2014 3rd International Conference on Geological and Environmental Sciences
IPCBEE vol. 73 (2014) © (2014) IACSIT Press, Singapore
DOI: 10.7763/IPCBEE. 2014. V73. 3

Piston Bowl Effect on Biodiesel NO_x Emissions

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Abstract. Recently, the usage of biodiesel as an alternative energy source instead of fossil-based fuels becomes very popular because biodiesel is totally renewable and has more favorable combustion emission profiles except NO_x emissions. Scientists are focusing on decreasing NO_x emissions in compression ignition engines. In this paper, effects of different bowl geometries on biodiesel NO_x emissions were theoretically studied in order to reach minimum NO_x levels. Simulations were carried out with diesel No.2, soybean and rapeseed biodiesel fuels using the simulation software Diesel-rk. Seven different piston bowl type were used in the tests and datas were compared. Results showed that Hasselman, Pan and Mexican Hat bowl geometries concluded less NO_x emissions then the other four. Air swirl velocities also showed that the bowl geometries were directly influence the NO_x emissions by effecting in-cylinder combustion.

Keywords: Combustion, piston bowl, DIESEL-RK, biodiesel, emissions.

1. Introduction

Due to the increase in the petroleum prices and the environmental concerns about exhaust emissions, biodiesel is becoming a famous subject for alternative fuel researchers. Biodiesel is typically produced through the reaction of a vegetable oil or animal fat with methanol or ethanol in the presence of a catalyst to yield methyl or ethyl esters (biodiesel) and glycerin. This reaction is called “transesterification”. The advantages of biodiesel are renewability, higher combustion efficiency, lower sulphur and aromatic content, higher flash point and higher biodegradability, and higher oxygen content [1]. Canakci [2] studied B20 (%20 soybean + %80 Disel No.2) and pure soybean biodiesel B100 in a compression ignition (CI) engine. They concluded that while biodiesel provided a significant reduction in the PM, CO and THC, NO_x emissions were found increased by 11.2%, which is in agreement with most of the literature. Ozener *et al.* [3] studied the effects of soybean biodiesel on a DI diesel engine performance, emission and combustion characteristics. They concluded that the nitric oxides (NO_x) emissions were found increased within the range of 6.95–17.62%. Lin *et al.* [4] studied different types of biodiesels (including the soybean and rapeseed methyl esters) in a CI engine. In the tests using soybean and rapeseed biodiesel, NO_x emissions were increased. Rounce *et al.* [5] tested rapeseed biodiesel for their combustion and emissions properties. They found increased NO_x emissions same as the others. Gill *et al.* [6] studied an oxygenated component (diglyme) and rapeseed biodiesel blend compared with a conventional fuel. They found that NOx emissions increased by the resulting higher heat release rate due to oxygen availability of RME. Gumus *et al.* [7] studied, from the perspective of emissions and engine performance, the effect of injection pressure when a direct injection (DI) diesel engine was fuelled with biodiesel and blends. They found that, the NO_x, CO_2 and O_2 emissions was increased while the smoke opacity, CO, THC emissions was decreased due to improved combustion compared to conventional diesel fuel (CDF). In a another work, McCarthy *et al.* [8] studied the performance and emissions of an internal combustion engine that was fuelled with 80% tallow (beef, pork and sheep) and 20% canola oil methyl ester. Similar to most of the literature they found the NO_x emissions increased. Many researches are available in the literature about biodiesel emission studies [9]-[12], [15].

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In this study, effect of different piston bowls geometries (seven bowl shapes) on the engine NO_x emissions were investigated by using two different alternative fuels which are Rapeseed Biodiesel and Soybean Biodiesel. Simulations were carried out with DIESEL-RK [13] software that calculates the emissions of NO_x levels.

2. Material and Method

2.1. Properties of Various Fuel and Engine Parameters

The NO_x emission values were investigated for seven different piston bowls using two different biodiesel fuels. Also Diesel no.2 was simulated in order to compare alternative fuels with usual diesel fuel. Figure 1 and Figure 2 shows the fuel properties of the alternative fuels which are default in Diesel RK simulation software. Four stroke four cylinder compression ignition engine model which has a compression ratio of 18:1, bore/stroke 150/180 mm was used during the simulations. Tests were carried out at nominal engine speed 1500 rpm. Fuel injection angle is set to 75 ^{o}.

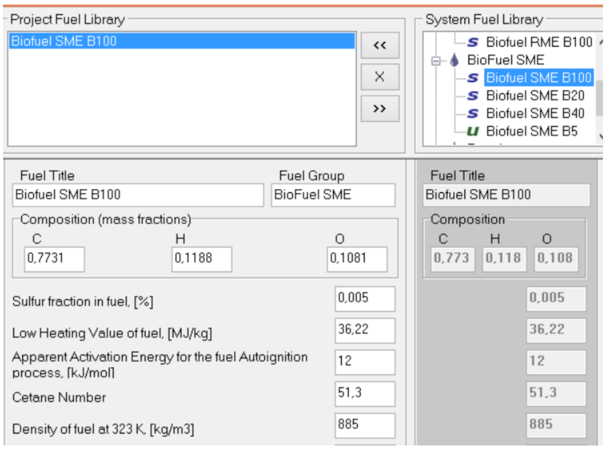


Fig. 1: Soybean Biodiesel General Specifications

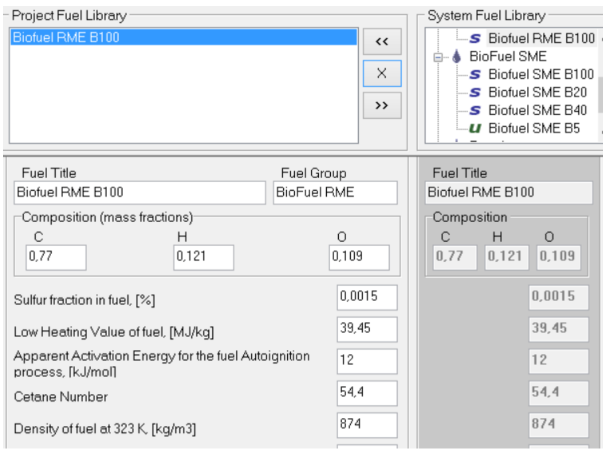


Fig. 2: Rapeseed Biodiesel General Specifications

2.2. Biodiesel Production

The most commonly used method of biodiesel production is the transesterification (alcoholysis) of oil (triglycerides) with methanol in the presence of a catalyst, which gives biodiesel and glycerol (by-product). The general reaction chemistry of biodiesel production is illustrated in Figure 3.

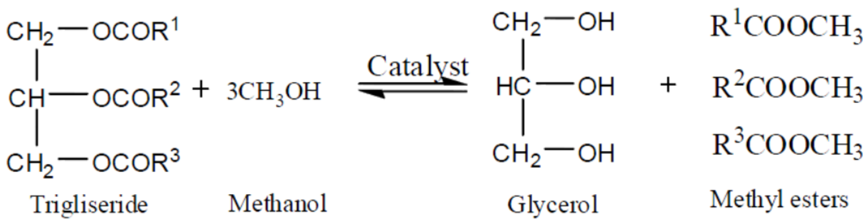


Fig. 3: Transesterification reaction

2.3. Diesel RK

Diesel-RK is full cycle thermodynamic engine simulation software. The program can be used for engine performances prediction such as specific fuel consumption, engine power, torque values, and also combustion and emission analysis. The RK-model has a capability to optimize the piston bowl geometry as well as air swirl patterns in order to develop combustion strategy [14]. 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. In this simulation study, Diesel-RK was used to calculate the NO_x emission values for seven different piston bowls fuelled with Diesel 2, Soybean Biodiesel and Rapeseed Biodiesel The schematic appearance of piston bowls used in simulation program is given in Figure 4.

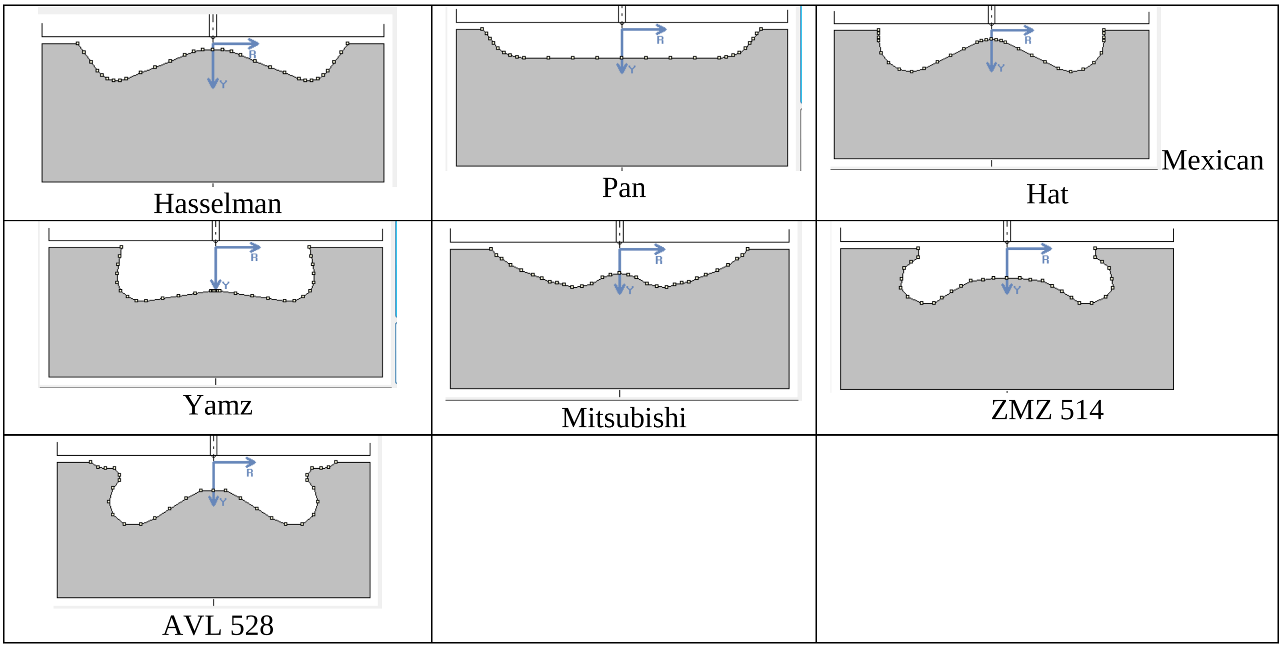


Fig. 4: Piston bowl geometries

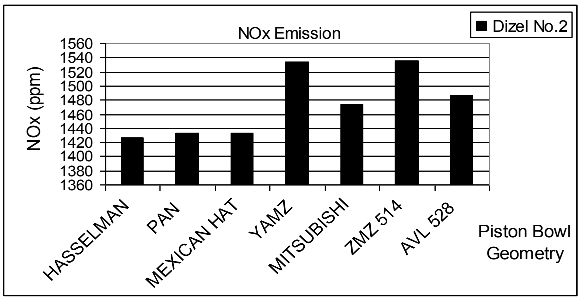
The shape of the piston bowl controls the movement of air and fuel as the piston comes up for the compression stroke. The air and fuel swirl into a vortex inside the piston bowl before combustion takes place, creating a homogenous and better mixture.

2.4. NO_x

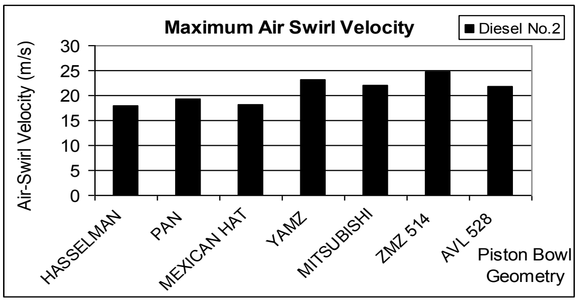
NO_x is a generic term for mono-nitrogen oxides NO and NO_2 (nitric oxide and nitrogen dioxide). They are produced from the reaction of nitrogen and oxygen gases in the air during combustion, especially at high temperatures. In areas of high motor vehicle traffic, such as in large cities, the amount of nitrogen oxides emitted into the atmosphere as air pollution can be significant. NO_x gases are formed whenever combustion occurs in the presence of nitrogen – as in an air-breathing engine; they also are produced naturally by lightning. In atmospheric chemistry, the term means the total concentration of NO and NO_2. NO_x gases react to form smog and acid rain as well as being central to the formation of tropospheric ozone. Biodiesel has more O_2 concentration than diesel fuel. Because of extra O_2, in cylinder temperature can easily be raise and the NO_x formation occurs. Complete combustion is generally resulted with high NO_x values.

3. Results and Discussion

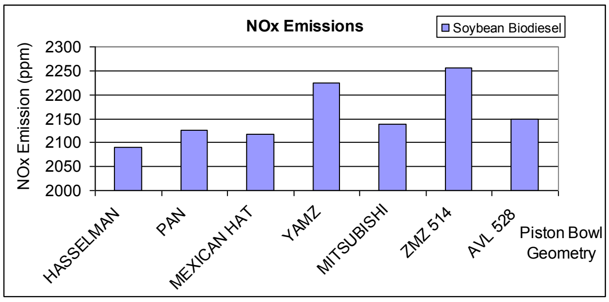
Figure 5 represents the result of NO_x emissions and Maximum Air-Swirl Velocities of Diesel fuel, Soybean biodiesel and Rapeseed biodiesel respectively. Figure 5.a, 5.c and 5.e shows the NO_x emissions of test fuels. Similar to the literature, NO_x emissions were found higher than diesel NO_x emissions. When it is examined according to bowl types, Yamz and ZMZ-514 type piston bowls have more NO_x emission than the others. This can be explained by a better air–fuel mixing due to a stronger spray penetration, oxygen content and improved combustion. Maximum air swirl velocities are shown in Figure 5.b, 5.d and 5.f. Air swirl velocity results also proved that Yamz and ZMZ-514 type piston geometries has a superior air-swirl characteristics than the others have. From the results, it can be suggested that straight type of piston bowls are preferable for the NO_x emissions if biodiesel fuels run in the compression ignition engines.



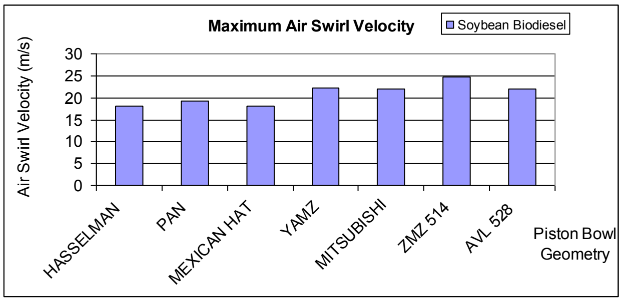
a) Diesel NO_x emissions



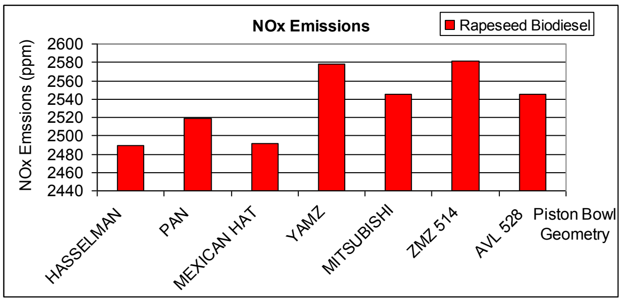
b) Diesel Air-Swirl Velocity



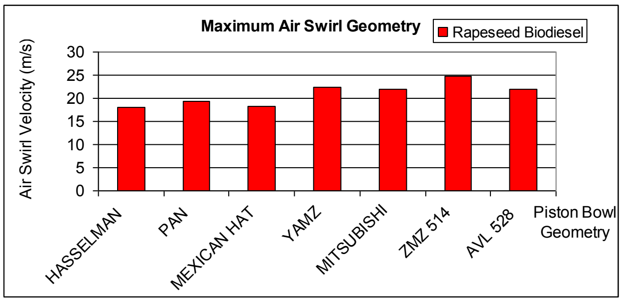
c) Soybean Biodiesel NO_x emissions



d) Soybean Biodiesel Air-Swirl Velocity



e) Soybean Biodiesel NO_x emissions



f) Soybean Biodiesel Air-Swirl Velocity

Fig. 5: NO_x and Maximum Air Swirl Velocity values versus Piston Geometry

4. Conclusions

The main aim of this study was to determine the effect of piston bowl geometry on the NO_x emission of a compression ignition engine fuelled with soybean biodiesel, rapeseed biodiesel and standard diesel fuel by using Diesel RK software simulator. It was found that the air and fuel swirl into a vortex inside the piston bowl before combustion creating a homogenous and better mixture in the Yamz and ZMZ-514 type piston bowls. Straight type of piston geometries such as Pan, Mitsubishi were found more available for reduced NO_x emissions in diesel engines. Diesel RK simulation software also proved that NO_x formations are directly related to air swirl velocities according to the movement of air and fuel in cylinder.

5. Acknowledgements

The authors wish to acknowledge the Cukurova University Scientific Research Projects Coordination for the financing this study in the field of engine emissions with different biodiesel fuels (Project No: MMF2013BAP8)

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