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Investigation on the Performance and Emissions of a Biodiesel Engine Fueled with Soybean Biodiesel and Diesel fuel

Abdulkadir YAŞAR[1], Emre KOCA[2],
[1] Çukurova University, Ceyhan Eng. Fac., Dept. of Mechanical Engineering, PO Box 01950, Ceyhan, Adana, Turkey
[2] Çukurova University, Dept. of Automotive Engineering, PO Box 01330, Sarıçam, Adana, Turkey
ayasar@cu.edu.tr, ekoca@student.cu.edu.tr

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Abstract: Biodiesel, which is an alternative to diesel fuel, is made from renewable biological sources such as vegetable oils and animal fats. It is biodegradable and nontoxic has low emission profiles and so is environmentally beneficial. In this study, the effects of different injection angles, compression ratios and different piston bowls (Pan and Mexican Hat) on the engine performance and emissions were investigated by using two different fuels which are standard diesel (D2) and SME B40(Soybean Oil Methyl Ester). Diesel-RK software was used for the simulation of an internal combustion engine. Simulation results include efficiency and power parameters as piston engine power, torque and specific fuel consumption and also ecological parameters as specific CO_2 and NO_x emissions. The results showed that the best optimized combination was the Pan piston bowl shape with SME B40 fueled at 22:1 compression ratio and at 50^o injection angle.
Key words: Compression ratio, piston bowl, DIESEL-RK, soybean biodiesel

INTRODUCTION

Alternative fuels for diesel engines have been becoming increasingly important due to diminishing petroleum reserves and the growing environmental concerns have made renewable fuels an exceptionally attractive alternative as a fuel for the future (Snare et al., 2007; Saka and Kusdiana, 2001; Candeia et al., 2009; Benjumea et al., 2008; Randazzoa and Sodre, 2011).

Biodiesel is derived from a varied range of edible and inedible vegetable oil, animal fats, used frying oil and waste cooking oil. The edible oil in use at present is soyabean, sunflower, rapeseed and palm. The inedible oil used as feedstock for biodiesel production includes J. curcas, M. indica, F. elastica, A. indica, C. inophyllum jatropha, neem, P. pinnata, rubber seed, mahua, silk cotton tree, waste cooking, microalgae, etc.

Biodiesel offers many benefits (USDA, 2003):

- It is renewable.
- It is energy efficient.
- It displaces petroleum-derived diesel fuel.
- It can be used in most diesel equipment with no or only minor modifications.
- It can reduce global warming gas emissions.
- It can reduce tailpipe emissions, including air toxins.
- It is non-toxic, biodegradable, and suitable for sensitive environments.
- It is made from either agricultural or recycled resources.

Also, higher cetane number and containing 10% to 11% oxygen by weight make the biodiesel environmentally friendly. These properties decrease the carbon monoxide (CO), hydrocarbons (HC) and particular matter (PM) emissions in the exhaust gas compared to petroleum diesel fuel. Unfortunately, most emissions tests have shown a slight increase in oxides of nitrogen (NO_x) (Saka and Kusdiana, 2001). Majority of the studies on biodiesel emission characteristics have reported increase in NO_x emissions with biodiesel (Sun et al., 2010). Advancing the combustion phasing, higher combustion temperatures, oxygen content of biodiesel and differences in the chemical composition of diesel and biodiesel are thought to be the possible causes of these effects of biodiesel on NO_x emissions. Canakci

(2007) studied No. 2 Diesel fuel, a 20% soybean biodiesel +80% No. 2 Diesel blend (B20) and pure soybean biodiesel B100 in a compression ignition (CI) engine. They found that biodiesel provided a significant reduction in the PM, CO and THC. Conversely, they found that NOx emissions increased by 11.2%, which is in agreement with most of the literature. Ozener et al. (2014) showed that, relative to diesel, biodiesel had a 1–4% decrease in the torque and an approximately 2–9% increase in the brake specific fuel consumption (BSFC) due to the lower heating value (LHV) of the biodiesel.

Engine parameters have a significant impact on the engine emission and performance characteristics. Compression ratio is one of these characteristics. Engine performance and emission parameters vary for different compression ratios. Variable compression ratios make different effect on petroleum diesel and biodiesel. Observing the details of the engine parameters by simulations can save both money and time. A few experimental studies on the effects of different bowl geometries of diesel engine fueled with biodiesel have been carried out recently. The combustion and emission formation processes in diesel engines have also a close relationship with the piston bowl geometry which can strongly affect the air fuel mixing before the combustion starts (Dolak and Reitz, 2011; Jaichandar and Annamalai, 2012; Jaichandar et al., 2012; Park, 2012; Rakopoulos et al., 2010; Shi and Reitz, 2008).

The spray characteristics of the fuel greatly affect the emissions from diesel engines. Spray development plays an important role in improving the combustion and emission characteristics of a fuel because it directly affects the air–fuel mixture formation. The literature search identified relatively few studies dealing with the injection and spray characteristics of biodiesel fuels. Payri et al. (2009) found that the injection system is significantly affected by higher density and viscosity of biofuel, since both needle motion and flow characteristics are altered. Som et al. (2010) showed that differences in the injection and spray behavior of the two fuels may require changes in the piston bowl design or in the injection and/or ambient conditions in order to use biodiesel in an existing diesel engine. In this theoretical study, compression ratio effect of Biodiesel engine fueled with Soybean Biodiesel and diesel fuel on engine performance and emission characteristics were investigated using different injection angles, different piston bowl geometries (Mexican Hat and Pan) and different fuels (Diesel No.2 and SME B40).

The purpose of this study is to determine the performance and emission values that simulated in software for two different fuels, two different piston bowl geometry, three different compression ratios and injection of fuel in four different injection angles.

MATERIAL and METHOD

Material

Properties of fuels and specification of engine

The fuel properties illustrated in Table 1 (Kuleshov, 2014) were taken directly from the programs own database. Also, engine specifications were illustrated in Table 2.

Table 1. Properties of diesel fuel and SME B40

Property	Diesel No.2	Biofuel SME B40
Composition (Mass Fractions)		
C	0,87	0,8297
H	0,126	0,123
O	0,004	0,0473
Low Heating Value [MJ/kg]	42,5	39,89
Cetane Number	48	49,37
Density of Fuel at 49,85 °C [kg/m^3]	830	852
Surface Tension at 49,85 °C [N/m]	0,028	0,0343
Dynamic Viscosity at 49,85 °C [Pa s]	0,003	0,0036
Molecular Mass	190	232,5

Table 2. Engine Specifications

Engine Type	4-Stroke / Diesel Engine
Number of Cylinders	6 Cylinders
Cylinder Bore x Stroke	150 x 180 (mm mm)
Compression Ratio	18:1, 20:1, 22:1
Nominal Engine Speed	1500 rpm
Cooling System	Liquid Cooling
Injector Numbers / Angles	6 / (20°, 30°, 40°,50°)
Cylinder Head Design	4 Valves
Engine Design	In-line

Biodiesel Production

Biodiesel production can be made by using several techniques. The most common technique is transesterification. In this technique, chemical reaction of vegetable oils or animal fat with alcohol in the presence of a catalyst forms esters and by-product glycerol. This ester is called biodiesel (Fangrui and Hanna, 1999). SME (Soybean Methyl Ester) is also a biodiesel which is a product of soybean oil. SME B40 biodiesel, which means diesel fuel blended with 40% biodiesel, was used in this theoretical study. Figure 1 shows a schematic diagram of the processes involved in biodiesel production.

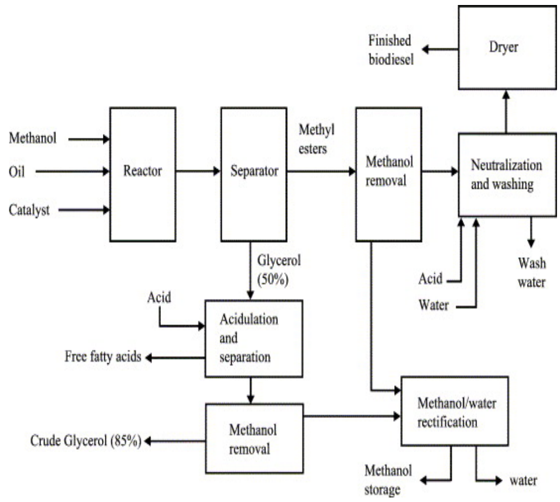

Figure 1. Process flow schematic for Biodiesel production (Gerpen, 2005)

Method

Diesel-RK

Simulations are carried out with DIESEL-RK software in this study. Diesel-RK is full cycle thermodynamic engine simulation software. Development of the DIESEL-RK software core has been started in 1981-82 in the department of Internal Combustion Engines (Piston Engines), Bauman Moscow State Technical University. And furthermore, this program developed itself until nowadays. The program can be used for modeling the diesel engine. After the simulation engine performance results like power, torque, fuel consumption and also ecological result like CO_2 and No_x emissions can be seen on the program. Additionally, program has a capability to optimize the piston bowl shape and fuel injection system parameters (sprays directions, diameter and number of nozzles) as well as to develop multiple injection strategy and the Common Rail controlling algorithm over the whole operating range. The DIESEL-RK combustion model supports the library of different fuels including different blends of biofuels with diesel oil.

Physical properties of biofuel blends are used in the spray evolution simulations and in modeling the evaporation and combustion processes (http://www.diesel-rk.bmstu.ru/Eng/index.php?page=Main). The DIESEL-RK software was used for computing the compression ratio effect on performance and emission characteristics of an internal combustion engine in this study. Simulations were executed using three compression ratios (18:1, 20:1, 22:1) with two different fuels (Diesel No.2 and SME B40) at four injector angles (20°, 30°, 40°, 50°). Simulations were also carried out considering two piston bowl shapes called as Pan and Mexican Hat. Schematic of this piston bowls can be seen in Figure 2.

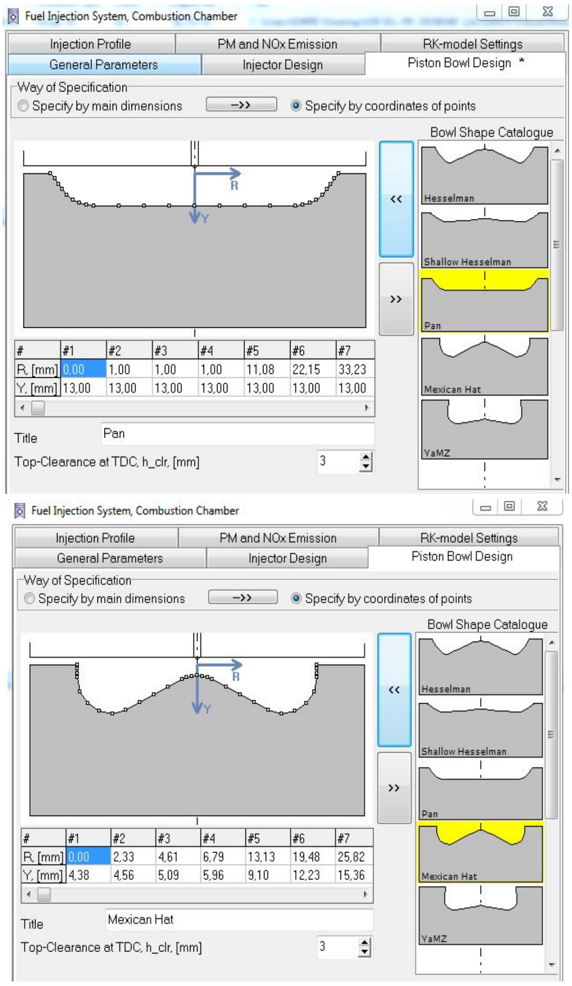

Figure 2. Diesel-RK software piston bowl design selection

RESULTS and DISCUSSION

Simulation results include engine performance parameters which are engine power, brake torque and specific fuel consumption also results include ecological parameters which are specific CO_2 and NO_x emissions. These parameters calculated in the presence of many various parameters which are two fuels (Diesel No.2 and SME B40), two piston bowl shapes (Pan and Mexican Hat), three compression ratios (18:1, 20:1, 22:1) and four injector angles (20°,30°,40°,50°). Results compared in graphics in terms of compression ratios and at 50° injector angle because it has the most efficient values when consider the high power value and low fuel consumption.

Injector angle versus engine power are simulated for Pan and Mexican Hat piston bowl shape and for two fuels Diesel No.2 and SME B40 in Figure 3. As it can be seen on the Figure 3, maximum power value was obtained 143,75 kW having 50° injector angle for diesel Pan piston bowl shape. These results are in agreement with the study carried out by Ozener et al. (2014).

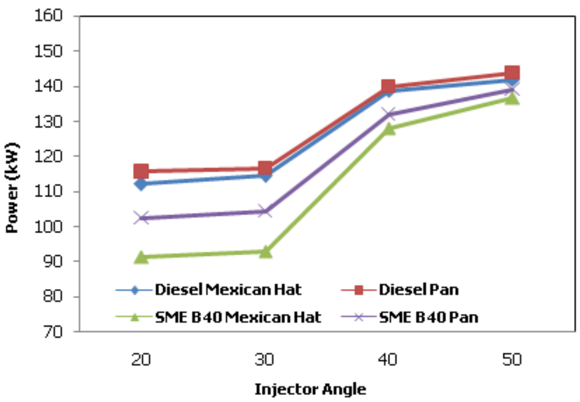

Figure 3. Variation of Injector Angle versus Engine Power

Injector angle versus fuel consumption are given in Figure 4 for Pan and Mexican Hat piston bowl shape and for two fuels Diesel No.2 and SME B40. As can be seen from Figure 4, the minimum fuel consumption value is obtained as 0,26091 kg/kWh at 50° injector angle for Diesel Mexican Hat. This situation is valid for all experiments. Because of this reason, all simulation result comparisons are made with respect to 50° injector angle.

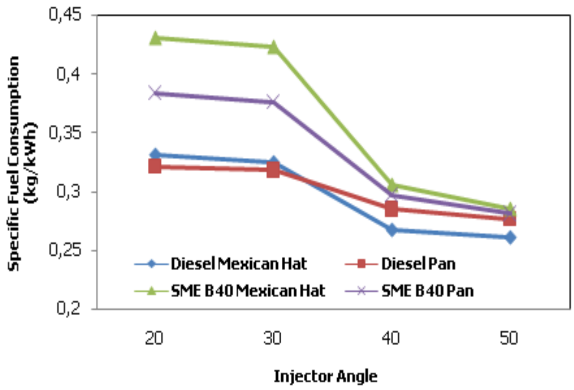

Figure 4. Variation of Injector Angle versus Fuel Consumption

Variation of compression ratio versus specific fuel consumption is shown for Pan and Mexican Hat piston bowl shape and for two fuels Diesel No.2 and SME B40 in Figure 5.

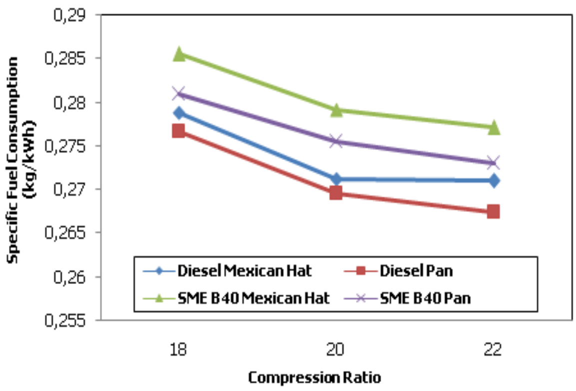

Figure 5. Variation of Compression Ratio versus Specific Fuel Consumption

Fuel consumption is lower when the compression ratio is higher for diesel Pan Piston bowl shape comparing with the Mexican Hat piston bowl shape.

Figure 6 shows the variation of compression ratio versus CO_2 emission for Pan and Mexican Hat piston bowl shape and for two fuels Diesel No.2 and SME B40.

Increment of compression ratios result in decreasing specific CO_2 emission in both piston bowl shape, especially for SME B40 Pan piston bowl shape. The most environmentally friendly value is 839,1 g/kWh for SME B40 fueled Pan piston bowl shape with a compression ratio of 22 and the highest CO_2 emission value is 895,7 g/kWh for diesel fueled Mexican Hat piston bowl type with a compression ratio of 18. The researchers showed that increased soybean biodiesel content in diesel oil increases CO_2 emission (Randazzoa and Sodre, 2011).

The variation of compression ratio versus NO_x is given in Figure 7.

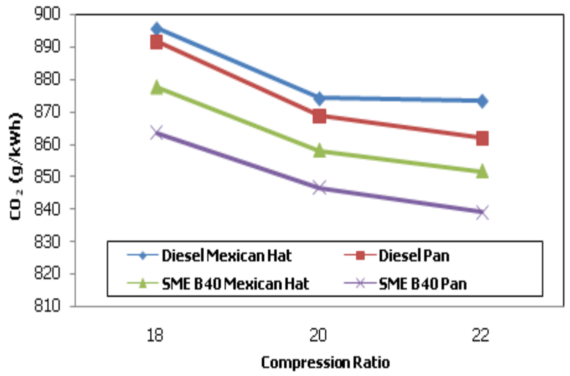

Figure 6. Variation of Compression Ratio versus CO_2 Emission

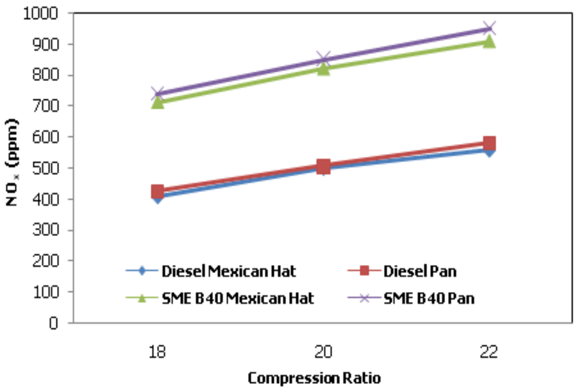

Figure 7. Variation of Compression Ratio versus NO_x

Compression ratio increase results in increasing NO_x for all conditions. The minimum NO_x value is observed in diesel piston shapes fueled with a compression ratio of 18. The highest NO_x value is obtained from SME B40 fueled Pan piston bowl shape with a compression ratio of 22 as 950,43 ppm. As it can be seen on the Figure 7, changing the fuel from diesel to biodiesel without changing the piston bowl shape increase the NO_x value. These results are good agreement with (Saka and Kusdiana, 2011).

CONCLUSIONS

The aim of this study was to determine the compression ratio effect on performance and emission of a diesel engine using biodiesel and diesel fuel using computer program Diesel-RK.

The following conclusions can be drawn from the study;

- For best optimized injector angle 50°, increasing the compression ratio increased the power.
- When the compression ratio is higher, it is observed that the fuel consumption is lower for diesel Pan Piston bowl shape in comparison with the Mexican Hat piston bowl shape.
- Increment of compression ratios caused decreasing specific CO_2 emission in both piston bowl shape, especially for SME B40 Pan Piston bowl shape.
- The highest NO_x value is obtained from SME B40 fueled Pan Piston bowl shape with at 22:1 compression ratio because of higher combustion temperatures and oxygen content of biodiesel.

As a result, it was shown that the best optimized combination was the Pan Piston bowl shape with SME B40 fueled at a compression ratio of 22 and 50° injection angle due to the air pattern inside the cylinder.

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REFERENCES

Benjumea P, Agudelo J, Agudelo A, 2008. Basic properties of palm oil biodiesel–diesel
Blends, Fuel. 87:2069–75.

Canakcı M., 2007. Combustion characteristics of a turbocharged DI compression ignition engine fueled with petroleum diesel fuels and biodiesel, Bioresour Technol, 98: 1167–1175.

Candeia RA, Silva MCD, Carvalho Filho JR, Brasilino MGA, Bicudo TC, Santos IMG, Souza A.G., 2009. Influence of soybean biodiesel content on basic properties of biodiesel–diesel blends, Fuel, 88: 738-743.

Dolak J, Reitz R., 2011. Optimization of the piston geometry of a diesel engine using a two-spray-angle nozzle, Proc Inst Mech Eng Pt D J Automobile Eng, 225: 406–421.

Fangrui M., Hanna MA., 1999. Biodisel production: a review, Bioresource Technology, 70: 1-15.

Gerpen JV., 2005. Biodiesel processing and production, Fuel Processing Technology, 86: 1097 – 1107.

http://www.diesel-rk.bmstu.ru/Eng/index.php?page=Main (Access.30.06.2014).

Jaichandar S, Annamalai K., 2012. Effects of open combustion chamber geometries on the performance of pongamia biodiesel in a DI diesel engine, Fuel, 98: 272–279.

Jaichandar S, Senthil Kumar P, Annamalai K., 2012. Combined effect of injection timing and combustion chamber geometry on the performance of a biodiesel fueled diesel engine, Energy, 47:388–94.

Kuleshov A., 2014. Diesel-RK version (4.1.3.143) [software]. Available from : http://www.diesel-rk.bmstu.ru/Eng/index.php?page=Main.

Ozener O, Yüksek L, Ergenç AT, Özkan M., 2014. Effects of soybean biodiesel on a DI diesel engine performance, emission and combustion characteristics, Fuel, 115: 875–883.

Park S., 2012. Optimization of combustion chamber geometry and engine operating conditions for compression ignition engines fueled with dimethyl ether, Fuel, 97: 61–71.

Payri R, Desantes JM, Salvador FJ, Manin J., 2009. Influence on diesel injection characteristics and behavior using biodiesel fuels, SAE paper, 2009-01-0851.

Rakopoulos CD, Kosmadakis GM, Pariotis EG., 2010. Investigation of piston bowl geometry and speed effects in a motored HSDI diesel engine using a CFD against a quasi-dimensional model, Energy Convers Manage, 51: 470–484.

Randazzoa ML, Sodre JR., 2011. Exhaust emissions from a diesel powered vehicle fuelled by soybean biodiesel blends (B3–B20) with ethanol as an additive (B20E2–B20E5), Fuel, 90: 98-103.

Saka S., Kusdiana D., 2001. Biodiesel fuel from rapeseed oil as prepared in supercritical methanol, 80: 225-231.

Shi Y, Reitz RD., 2008, Optimization study of the effects of bowl geometry, spray targeting, and swirl ratio for a heavy-duty diesel engine operated at low and high load, Int J Engine Res, 9: 325–346.

Snare M, Kubickova I, Maki-Arvela P, Eranen K, Warna J, Murzin DY., 2007. Production of diesel fuel from renewable feeds: Kinetics of ethyl stearate decarboxylation. Chem Eng J., 134:29–34.

Som S, Longman DE, Ramírez AI, Aggarwal SK., 2010. A comparison of injector flow and spray characteristics of biodiesel with petrodiesel, Fuel, 89: 4014–4024.

Sun J, Caton JA, Jacobs TJ., 2010. Oxides of nitrogen emissions from biodiesel-fuelled diesel engines, Prog Energy Combust Sci, 36: 677–85.

USDA (United States Department of Agriculture). Production estimates and crop assessment division of foreign agricultural service. EU: Biodiesel industry expanding use of oilseeds, 2003. http://www.biodiesel.org/resources/reportsdatabase/reports/gen/20030920_gen330.pdf.