A Study on the Usability of Biodiesel Fuel Derived from Rice Bran Oil as an Alternative Fuel for IDI Diesel Engine

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The world is faced with a problem of air pollution due to the exhaust emissions from automobile. Recently, lots of researchers have been attracted to develope various alternative fuels and to use renewable fuels as a solution of these problems. There are many alternative fuels studied in place of diesel fuel made from petroleum. Biodiesel fuel (BDF) is a domestically produced, renewable fuel that can be manufactured from vegetable oils, used vegetable oils, or animal fats. In this study, the usability of BDF, one of the oxygenated fuels as an alternative fuel for diesel engines was investigated in an IDI diesel engine. Emissions were characterized with a neat BDF and with a blend of BDF and conventional diesel fuel. Since the BDF includes oxygen of about 11%, it could influence the combustion process strongly. Therefore, the use of BDF resulted in lower emissions of carbon monoxide and smoke emissions with some increase in emissions of oxides of nitrogen. It is concluded that BDF can be utilized effectively as a renewable fuel for IDI diesel engines.

Key Words: Alternative Fuel, Biodiesel Fuel(BDF), Smoke, Nitrogen Oxides, Exhaust Gas Emission, Oxygenated Fuel

1. Introduction

Due to the problems of price and finiteness of conventional petroleum oil used in automobile vehicle and the environmental pollution derived from the exhaust emission of vehicle such as the smog of big cities, many researchers have tried to solve these problems by using alternative and renewable fuels. Vegetable oils have been studied by lots of researchers as an alternative fuel of diesel engine with higher thermal efficiency and power (Kyle et al., 1993 ; 2).

BDF derived from vegetable oils, used vegetable oils, or animal fats can be used as a substitute for conventional petroleum fuel in diesel engines without modification. Also BDF has safe properties to use in diesel engine.

It is already being tried to legislate BDF for commercial business by the American Soybean Associations in U.S. (Howell, 1997)

Ziejewski et al. (1984) reported that the smoke with the blending oils was reduced compared to conventional diesel fuel when the blending oils with biodiesel and conventional diesel fuel or neat biodiesel were used in diesel engine. Scholl et al. (Kyle et al., 1993) and Schumacher et al. (1992 ; 1993) also reported reductions in smoke when fueling with BDF derived from soybean as compared to diesel fuel. Reece et al. (1993) reported that a blend oil of rapeseed oil 20% and diesel fuel 80% resulted in reduction in smoke in diesel engine. Schumacher et al. (1996) observed slightly reduced power with 100% neat biodiesel in DI diesel engine, but Feldman et al. (1992) reported increase in power when fueling with BDF with controlled fuel injection timing in a 3 cylinder DI diesel engine.

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In Korea, Oh(1996; 1998) showed that the vegetable oils such as used vegetable oil could be easily used with reduction in smoke in a single cylinder DI diesel engine. But there are no results on the combustion characteristics of IDI diesel engine with BDF derived from rice bran oils that can be continuously produced in Korea annually.

The purpose of this paper is to determine the effects of BDF in IDI diesel engine as compared to conventional diesel fuel. Especially, performance and emissions with BDF compared to diesel fuel are investigated in a 4 cylinder IDI diesel engine without any modifications.

2. Experimental Apparatus and Methods

2.1 Test description and fuel

In this study, a water-cooled, 4 cylinders, 4 stroke, and commercial indirect injection diesel engine without any modifications was investigated. Test engine with compression ratio 21, displacement 2476(cc) and pre-combustion chamber was motored by the starting motor and manually controlled by the eddy current type engine dynamometer(HW130), which are capable of maintaining engine speed constant automatically and absorbing engine power output of 130kW. The principal specifications of test engine are given in Table 1.

Table 1 The specification of test engine

Item	Specification
Engine model	HD D4BA
Bore×stroke	91.1×95(mm)
Displacement	2476(cm^3)
Compression ratio	21
Combustion chamber	Pre-combustion
Injection timing	Variable
Coolant temperature	80±2℃

Table 2 shows the properties of fuels used in this test. BDF derived from rice bran oils that can be produced annually in Korea has lower energy density than diesel fuel, but it is easy to use and store the BDF because of higher cetane number and higher flash point. Also, the BDF includes oxygen of about 11%, it could influence the combustion process strongly.

Four test fuels were used during this program, including a neat(100%) BDF, a neat(100%) diesel fuel, and blends of 20 and 50 percent BDF by volume in the diesel fuel.

Table 2 Properties of test fuels

Item	Diesel fuel	Biodiesel fuel
Gravity(15/4℃)	0.8373	0.8796
Viscosity(50℃, cSt)	3.0	4.2
Lower heating value(MJ/kg)	45.88	39.163
Cetane number	51.4	57.9
Carbon content(wt.%)	85.83	76.22
Hydrogen content(wt.%)	13.82	12.38
Nitrogen content(wt.%)	0.16	0.14
Oxygen content(wt.%)	0	11.26

2.2 Test procedures

Test engine was operated at 80±2℃ cooling water under all experimental conditions. After completing test work on a selected fuel, fuel filter and engine oil were exchanged with new ones in order to avoid any effect on the next test.

The experiments were conducted with four fuels at engine speed 1000 rpm, 1500 rpm, 2000 rpm, and 2500 rpm, and at engine load 0%, 25%, 50%, 75%, 90%, and 100%. To investigate exhaust emissions with BDF, Bosch type smoke meter (HBN-1500) and exhaust gas analyser(Green line MK) employing electrochemical cell type detector were installed at the position of 300 mm down the exhaust pipe from the exhaust manifold.

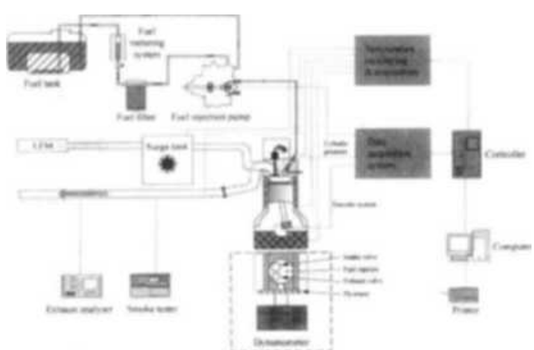

Fig. 1 Schematic diagram of experimental apparatus

Fuel consumption rate were also measured with 150 cc measuring gauge and stop watch.

To analyze the combustion characteristics of diesel engine with BDF, piezoelectric pressure sensor (Kistler 6061B) with a water-refrigerated adaptor was mounted on the pre-chamber of forth cylinder, and the pressure data generated from the sensor were sent to a data acquisition system through the pressure transducer (Kistler 5011).

Figure 1 shows the schematic diagram of experimental apparatus.

3. Experimental Results and Discussion

3.1 Engine performance with BDF

Figure 2 shows the effects of BDF on engine performance such as torque, power, brake specific energy consumption (BSEC), and noise at full load (100% load). Torque, power, and noise had no difference with BDF content in diesel fuel even though the lower heating value of BDF was lower than that of diesel fuel. But BSEC was generally improved by mixing BDF in diesel fuel.

To investigate the effects of BDF in diesel engine based on the data of Fig. 2, the cylinder pressure, the pressure rising rate, and the rate of heat release at 2500 rpm and full load are considered as given in Fig. 3. It was found that as the BDF content in diesel fuel increased, the starting time of heat release was advanced. This trend is mainly related to the shortened auto-ignition delay period of premixed mixture due to higher cetane number of BDF.

As the BDF content in diesel fuel increased, the peak of combustion pressure with BDF increased more than that with diesel fuel. It was thought that this resulted from the effect of oxygen in BDF because the oxygen in BDF accelerated the com-

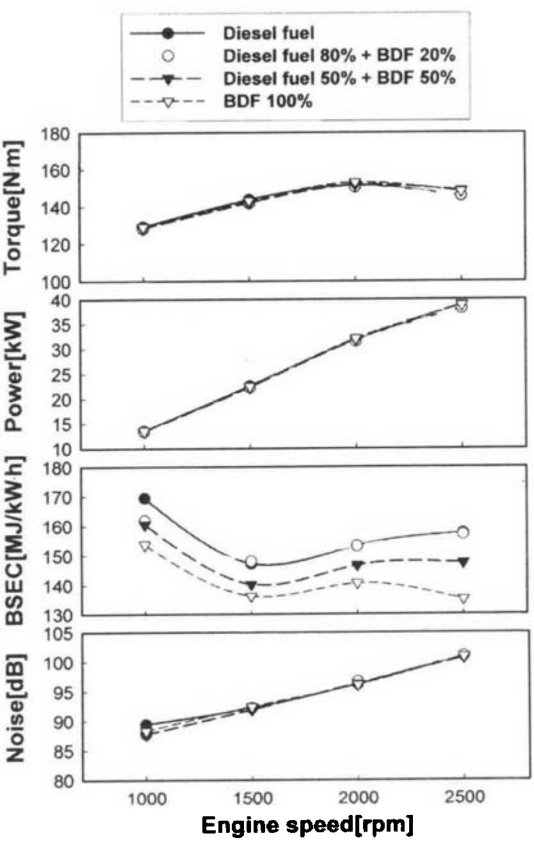

Fig. 2 Engine performance versus engine speed at engine load 100%

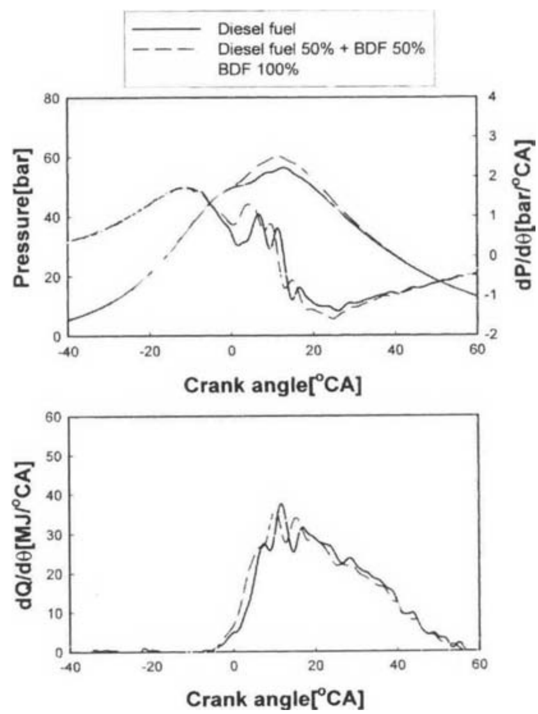

Fig. 3 Pressure, $dP/d\theta$, and $dQ/d\theta$ at engine speed 2500 rpm and load 100%

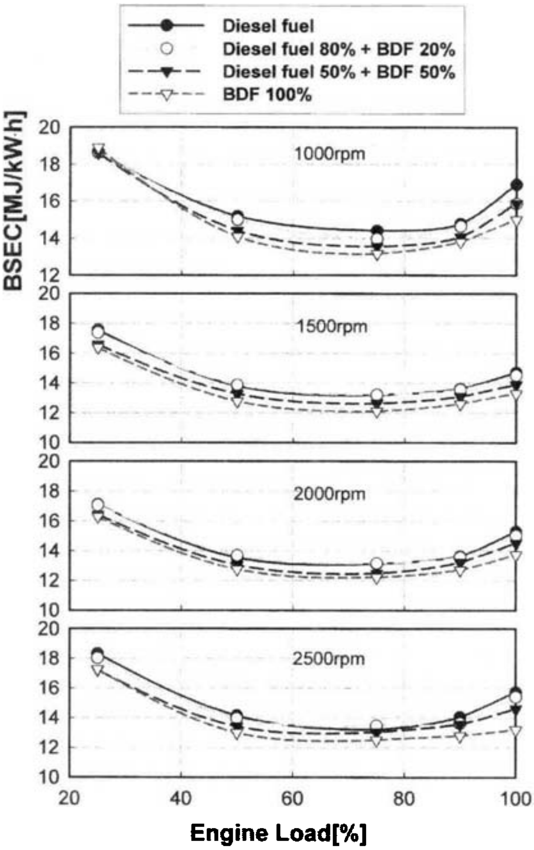

Fig. 4 BSEC versus engine load at various engine speeds

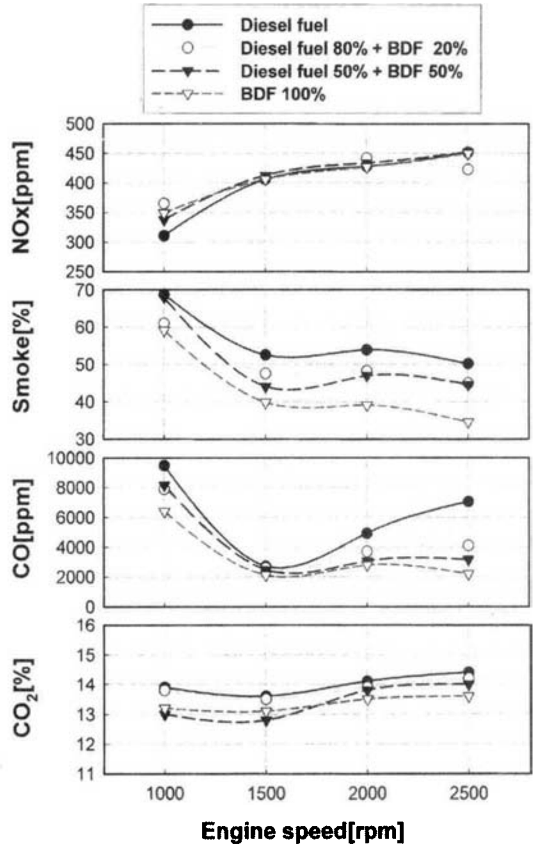

Fig. 5 Exhaust emissions versus engine speed at engine load 100%

plete combustion strongly and rapidly. Since the BDF includes oxygen of about 11%, it could influence the combustion process strongly. Thus, it was analyzed that this resulted in the decrease of BSEC with BDF as shown in Fig. 2.

Figure 4 shows BSEC with test fuels versus engine load at various engine speeds. BSEC with a blend of 20% BDF was slightly more decreased than that with diesel fuel or similar to that with diesel fuel, but it could be observed from this figure that BDF content in diesel fuel had a significant effect on BSEC at all engine load conditions as well as at all engine speed conditions.

3.2 Exhaust emissions with BDF

Figure 5 shows the characteristics of exhaust emissions with BDF at full load (100% load). Unlikely at the DI diesel engine, NOx with BDF at all test conditions was exhausted with a little increase compared to that with diesel fuel, but there was no special trend with respect to BDF content in diesel fuel.

It was considered that the starting time of ignition at the IDI diesel engine with the pre-combustion chamber was less sensitive to the type of fuel than that at the DI diesel engine, and the amounts of BDF for premixed ignition were smaller than those of diesel fuel due to higher cetane number of BDF.

At the variation of engine speeds, smoke density, CO, and CO_2 were exhausted with the greatest reductions of 34%, 70%, and 6% respectively at 2500rpm and the reduction rates of smoke, CO, and CO_2 also increased as the BDF contents blended in diesel fuel increased. It is thought that this results from two main reasons. One is that

BDF has more strong combustion process at the high load and high speed because of oxygen contents in BDF. Another is that BDF has less amount of carbon.

Figure 6 shows the exhaust characteristics of smoke and NOx versus BDF content in diesel fuel. By increasing the BDF content in diesel fuel, smoke was gradually reduced, but NOx was slightly increased more than that of diesel fuel except at 1000 rpm. It was different results from the those of DI diesel engines with BDF that had generally great reduction in smoke and great increase in NOx.

However, at all the engine speed, smoke emissions with BDF were reduced and NOx emissions were increased. And at 1000 rpm, diesel engine with BDF exhausted the highest value of smoke and the lowest value of NOx emissions. This is because the lowest temperature in combustion chamber was occurred at 1000 rpm. From this results, it is found that a traditional trade-off relation of smoke and NOx with the variation of speed is revealed when BDF used in IDI diesel engine.

Figure 7 shows the variations of the exhaust emissions versus various engine loads at the engine speed 1500 rpm. With all fuels, as the engine load increases, it is observed that NOx emissions are increased up to middle load (50% load) and reversed at the limit of engine load 50% and it

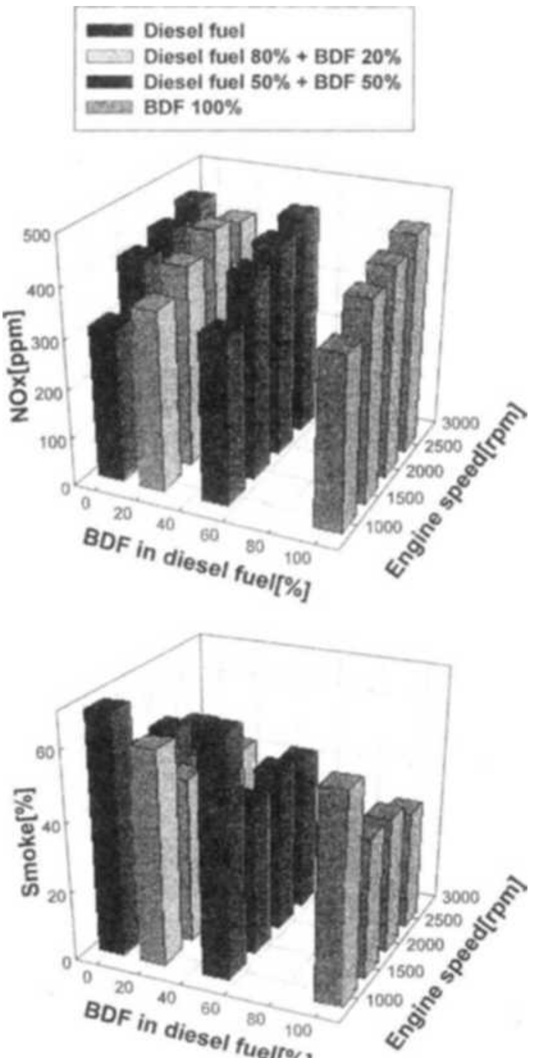

Fig. 6 Smoke and NOx versus BDF content in diesel fuel at engine load 100%

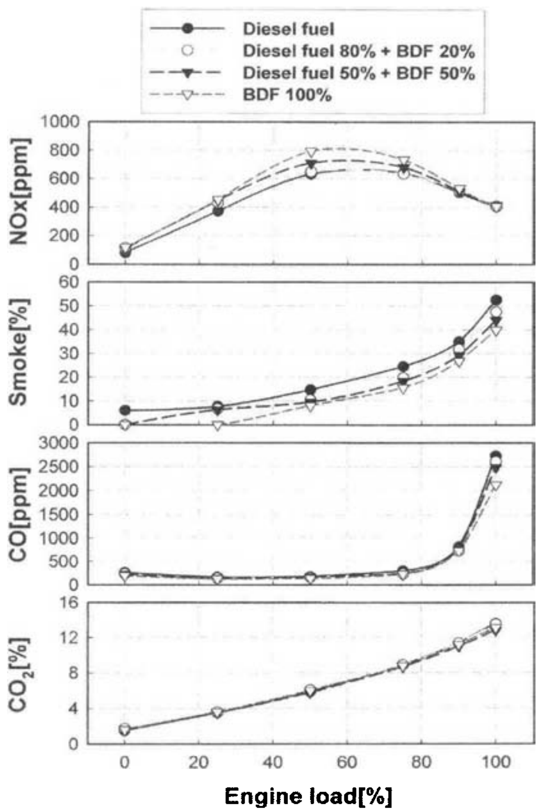

Fig. 7 Exhaust emissions and BSEC versus engine load at engine speed 1500 rpm

start decreasing. But NOx emissions was increased with increase of BDF content in diesel fuel and was remarkably increased at the middle load (50 % load).

Smoke density was increased with the engine load, but decreased with BDF content in diesel fuel. With all fuels, CO was remarkably more exhausted at the high load than at the low load, but CO emissions were also decreased with BDF content in diesel fuel. It was thought that this is caused by the increase of oxygen content in fuel, which was characterized by an increase in BDF in diesel fuel and which strongly accelerated a complete combustion even with the lower energy density of BDF. This was well supported by the temperature in combustion chamber as shown in Fig. 8. It was found that the temperature in combustion chamber with BDF is higher than with diesel fuel.

To investigate the effects of BDF content in diesel fuel on NOx and smoke according to the variations of engine load at 1500 rpm, the smoke and NOx emissions versus BDF in diesel fuel at various engine loads are considered as given in Fig. 9. It was found that smoke emissions with all fuels increased as engine load increased, and reached the peak at high load. It was also observed that smoke emissions were remarkably reduced with increase of BDF in diesel fuel. Especially, smoke emissions with neat BDF were reduced up to 24% at high load. Furthermore, it was also found from this results that BDF exerted more effects at high load than at low load.

However, the tendency of NOx emissions on the variation of engine load is different from that of smoke. As engine load increased, a special trend on NOx emissions was observed. NOx was remarkably exhausted at engine load 50% and 75%. And as the BDF content in diesel fuel increased, NOx concentrations was only increased at engine load 0%, 50% and 75%, and was similar to that with diesel fuel at engine load 90% and 100%.

Hence, when neat BDF was used in diesel engine without any modifications, BDF reduced the smoke density without increase of NOx at high load. This means that at high load, there are no trade-off relations between smoke and NOx with BDF. Therefore, it is useful to use BDF as an alternative fuel in diesel engine usually operated at high load.

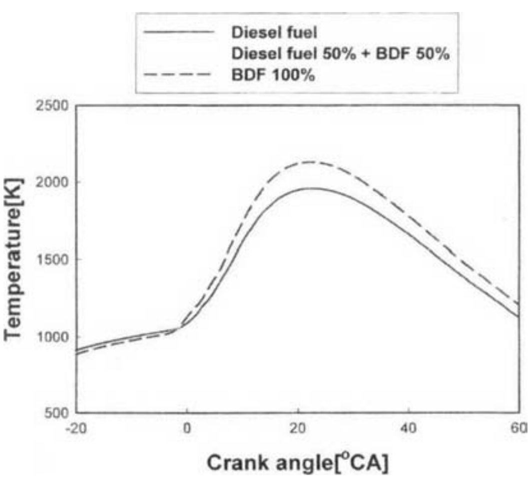

Fig. 8 Gas temperature in combustion chamber at engine speed 1500 rpm and engine load 50%

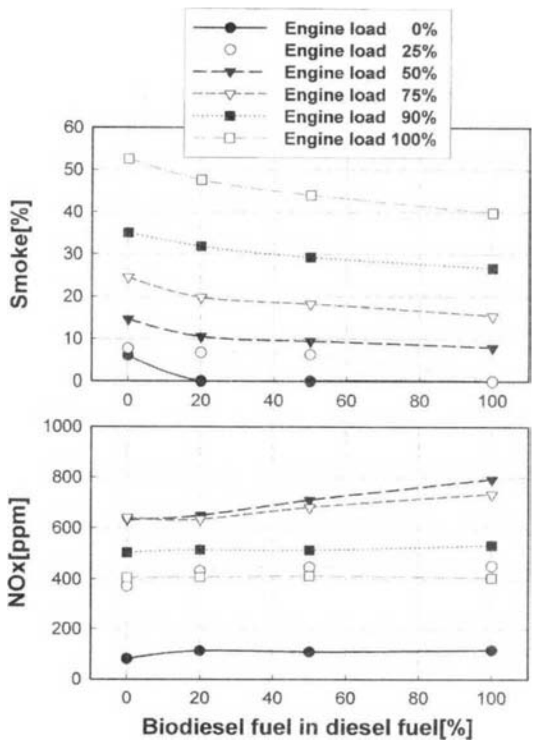

Fig. 9 Smoke and NOx versus BDF content in diesel fuel at engine speed 1500 rpm

Figure 10 shows the characteristics of smoke and NOx with BDF based on those with diesel fuel versus BDF in diesel fuel at various engine speeds and loads. NOx emissions with BDF were slightly increased at all the test conditions, but were especially increased more at low speed and low load region than at high speed and high load region. That is, at high speed and high load regions, the characteristics of NOx emissions with BDF were a little different from those with diesel fuel, but the difference of NOx level between BDF and diesel fuel at low speed and low load regions was great.

The smoke emissions with BDF was also decreased more than those with diesel fuel over whole test conditions, and the reduction rate of smoke emissions was increased as BDF content in diesel fuel increased. It was also found that the reductions rate of smoke represented remarkably at high load.

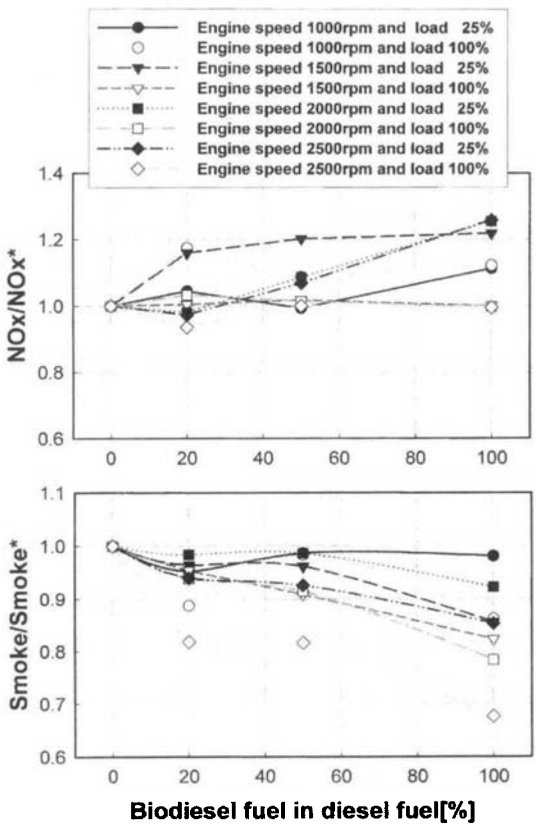

Fig. 10 Variation of smoke and NOx versus BDF content in diesel fuel at various engine speeds and loads

However, emissions trends of this IDI diesel engine fueled with BDF are different from those of DI diesel engines which are characterized by higher reduction of smoke and higher increase of NOx with BDF(Agarwal et al., 2001 ; Lue et al., 2001). From this results, it is found that the characteristics of smoke and NOx with BDF are increasingly affected with different types of combustion chamber and BDF is more effective for emission reduction in IDI diesel engine than in DI diesel engine.

According to the aforementioned studies, BDF was associated with lower CO, CO_2, and smoke emissions compared to the levels associated with diesel fuel.

This study also shows that the blends of BDF and diesel fuel have lower smoke concentrations than diesel fuel at all speeds and loads, but have higher NOx emissions than diesel fuel at low speed range (1000-1500 rpm) and low load ranges (0%, 50%, and 75%). Therefore, BDF was also very effective for reduction of smoke although NOx was increased more than that of diesel fuel at low speed and low load.

4. Conclusion

This study was carried out to investigate the combustion characteristics of BDF in IDI diesel engine.

Torque and power with BDF was similar to that with diesel fuel, but brake specific energy consumption with the blends of BDF in diesel fuel decreased as BDF content in diesel fuel increased.

BDF was also very effective for reducing smoke at high load, and smoke emissions were decreased with increase in BDF content in diesel fuel.

NOx emissions with BDF were increased at low and medium loads, but was similar to that with diesel fuel at high load. Also, increase rate of NOx emissions with BDF in IDI diesel engine under all conditions was lower than in DI diesel engine.

It was concluded that BDF could be utilized effectively as a renewable and low-pollution alternative fuel for IDI diesel engine.

Acknowledgment

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