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# The Simulation of Performance and Emissions from Rapeseed and Soybean Methyl Ester in Different Injection Pressures

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## Abstract

Biodiesel is one of the promising alternative fuels of the future that is environmentally friendly. Biodiesel can be produced from rapeseed, soybeans, coconut oil, jatropha and many others. It is important to analyze the effect of comparison between diesel fuel and biodiesel to study the effect of combustion and emissions of these fuels. In this research, the simulation of combustion and emission is done with Diesel RK. Three fuels are studied; diesel fuel, rapeseed methyl ester (RME) and soybean methyl ester (SME). The engine was simulated at 2000 rpm and the injection pressures were 944, 1191, 1297, 1420 and 1729 bar respectively. The results show that the specific fuel consumption (SFC), particulate matter (PM), and $CO_2$ emissions of diesel fuel are relatively the same for different injection pressures. However, the SFC, PM and $CO_2$ emissions for rapeseed methyl ester and soybean methyl ester decrease with increasing injection pressure. These results can prove that higher injection pressures in diesel engines can improve combustion and reduce emissions of biodiesel fuel as compared to diesel fuel.

Keywords: Diesel RK; Emissions; Diesel Fuel; Injection Pressures; Rapeseed Methyl Ester; Soybean methyl ester.

# The Simulation of Performance and Emissions from Rapeseed and Soybean Methyl Ester in Different Injection Pressures

## 1. Introduction

The demand for fossil fuels has been increasing for the past decades. However, the supply of fossil fuels is decreasing every year. This leads the researchers to find alternative fuels to replace the fossil fuels. Biodiesel is one of the alternative fuels that can replace fossil fuels. The use of biodiesel has been researched for many decades and it has been proved that it can be used in diesel engine without some modifications. Biodiesel is produced through a trans-esterification process using alcohol and catalyst. Biodiesel can be produced from jatropha [1], rapeseed [2], carbera mangas [3], coconut oil [4] and many others. Biodiesel can be one of the alternative fuels that can reduce some emissions such as HC, SOx and some particulate matter (PM) [5]. However, the high viscosity and density of biodiesel can cause some difficulties in fuel atomization and injection. Moreover, the sauter mean diameter (SMD) in biodiesels is affected at high and low injection pressures. The SMD of biodiesel is higher than that of diesel fuel and is affected by evaporation in the chamber [6]. However, these problems can be minimized by blending with diesel fuel and using some additives in the fuels.

The discussion of biodiesel production has been going on for almost 50 years [7]. Ramadas, et al. [8] investigated that the fuel properties in biodiesels can affect the combustion in the diesel engines. Bhikuning, et al. [9] studied that viscosity, density and surface tension in biodiesel can have effects on spray penetration, spray angle and sauter mean diameter in a constant volume chamber. Shroder, et al. [10] analyzed the emissions of soybean methyl ester compared to diesel fuel. The NOx emissions from soybean are higher than diesel fuel. However, $CO_2$ emission can be reduced due to oxygen content in biodiesel. Al_Dawody and Bhatti [11] investigated the combustion and emissions of soybean methyl ester (SME) experimentally and computationally with diesel RK. The results show that SME can reduce smoke opacity up to 48.23% and has higher brake specific fuel consumption (BSFC) than diesel fuel. The simulation results show good agreement between with two fuels. Qi, et al. [12] investigated the atomization and combustion of SME and rapeseed methyl ester (RME). The results show that the liquid length and droplet size are higher for biodiesel than diesel fuel.

This happened due to the surface tension and lack of evaporation due to lower vapor pressure. This can be influenced to slow down the evaporation rate in the atomization process. Aldhaidhaw, et al. [13] investigated the effect of a 20% blend of rapeseed methyl ester (B20) and diesel fuel. The results show that the brake specific fuel consumption of B20 was higher than that of diesel fuel. However, carbon monoxide and smoke emissions were lower than diesel fuel. Nevertheless, the NOx emissions were higher than diesel fuel.

In this study, the combustion and emissions of biodiesel fuels are investigated by using Diesel RK simulation. The biodiesel fuels are produced from pure rapeseed methyl ester (RME) and soybean methyl ester (SME). The objective of this study is to understand the specific fuel consumption (SFC), sauter mean diameter (SMD) and brake mean effective pressure (BMEP) as well as some emissions of RME and SME in Diesel RK simulation and compare with diesel fuel (DF).

## 2. Method

### 2.1. Diesel RK Software Model

Diesel RK is a simulation software for the analysis of the thermodynamic full cycle engine. The advantage of using diesel RK is that it can calculate thermodynamic diesels running on diesel fuel, methanol, and biodiesel. In addition, it can analyze thermodynamics in SI engines, including pre-chamber fueled with natural gas, pipeline gas, wood gas, etc [14]. The RK model is capable of analyzing the piston shape and fuel injection system. Moreover, it can develop common rail control together with EGR (Exhaust Gas Recirculation) in the system [15].

### 2.2. Simulation Method

In order to simulate the diesel RK, general parameters must be input for engine specification. Figure 1 shows the diesel RK proceeds, first, a new project must be created by entering the engine specification. Then, the project has to be saved. After that, the operating regimes must be saved, in this section, setting the RPM in the engine, setting the ambient temperature condition, etc. Then, check the correctness of the nozzle configuration and the shape of the combustion chamber. The combustion chamber must be set and the actual piston bowl configuration entered for the engine under study. After that, the correctness of the injection characteristics must be checked. Figure 2 shows the spray visualization at 2000 rpm and an injection pressure (Pinj) of 944 bar. Then, calculate the simulation and analyze the parameters.

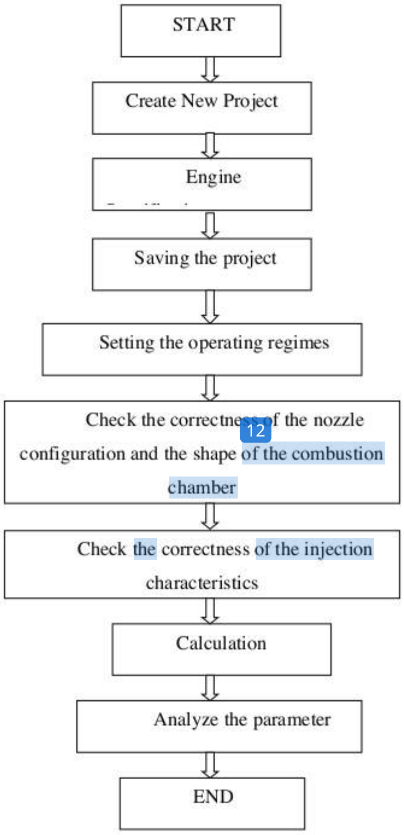

Figure 1. Diesel RK Simulation

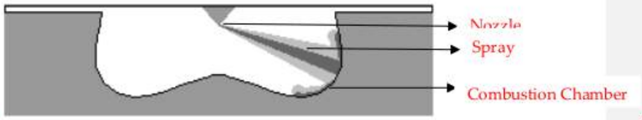

Figure 2. Spray visualization in diesel engine at 2000 rpm, Pinj 944 bar

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### 2.3. Material

Four fuels were tested in this study; diesel fuel (DF), 100% rapeseed methyl ester (RME) and 100% soybean methyl ester (SME). The fuel properties can be seen in Table 1. Density, viscosity, cetane number and surface tension of SME and RME are higher than those of diesel fuel. However, diesel fuel has a higher LHV than SME and RME. Oxygen content in diesel fuel is not present, however, RME and SME have some oxygen content which would be beneficial for biodiesel to reduce emissions.

Table 1. Fuel properties from all fuels [15, 16]

| Properties | Units | Diesel Fuel (DF) | Soybean Methyl Ester (SME) | Rapeseed Methyl Ester (RME) |
|---|---|---|---|---|
| LHV | MJ/kg | 42.5 | 36.22 | 39.45 |
| Density (323 K) | kg/cm$^3$ | 830 | 885 | 874 |
| Viscosity (323 K) | PaS | 0.00463 | 0.00692 | 0.00692 |
| Cetane Number | - | 48 | 51.3 | 54.4 |
| Surface Tension (323 K) | N/m | 0.028 | 0.0433 | 0.0315 |
| Carbon Content | % | 0.87 | 0.7731 | 0.77 |
| Oxygen Content | % | 0 | 0.1081 | 0.109 |
| Hydrogen Content | % | 0.126 | 0.1188 | 0.121 |

### 2.4 Engine Specification

In this study, the simulations were performed using the engine specification in Table 2. The engine was running at 2000 rpm and the injection pressures (Pinj) were simulated at 944, 1191, 1297, 1420 and 1729 bar and the injection nozzle bore was 0.123 mm.

Table 2. Engine Specification [5]

| Type | Supercharged direct-injection single cylinder 4 stroke |
|---|---|
| Bore x Stroke [mm] | 85 x 96.9 |
| Displacement [cm$^3$] | 550 |
| Compression ratio | 16.3 |
| Fuel injection system | Common rail |
| Number of holes | 7 |
| Injection nozzle hole [mm] | 0.123 |
| Injection pressure [bar] | 944, 1191, 1297, 1420, 1729 |
| Engine speed [rpm] | 2000 |

## 3. Result and Discussion

### 3.1. Sauter Mean Diameter (SMD)

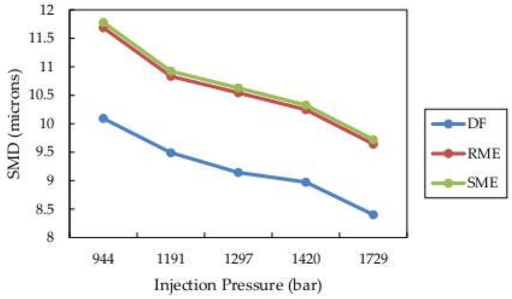

Figure 3. Sauter mean diameter (SMD) from all fuels

The Sauter Mean Diameter (SMD) is defined as the diameter of a sphere having the same volume and surface area ratio of small particles [17]. The SMD can be specified for spray atomization characteristics in the chamber. As can be seen in Figure 3 that the SMD for DF, RME and SME decreased with increasing injection pressure. These results are in agreement with those of Qi et al. [18] and Mahanggi et al. [19]. For comparison, at 944 bar, the SMD of RME and SME are 10,922 and 11,78 microns, respectively. At 1191 bar, the SMD of RME and SME decrease to 10,833 and 10,922 microns, respectively. And at 1729 bar, the SMD of RME and SME decreased to 9,6428 and 9,7214 microns. A small size of SMD in fuel can make evaporation in the combustion chamber easier than a large size. This is because a small size of SMD can vaporize more easily than a large size [9]. Higher SMD for RME and SME than DF due to higher viscosity, surface tension and density in biodiesel than DF. Higher viscosity may make it difficult to atomize the fuel. Therefore, spray atomization can be improved by in high injection pressures due to the small size of the fuels.

## 3.2. Engine Performance

### 3.2.1. Specific Fuel Consumption (SFC)

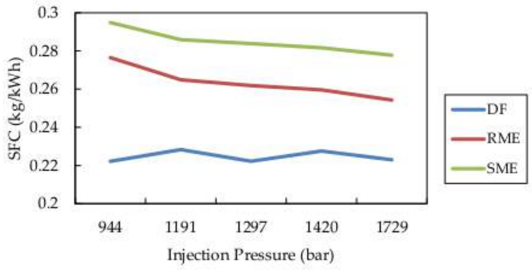

Figure 4. Specific fuel consumption (SFC) from all fuels

The specific fuel consumption (SFC) of all fuels can be seen in Figure 4. It can be shown that the specific fuel consumption for diesel fuel in does not show too many differences at injection pressures. These results are in agreement with those of Bakar et al. [20]. This is due to the fact that the density and viscosity of diesel fuel is lower than that of biodiesel fuel. However, the specific fuel consumption for DF may decrease to 0,23% when the injection pressure ranges from 1420 bar to 1729 bar. This is because the higher Injection pressures can make the particles of the fuel smaller and facilitate evaporation. Moreover, the specific fuel consumption for RME and SME decreased with increasing injection pressure. These results are consistent with those of other studies from Mahanggi e al. [19] and Kim et al. [21]. At low injection pressure (944 bar), the specific fuel consumption of SME and RME are higher than DF. This is due to the fact that viscosity and density of SME and RME are higher than those of DF. Higher viscosity and density can cause the particles of the fuels to be larger and difficult to evaporate. This can cause the engine to have low power and higher specific fuel consumption. At an injection pressure of 1729 bar, the specific fuel consumption for RME and SME decreased by up to 8.03% and 5.78%, respectively, compared to an injection pressure of 944 bar. This is due to the fact that as the injection pressure increases, the particles of the fuels are smaller and can cause better the combustion due to good atomization in the engine.

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3.2.2. Brake Mean Effective Pressure

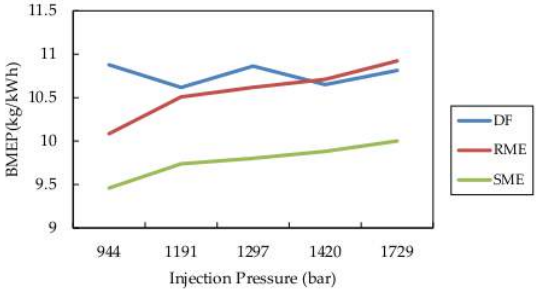

Figure 5. Brake mean effective pressure from all fuels

Figure 5 shows the brake mean effective pressure (BMEP) of all fuels. It can be seen that the BMEP of DF remained constant with increasing injection pressure. Nevertheless, the BMEP for RME and SME increased with increasing injection pressure. These results are in agreement with those of Kim et al. [21] and Bakar et al. [20]. This happened because by increasing the injection pressures, the diameter of the fuels (SMD) becomes smaller, this can improve the fuel -air mixing in the combustion chamber [18] and the fuels can be burnt more easily. Compared with the injection pressure of 1729 bar, the BMEP of RME and SME was increased up to 7.67% and 5.42% from the injection pressure of 944 bar, respectively. The increase in BMEP value at high injection pressure is due to the improved combustion as the SMD of RME and SME can be easily vaporized.

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## 3.3. Emissions

### 3.3.1. $CO_2$

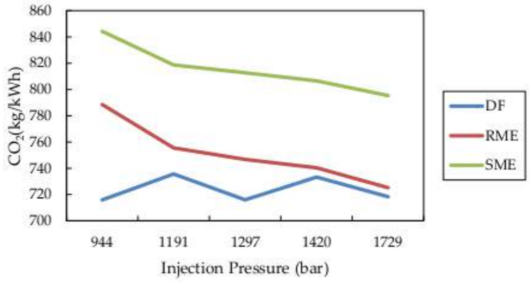

Figure 6. $CO_2$ emissions from all fuels

The $CO_2$ emissions of all fuels can be shown in Figure 6. Diesel fuel has the lowest $CO_2$ emission than RME and SME. However, in this study, RME and SME are 100% biodiesel without blending with DF. Therefore, the values of $CO_2$ emissions of pure RME and SME are still high compared to DF. In addition, $CO_2$ emission are not legally required emissions, but are usually counted in regular engine emissions tests to understand the fuel consumption in the engine [22].

As can be seen in Figure 6, the value of $CO_2$ emission remained constant for diesel fuel, which shows that higher injection pressures have no effect for DF. On the other hand, for RME and SME, the value of $CO_2$ decreased with increasing injection pressure. These results are in agreement with other studies by Kim et al. [21], Canakci et al. [23], and Yoon e al. [24]. The value of $CO_2$ emissions of RME decreases up to 8,03% from injection pressure 944 bar to 1729 bar. Moreover, the $CO_2$ emissions of SME are reduced by up to 5,78% from injection pressure 944 bar to 1729 bar. The reduction in $CO_2$ emissions is due to the oxygen content in RME and SME. The oxygen content in biodiesel can cause complete combustion, which can prolong the mixing in the combustion chamber [25, 26, 27]. ~~As high viscosity in RME and SME can~~

~~influence $CO_2$ emissions when the injection pressures are higher, therefore, the emissions become lower.~~

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### 3.3.2. Particulate Matter (PM)

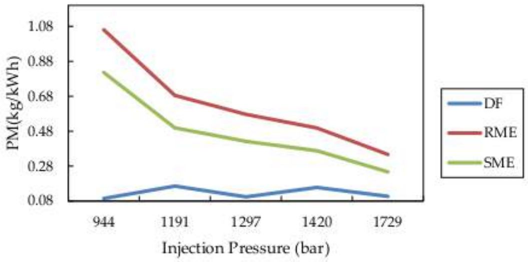

Figure 7. Particulate matter in all fuels

Particulate emissions in this study can be seen in Figure 7. As the injection pressure increased, the PM emissions decreased. This study is in agreement with Yoon et al. [24] and Kim et al. [21]. The SMD and viscosity of RME and SME are larger than those of diesel fuel. However, as the injection pressure increases, the diameter of the fuels of RME and SME becomes smaller. This phenomenon is due to the fact that when the diameter of the fuels is smaller, the atomization is improved, and the fuels vaporize more easily, leading to faster combustion, which decreases the PM emissions. The faster vaporization rate may cause a lower ignition temperature as the thermal energy is converted to latent heat for phase change during vaporization [28]. PM emissions for RME at an injection pressure of 1729 bar can be down up to 30.45% than at injection pressure of 944 bar. In addition, PM emissions of SME at an injection pressure of 1729 bar can decrease to 32,9% compared to the injection pressure of 944 bar.

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## 4. Conclusion

In this study, the simulation between DF, RME and SME was investigated by using Diesel RK. The result shows that as the injection pressure increases, the spray atomization can be improved. This happened because at higher injection, the fuel droplet diameter decreased. Therefore, the small fuel droplets can evaporate easily, resulting in faster combustion during combustion process. Pure biodiesel without blending RME and SME has good results in engine performance and emissions when injection pressures are increased. Therefore, it is recommended to run biodiesel fuel at higher injection pressure to improve atomization and combustion when operating in diesel engines.

## 5. Author's declaration

**Authors' contributions and responsibilities**

Write the contribution of each author here, or mark the following column.

☑ The authors made substantial contributions to the conception and design of the study.

☑ The authors took responsibility for data analysis, interpretation and discussion of results.

☑ The authors read and approved the final manuscript.

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**Availability of data and materials**

☑ All data are available from the authors.

**Competing interests**

☑ The authors declare no competing interest.

**Additional information**

Write additional information related to this research, if any.

## 6. Acknowledgement

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