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A STUDY ON THE APPLICATION OF PALM OIL BIODIESEL ON THE COMBUSTION AND EMISSION CHARACTERISTICS UNDER IDLE CONDITION IN A CRDI ENGINE

[1]HO YOUNG KIM, [2]JUN CONG GE, [3]CHOON BONG PARK, [4]DOO SUNG LEE, [5]NAG JUNG CHOI

[1,2,3,4,5]Division of Mechanical Design Engineering, Chonbuk National University,
567 Baekje-daero, Deokjin-gu, Jeonju-si, Jeollabuk-do, 54896 Republic of Korea.
Email: [1]jerryme@naver.com, [2]freedefeng@naver.com,[3]park03000@hanmail.net, [4]leeds4633@hanmail.net
[5]njchoi@jbnu.ac.kr

Abstract - This study describes the effects of palm oil biodiesel (PD) blended with diesel on the combustion performance, emission characteristics and soot morphology in a 4-cylinder common-rail direct injection (CRDI) diesel engine. 5 kinds of biodiesel fuels are blended with diesel in 0%, 10%, 20%, 30% and 100% proportions by volume. The engine is operated on idle speed, 750rpm and load conditions of engine are 0 Nm and 40Nm. Combustion results show that IMEP is increase as increasing blend ratio at high load and is steady at low load. The power is enough to stay idle. But fuel consumption is increased. And Emission results show that the oxygen in fuel has a great influence on the production of exhaust emissions. All emissions are decreased in blend ratio 10%, 20%. EspeciallyNOx is decreased because of high viscosity and low heating values of biodiesel even though combustion is improved by oxygen. But NOx and CO are increased above a certain blend ratio. The sizes of soot are decreased. Biodiesel is a fuel that can provide enough performance to keep the vehicle in terms of power andreducing pollutants.

Index terms - Palm Oil Biodiesel, Idle, Combustion, NOx, HC, CO, Soot.

I. INTRODUCTION

The regulations on the environmental pollutants emitted by the use of fossil fuels in internal combustion engines are strengthened, and the engine technology for this is being developed. Research on the reduction of environmental pollutants through fundamental improvement of the internal combustion engine power source as well as development of engine mechanical technology is also underway. A typical example is the use of biodiesel. In 2018, the state of Minnesota has passed a law that will double B10 (biodiesel blend ratio 10%) to B20 (biodiesel blend ratio 20%), and it will be sold in earnest from 2019.In this way, it is possible to use biodiesel as a fuel without modifying the mechanical change of the diesel engine and to reduce exhaust pollutants, so that much research is being conducted on its use and application. Gun et al.[1)] and Choi et al.[2)] have applied biodiesel mixed with low-sulfur diesel or itself to a diesel engine and confirmed power and reduction ofpollutant emissions according to the biodiesel blend ratio. In addition, Ge et al.[3)] studied the effect of EGR and injection timing on the generation of exhaust pollutants by applying canola oil biodiesel to common rail diesel engines by blending with diesel fuel. Ruina Li et al.[4)] conducted a study on the shape of soot particles generated when biodiesel was used. As the content of biodiesel increased, the size of PM became smaller and aggregated in a lump form.

The above studies have been carried out at a sufficient load and at a rotational speed conditions which have enough fuel injection quantity for engine operation. However, an engine applied to a vehicle is not operated only under these conditions. Actually the worst combustion condition of engine operation isidle. Idling is the lowest speed at which the engine can operate without any action by the driver when a vehicle is stopped. And the injection pressure is also lowest. In fact, according to 2007 US Environmental Protection Agency, it was found that idling in urban driving mode accounted for about 17%.

There is a lack of research on how the advantages of biodiesel (high cetane number and oxygen) and disadvantages (high viscosity and low calorific value) under idle which is the worst conditions affect the combustion in the cylinder and emissions. In this study, combustion and exhaust characteristics were confirmed by applying palm oil biodiesel (blended with diesel at 0%, 10%, 20%, 30%, 100% proportions by volume) to confirm the suitability of biodiesel in idling condition (750rpm).

II. TEST ENGINE AND FUEL PROPERTIES

The engine used in the experiment is a four-cylinder 2.0-liter Common Rail diesel engine applied to a real vehicle. Control of the engine is performed by an ECU (Engine Control Unit). Detailed specifications are shown in Table 1.

Table1. Engine specifications

Items	Specification
Engine Type	In-line 4cylinder
Maximum Power	82kW / 4000rpm

Maximum Torque	260Nm / 2000rpm
Bore x Stroke	81mm x 96mm
Displacement	1979cc
Compression Ratio	17.7 : 1
FIE System Type	Bosch CRDI

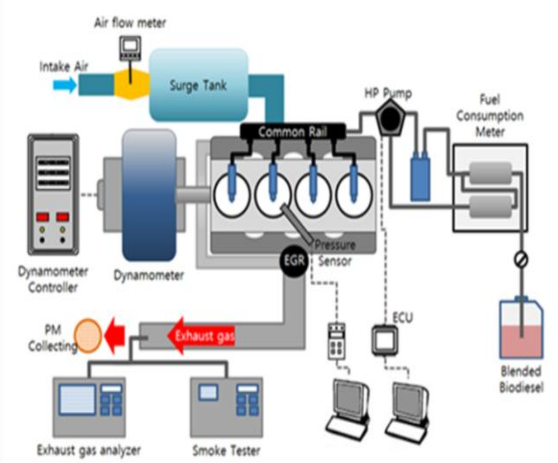


Figure 1. Schematic diagram of experimental system

Table 2. Properties of test fuels[5]

Characteristic	Test Fuels PD0	PD10	PD20	PD30	PD100
Density (kg/㎥ at 15℃)	827	833	835	841	877
Viscosity (㎟/s at 40℃)	2.28	2.49	2.82	2.85	4.56
Calorific value (MJ/kg)	45.8	45.1	44.6	44	40.5
Cetane Index	48.9	53.1	55.9	57.7	71.3
Flash point(℃)	64	69	71.5	82	196

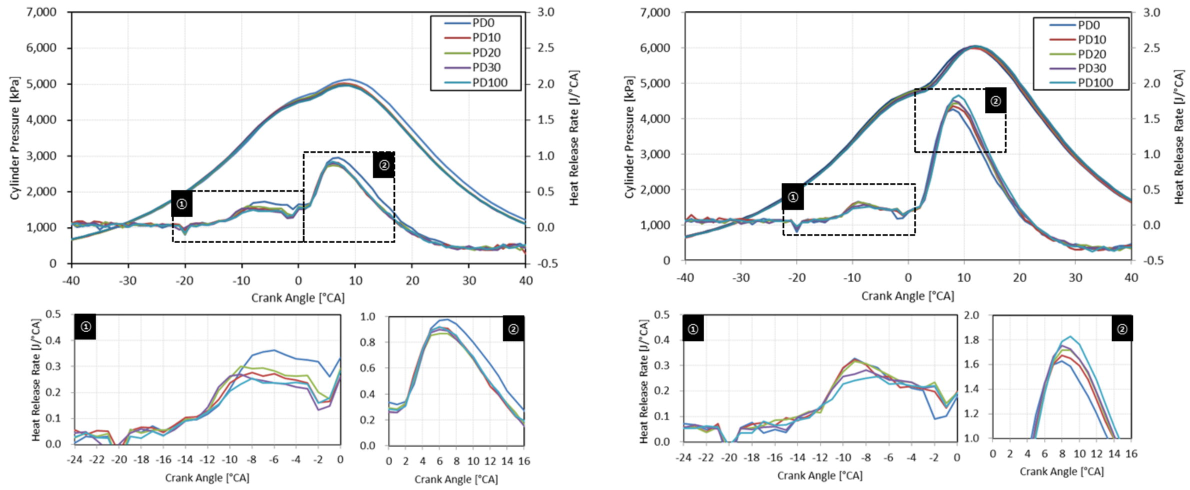
Table 3. Test conditions

Items	Condition
Engine speed	750rpm(Idle speed)
Engine Load	0Nm& 40Nm
Cooling water / Intake temperature	344±3 / 293±3 K
Fuel Injection Pressure	280bar
Main & Pilot Injection Timing	Main BTDC 2°CA, Pilot BTDC 20°CA

The fuels used in this experiment are blended with diesel and palm oil biodiesel. Palm oil produces about 87% of the world's production in Southeast Asia, Malaysia and Indonesia. Using palm oil is the easiest way to apply biodiesel in Asia.

Here, the blended biodiesel is expressed as PD. PD0 is 100% diesel with no palm oil blend, and PD100 is 100% pure palm oil biodiesel with no diesel fuel. The others, PD10, 20 and 30 are blended as 10%, 20%, and 30% proportions by volume. The specifications for the fuels used in this experiment are shown in Table 2. These specifications refer to R.El-Arbyet al.[5]'s study.

III. EXPERIMENTAL SETUP AND MEASUREMENT



(a) Engine load 0Nm (b) Engine load 40Nm

Figure 2. Combustion Pressure & Heat Release rate under engine load 0Nm & 40Nm with blended biodiesels

As Figure 1, experimental equipment, an eddy current type dynamometer (DY-230kW)equipped with a fuel supply system and a fuel pump, a green line (MK2) as an exhaust gas analysis system and a OPA-102 as a partial flow collecting type for soot analyzer were used. The combustion pressure was acquired and analyzed with a piezo-electric type pressure sensor (Kistler, 6056a) at the position of the glow plug. The discharged soot was collected by a copper grid and analyzed the shape of the soot particles by TEM (Transmission Electron Microscope) and SEM (Scanning Electron Microscope) photos.

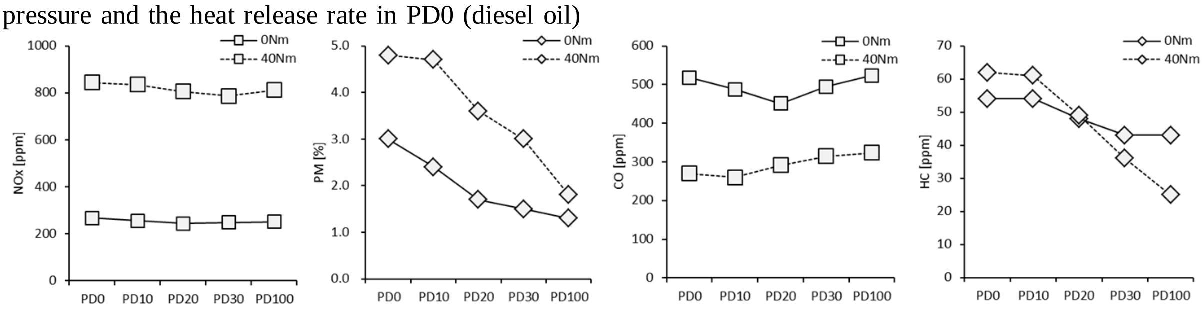
In this experiment, the rotation speed of the engine was set to 750 rpm at idle speed, and the engine load was 0Nm, which is the no-load condition, and 40Nm, to simulate the situation using the external load device of the actual vehicle. The Pilot injection was applied. The main injection timing was BTDC 2degree and pilot injection timing is BTDC 20 degree, and injection pressure was fixed at 280bar. The experimental conditions are summarized in Table 3.

The combustion pressure and the heat Release rate were averaged over 200 cycles. The exhaust gas and soot were measured by the exhaust and smoke detector when the combustion condition was stabilized according to the experimental conditions.

IV. RESULTS AND DISCUSSION

4.1. Combustion analysis

Figure 2 shows that the characteristics of the combustion are different depending on the blendratio of biodiesel and engine loads.Under the engine load of 0 Nm, the combustion pressure and heat release rate in the cylinder are decreased with the increase of the blend ratio. It can be seen that the combustion pressure and the heat release rate in PD0 (diesel oil) are the maximum. As the blend ratio increases, the cetane number increases, so that the ignition delay period decreases.it means the combustion starts quickly. However, high viscosity of the biodiesel, low injection pressure and low air flow at the condition of idling make the atomization of fuel and the mixture of air and fuel worse in the cylinder. And the low calorific value of it deteriorates also the combustion environment in the cylinder. For the above reasons, the ignition delay of PD100 is retarded under the condition of idle. At an engine load of 40 Nm, the amount of fuel injected increases and the pressure in the combustion chamber rises. This changes the characteristics of the combustion.Even when the blending rate is increased, the ignition delays are the same, but the rapid combustion of the pilot injection is reduced due to the difference in calorific value and poor atomization. That is, the initial combustion of the pilot injection of PD0 is the most abrupt and the PD100 is the lowest.Also, as the blend ratio increases, the combustion of the pre-injected fuel proceeds slowly due to the high viscosity so that a part of the pre-injected fuel is burned together with the main injected fuel without completing the combustion. This makesmuch higher cylinder pressure and heat release rate of the combustion of main injected fuel.It is thought that the increase of oxygen content due tothe increase of injected biodiesel according to the higher engine load also influences.



(a) NOx (b) PM (c) CO (d) HC

Figure 5. Exhaust emissions under engine load 0Nm & 40Nm with blended biodiesels

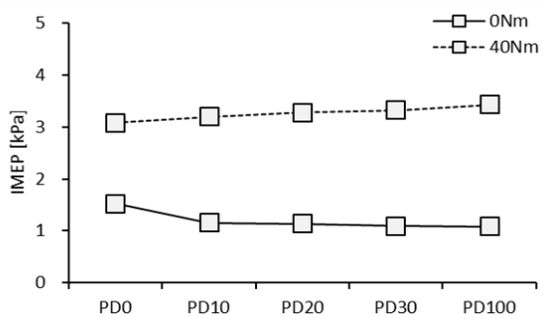


Figure 3 . IMEP under engine load 0Nm & 40Nm with blended biodiesels

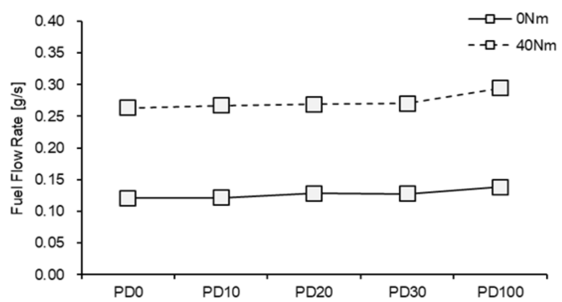
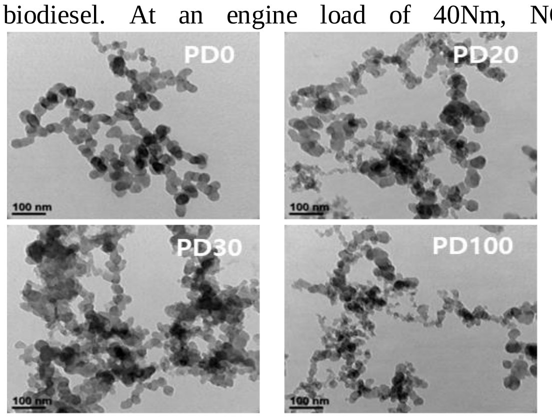


Figure 4 Fuel Flow Rate under engine load 0Nm & 40Nm with blended biodiesels

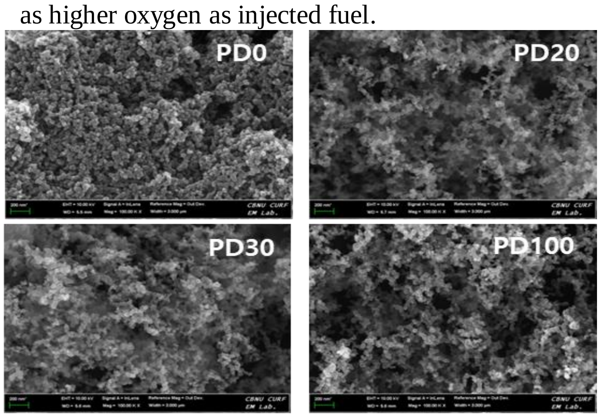
Figure 3 shows the IMEP depending on blend ratio and engine load. At the engine load of 40Nm, the IMEP increases as blend ratio increases. At the engine load of 0Nm, the IMEP of PD is the highest and the other blends are lower than it, but the levels are similar each other. It is considered that this is due to the improvement of combustion by the oxygen content as the blend ratio increases. The fuel flow rate according to the engine load and the blend ratio is shown at Figure 4. It means that the fuel consumption rate slightly increases as the blend ratio of biodiesel increases in Figure4. More fuel requires for the same engine power to stay idle condition because biodiesel has high density which means high mass per unit volume and low heat output.

4.2. Emissions

It shows the emission characteristics of exhaust according to the blend ratio of biodiesel and engine load in Figure 5.NOx level is decreased as increasing blend ratio and raised again above a certain level. This can be confirmed by the combustion characteristics identified above.The generation of NOx occurs during the sudden combustion pressure rise at the early pre-injection and main injection.At the engine load of 0 Nm, as the blend rate increases, decreased ignition delay results in a reduction of premixed combustion so that NOx generation is reduced. And lower combustion due to lower calorific value, higher viscosityand lower injection pressureare also the reasons of NOx reduction.In PD100, the combustion is improved by the influence of oxygen so that the amount of NOx is increased, the emission of NOx is considered to be kept constant by offsetting each other due to advantage and disadvantage of biodiesel. At an engine load of 40Nm, NOx production increases during the combustion of pre-injection at the low blend ratio but reduced at the main injection. However, when the blend ratio is increased, NOx generated in the combustion of the pre-injection is reduced, especially in PD100, but a part of the pre-injected fuel is burned together with the main injection so that the heat generation rate is rapidly increased and the generation of NOx is increased.It can be seen that PM decreases with the increase of blend ratio due to decrease of soot nucleation because of decreasing locally rich region and oxidation promotion by oxygenation. But as increasing more blend ratio, CO is increased again.At lower blend ratios, PD10 and PD20, the CO is reduced due to the decrease of the partially rich zone due to the influence of oxygen, but when the blend ratio is increased, the higher viscosity of the biodiesel increases due to the deterioration of atomization by the low injection pressure and the lower air flow make more CO. HC shows a tendency to decrease due to the longer combustion period by increasing of cetane number and the effect of oxygen with increasing blend ratio. The HC level is much higher than the level of lower blend ratio at high engine load but as increased blend ratio the HC level is decreased as higher oxygen as injected fuel.



(a) TEM Photos



(b) SEM Photos

Figure 6. TEM & SEM photos of PM under biodiesel blend rate

The size and shape of the soot particles can be seen in Figure 6. As the blend ratio of biodiesel increases, the size of the soot particles decreases and the discharged soot is agglomerated and the morphology developed to cluster.This is the same as the results of Ruinal Li et al.[4]. Due to the oxygen effect of biodiesel, the size of PM is reduced by oxidizing the unburned hydrocarbons. It is also believed that PM is partly coalesced due to partial oxidation of PM.

CONCLUSION

Under bad conditions such as idling (Low air flow and injection pressure), the oxygen content of biodiesel has a great effect on combustion than the high viscosity and low calorific value. The IMEP is enough to stay idle at all blend ratio.PM, CO and HC are reduced due to the influence of oxygen content in biodiesel. Generally, NOx is known to increase as the amount of biodiesel is increased because of combustion improvement by oxygen in the biodiesel. But under idling condition, NOx is reduced by deterioration of atomization due to high viscosity, low calorific value and high cetane number rather than the effect of oxygen content.However, when the blend ratio is above a certain level, NOx is increased, so it should be used within an appropriate blend ratio. Especially PD10 and PD 20, currently available fuel in market, compared with pure diesel (PD0), it is suitable for performance and reduction of exhaust pollutants. As a result of confirming the morphology of the soot particles, the size of the soot particles becomes smaller as the blend ratio increases. Therefore, further investigation of fine specks of dusts such as PN and trace metal emission is needed to more closely examine the applicability of biodiesel.

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