specification. The three cylinder four stroke pre-combustion chamber type compression ignition engine is used for the combustion analysis. Recently, Pre-combustion chamber type compression ignition engine is hardly used because the cooling loss and the squeezing loss are large. It is a method that burns in pre-combustion chamber partially, gushes the fuel-air mixture from the transfer passage in the high pressure, and burns completely by mixing it with air by the combustion swirling current. Moreover, pre-combustion chamber is not cooled enough in general. Therefore, because it is very a high temperature, it is possible to use it also with a malignant fuel [3].

Figure 1 is the schematic diagram of the experimental set up. The fuel goes out of the tank and enters the injection nozzle through the injection pump. The air supply goes out of the surge tank and enters the combustion chamber through the orifice. The exhaust gas goes out of the combustion chamber, and a small amount of gas enters the gas analyzer, and the other exhausted in atmosphere.

In this experiment, the supercharging of 21kPa was done, the rotational speed of engine was 1500 rpm constant, and the load was set to four stages (25%, 50%, 75%, and 100%) for maximum output (33.1kw). There are five kinds of test fuel of this experiment, that is, MDO, the Jatropha oil, and blended fuels (Jatropha oil 25% + MDO 75%, Jatropha oil 50% + MDO 50%, and Jatropha oil 75% + MDO 25%). Experiments were carried out at the constant fuel temperature, $50(\pm 5)$ degree Celsius, at the nozzle inlet

Table.1 Fatty acid distribution of Jatropha

Numerical symbol	Fatty acid	Fatty acid (%)
18:1	Oleic acid	40.5
18:2	Linoleic acid	35.9
16:0	Palmitic acid	6.8
18:1	Vaccenic acid	1.0
18:3	Linolenic acid	0.2
20:0	Arachidic acid	0.2
16:1	Palmitoleic acid	0.8

Table.2 Properties of MDO and Jatropha Oil

Test fuel	MDO	Jatropha oil
Flash point (°C)	82.0	254
Cetane number	52.0	36.7 (reference)
Distillation Characteristics (°C)		
10%		304.0
50%		312.5
90%		334.5
Density (15°C), g/cm ³	0.8452	0.9197
Calorific value, J/g	45,600	39,490

position for every fuel condition where the fuel viscosities vary with the fuel mixing ratio.

In the experiment, the engine was started with light oil, and did the warm-up. Next, the state of driving measured after switching to test fuel, and changing the load and we measured the measurement item settling down. The measurement item is an atmospheric state, an amount of the inhalation air, an exhaust temperature, NO_x, CO₂, CO and O₂ emission, smoke concentration, combustion pressure (pressure in the cylinder), fuel jet tube pressure, and a fuel input rating. The sensor of the combustion pressure is an installation only of the main combustion chamber.

3. Result

3.1 Properties measurement

Figure 2 shows a result of the kinematic viscosity measurement. The viscosity of MDO was a low value of 10 cSt and did not have the change by the temperature change. The viscosity of the Jatropha oil has decreased rapidly by the rise of temperature. At 20 degree Celsius, the viscosity of the blended fuel (Jatropha oil 75% + MDO 25%) was lower than one-third of that of Jatropha oil. The use of the Jatropha oil at the normal temperature becomes possible by adjusting the mixed quantity with MDO from the above-mentioned.

Table. 3 Engine specifications

Model	YANMAR 3ESDL
Type	4 stroke Pre-combustion chamber type compression ignition engine
Number of Cylinders	3
Bore × Stroke	120[mm] × 135[mm]
Displacement	1526 × 3[cm ³]
Compression ratio	18.7 (Top clearance 1[mm])
Fuel injection timing	Before T.D.C 10°
Rated output	25.7 kW@1500rpm
Injection pump	Bosch PF type
Nozzle type	Pintle type nozzle
Injector opening pressure	15.7[MPa]

Fig.1 Schematic diagram of the experimental set up

Figure 3 shows the photograph of the mixed fuel (Jatropha oil 50% + MDO 50%) with passing time. The blended fuel did not separate into several layers leaving for one month after mixing each fuel. Moreover, the oxide was not generated for one week though it was the Jatropha oil with low oxidative stability. The blended fuel can be kept and utilized with passing a long time after mixing each fuel, because of its high stability in the keeping of mixing state.

3.2 Combustion analysis

Figure 4 and figure 5 show the fuel injection pressure of minimum output (8.3kw) and maximum output (33.1kw). In both cases, pressure rising became earlier and the fuel injection period became longer as the mixture ratio of the Jatropha oil increased. As for the lower compressibility ratio of Jatropha oil, the fuel injection in the pre combustion chamber started earlier with the mixture ratio of the Jatropha oil increased.

Figure 6 shows the fuel consumption. The fuel consumption increased as the mixture ratio of the Jatropha oil increased, because the calorific value for the Jatropha oil is lower by around 10% in comparison with MDO.

Figure 7 shows the combustion pressure of minimum output (8.3kw). Rising up of pressure was almost the same time in all the fuels and the maximum pressure increased as the

Fig.2 Viscosity of MDO and Jatropha

Fig.3 Blended fuel

mixture ratio of the Jatropha oil increased. Figure 8 shows the combustion pressure of maximum output (33.1kW). Rising up of pressure became earlier and the maximum pressure rose as the mixture ratio of the Jatropha oil increased. Due to the compressibility of Jatropha oil, the fuel injection pressure rises earlier and the fuel injection tends to start earlier than the MDO. Thus, the rising up of combustion pressure of Jatropha oil became earlier than that of MDO. As for the poorer ignitability of Jatropha oil, much fuel begins to blow in the main combustion chamber with

the increase of the mixture ratio in comparison with MDO, and it is thought that pressure at the maximum rose.

Figure 9 shows the NOx emissions. NOx emissions did not change with the fuel mixing condition for the case of lower engine load. However, NOx emissions tend to decrease with increasing in the mixing ratio of Jatropha oil for the higher engine load cases. In the pre-combustion chamber type diesel engine, it is known that NOx emission becomes smaller due to the lean fuel/air mixture combustion when the burning amount of the mixture in the main chamber turns to

Fig.4 The fuel injection pressure of minimum output

Fig.7 The combustion pressure of minimum output

Fig.5 The fuel injection pressure of maximum output

Fig.8 The combustion pressure of maximum output

Fig.6 The fuel consumption

Fig.9 The NOx emissions

be larger [4]. This knowledge could explain the tendency of NOx emissions in this study.

Figure 10 shows the HC emissions. The HC emissions showed emissions of the quantity same as MDO even if we mixed the Jatropha oil.

Figure 11 shows the smoke concentration. It lowered as the mixture ratio of the Jatropha oil increased. Moreover, it became the lowest value of each fuel when the output was 17kw. For the case of lower engine load, the pressure rising rate in the pre-combustion chamber becomes lower and the injection speed of the burning fuel mixture from the transfer passage to the main combustion chamber becomes slower than the higher engine load case. Thus, the mixing of burning fuel with air in the main combustion chamber for the lower load case becomes insufficient compared to the higher load case which results in higher emission of Smoke. The Jatropha oil of the biomass fuel contains the oxygen content of about 10w%, so the Jatropha oil burn more smokelessly than MDO.

Figure 12 shows the change in thermal efficiency. Thermal efficiency was an equal value though the mixture ratio of the Jatropha oil increased where the fuel consumption increased.

Fig.10 The HC emissions

Fig.11 The smoke concentration

The calorific value of Jatropha oil is around 86% of MDO, thus the Jatropha oil must be injected 1.2 times more than the MDO to obtain the same calorific heat. The fuel consumptions show this tendency, as shown in Fig.6. As described with Fig.7 and 8, the rising up of combustion pressure of Jatropha oil became earlier than that of MDO. So, the combustion proportion in the main chamber became larger which results in enhancement of combustion efficiency. Therefore, the thermal efficiency of the Jatropha oil mixing cases can be obtained almost equal value with the MDO.

Figure 13 shows the nozzle surface after each experiment. The photograph at the right is MDO 100% where the engine was operated about 45 minutes with 4 kg fuel burned. A small particulate deposit was thinly generated on the nozzle surface.

The photograph at the middle is the three blended fuels cases where the engine was worked about 3 hours with 12 kg fuel burned. It is thicker than that of MDO. The photograph on the left is the Jatropha oil 100% where the increased, the smoke concentration decreased, and the engine was operated about 70 minutes with 4 kg fuel burned. It can be seen a large carbon deposit, but the fuel can still be injected normally. When the mixture ratio of the Jatropha oil carbon deposit had a tendency to increase. The Jatropha oil is the low cetane number doesn't burn enough in the pre-combustion chamber, a lot of the unburned fuel become deposited on the nozzle surface.

Fig.12 The Brake thermal efficiency

Jatropha

Blend Fuel

MDO

Fig.13 The nozzle surface

4. Conclusion

In the present study, the kinematic viscosity measurement and the burn analysis on the fuel were done by using the Jatropha oil, MDO, and the blended fuel in the pre-combustion type compression ignition engine.

As a result, the following findings were obtained.

- Kinematic viscosity decreased with the increase of the mixture ratio of MDO in Jatropha oil.
- Rising up of pressure became earlier by decreasing a mixture ratio of MDO in Jatropha oil.
- The NO_x discharges by the combustion decreased in the medium- and high-levels output by decreasing a mixture ratio of MDO in Jatropha oil.
- The smoke density decreased, but the sedimentation of the carbon deposit in the pre-combustion chamber increased as the mixture ratio of the Jatropha oil increased.
- The value of the thermal efficiency showed an approximately equal value with each fuel.

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