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Computational Fluid Dynamics Analysis of High Injection Pressure Blended Biodiesel

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Abstract. Biodiesel have great potential for substitution with petrol fuel for the purpose of achieving clean energy production and emission reduction. Among the methods that can control the combustion properties, controlling of the fuel injection conditions is one of the successful methods. The purpose of this study is to investigate the effect of high injection pressure of biodiesel blends on spray characteristics using Computational Fluid Dynamics (CFD). Injection pressure was observed at 220 MPa, 250 MPa and 280 MPa. The ambient temperature was kept held at 1050 K and ambient pressure 8 MPa in order to simulate the effect of boost pressure or turbo charger during combustion process. Computational Fluid Dynamics were used to investigate the spray characteristics of biodiesel blends such as spray penetration length, spray angle and mixture formation of fuel-air mixing. The results shows that increases of injection pressure, wider spray angle is produced by biodiesel blends and diesel fuel. The injection pressure strongly affects the mixture formation, characteristics of fuel spray, longer spray penetration length thus promotes the fuel and air mixing.

1. Introduction

Nitrogen (NOx) and particulate matter (PM) are the major pollutants of concern released by compression ignition (CI) engine. In controlling emissions, higher fuel injection pressures, split and multiple injections, exhaust gas recirculation (EGR) and intake air pressure boosting were being applied [1-4]. Biodiesel produced from different sources is considered as an alternative fuel for diesel in many countries in order to ensure energy security in prevailing situation of shortage of petroleum based fuels [5-7]. In addition, in terms of emissions, considering a strong correlation between the toxicity of particulates with their size and number concentrations, newer emission legislations have been started to enforce limits on the number of particulates released in addition to particulate mass emissions. Biodiesel is a clean-burning alternative fuel produced from domestic, renewable resources that are more efficient to produce [8-10]. On the other hand, the main issue of the biodiesel implementation is the effects of biodiesel properties on the mixture formation especially the fuel-air

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mixing in the combustion chamber. Therefore it is significant to study the effect of various fuel injection strategies on mixing characteristics. Spray penetration length and spray angle are the main concern once using biodiesel fuel in the diesel engine [11]. In term of spray penetration, as biodiesel has higher viscosity than standard diesel, biodiesel fuels have higher penetration length than diesel fuel [12].

Many experimental studies have been carried out to investigate the effects of ambient and fuel characteristics on spray. These experimental results have been used as benchmark data for numerical simulations. For example, Avinash et al. [13] carried out an experimental study of the effect of fuel injection pressure and injection timing on spray characteristics and particulate size-number. Hongzhan Xie et al. [14] conducted an experimental study on macroscopic spray characteristics of biodiesel and diesel in a constant volume chamber. Compare both results from the papers, high emission production by biodiesel fuel is the main concern if biodiesel is to be commercialized as the main alternative fuel to be used in diesel engine. Emission reduction can be achieved if the combustion process can be controlled. Controlling injection parameters is one of the ways to control combustion process. Therefore, the goal of this study is to investigate the effects of high injection pressure of biodiesel blends on spray characteristics using Computational Fluid Dynamics (CFD). In this study, only one type of fuel injector is used with orifice (0.12) mm and angle of 60º. The injection pressures that will be used are 220 MPa, 250 MPa, 280 MPa with the ambient pressure and ambient temperature in the combustion chamber were kept constant at 8 MPa and 1050 K respectively.

2. Simulation Set up

Generally, the simulation in ANSYS FLUENT involves three main stages which are pre-processing, solver and post processing. The design of injector used in this study is only focused on the injector head and combustion chamber. A complete injector has six orifice holes with an angle of 60º between each other. Figure 1 shows the 3D model of cross section in internal combustion chamber of rapid compression machine (RCM) while the geometry of injector with six orifice holes drawn using Solidworks software as shown in Figure 2. Figure 3 shows the section geometry of the combustion chamber. It is 1/6 section from the overall geometry because there are 6 nozzle orifices in the actual RCM and 1/6 section is adequate and considered sufficient for the simulation analysis.

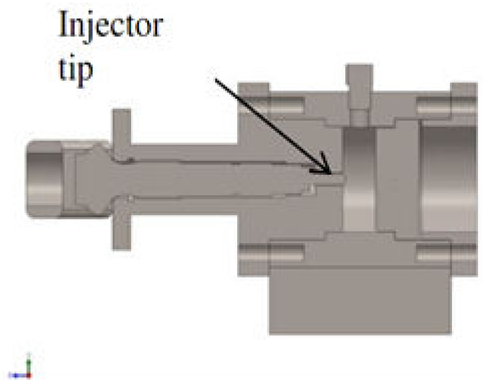

Figure 1: Cross sectional area of internal combustion chamber in RCM.

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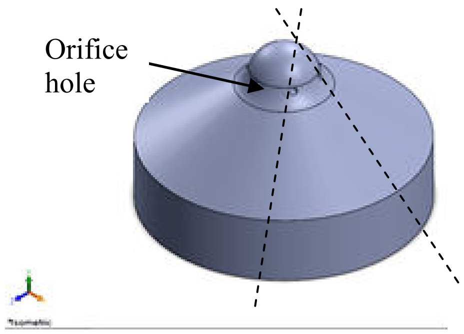

Figure 2: The geometry of injector with six orifice holes

Figure 3: Geometry of 1/6 part of injector inside combustion chamber

The meshing used in this study can be seen in Figure 4. In order to simulate this case, the boundary conditions applied while mesh generated by mapped meshing were inlet, outlet and the wall. These boundary conditions are shown in Figure 5 to Figure 7. Meanwhile, Table 1 shows the boundary conditions used in ANSYS Fluent to conduct the simulations.

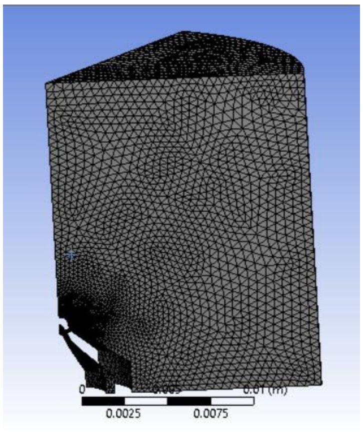

Figure 4: Meshing used in the chamber

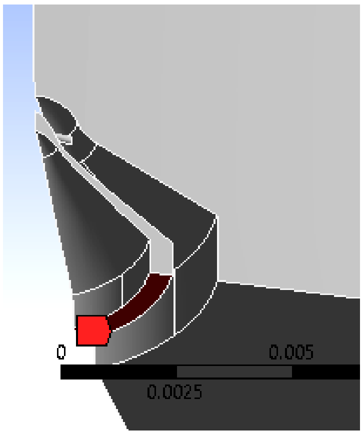

Figure 5: Inlet position on the spray injector

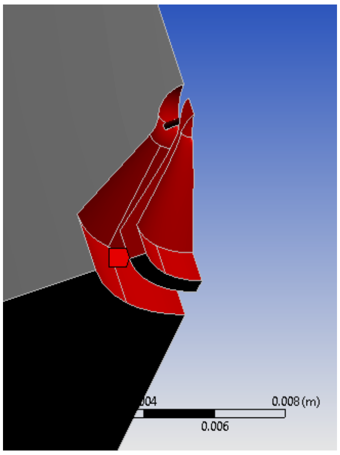

Figure 6: Outlet position inside the chamber

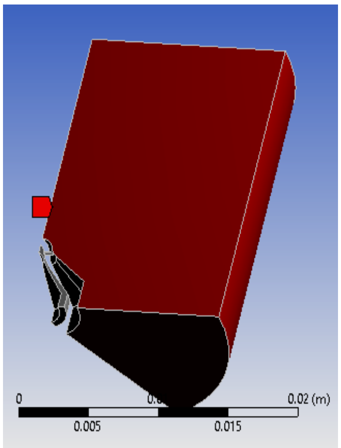

Figure 7: Wall position at injector and chamber

Table 1: Boundary conditions used in ANSYS Fluent

General	Pressure based with absolute velocity formulation	Transient time
Model	Species transport	Biodiesel
Viscous	k-epsilon (2equation)	Realizable
Material	Air	Diesel-vapor
Boundary Condition	Inlet	Outlet Wall
Parameters	Injection pressure	220MPa 250MPa 280MPa
	Ambient pressure	8MPa
	Ambient temperature	1050K

3. Result and Discussion

The results of the simulation work were discussed in this section. As mentioned in the objectives, the interesting properties that require to carried out in this study is the effect of high biodiesel blending ratio and injection pressure on spray characteristics. The fuels used in this study were blends of 10 vol% (B10) and 20 vol% (B20) palm oil. The biodiesel blending were compared with standard diesel at different injection pressures which are 220 MPa, 250 MPa and 280 MPa. The ambient pressure is 8 MPa and ambient temperature is 1050 K and both parameters were kept constant in this study.

The image results of different fuels at different injection pressures are clearly shown in Figure 8. The size of droplet diameter is usually dependent on the parameters that have been used during simulation. From the figure, it was shown that injection pressure greatly affects the droplet diameter. It can be seen that B20 fuel shows richer and larger droplet size compared to standard diesel and B10 fuel. The viscosity of the fuel will increase as the blending ratio increased up thus causes fuel hard to evaporate and change into smaller droplet size.

Figure 9 illustrated the comparison between standard diesel fuel and B20 at 250 MPa. It can be seen that the spray produced by both fuels are different where diesel depicts smaller spray droplets with wider cone angle than B20. Spray droplets produced by B20 are bigger with longer spray penetration. The fuel droplets of B20 travel further than the nozzle and near the wall thus resulting in better air fuel mixing in chamber which indirectly causing in completed combustion process.

Spray penetration lengths of different blending ratio of biodiesel blends under different injection pressures are presented in Figure 10. As the higher pressure injector, the longer length penetration will influence. It seems that both B10 and B20 blends have longer penetration length compared to the diesel fuel. Moreover, B20 as a blended fuel gives longest spray penetration length. The difference of spray penetration length between B10 and B20 is small. Therefore, B10 and B20 have given almost similar trend of spray penetration length. The spray penetration length was resisted with the constant ambient pressure and ambient temperature.

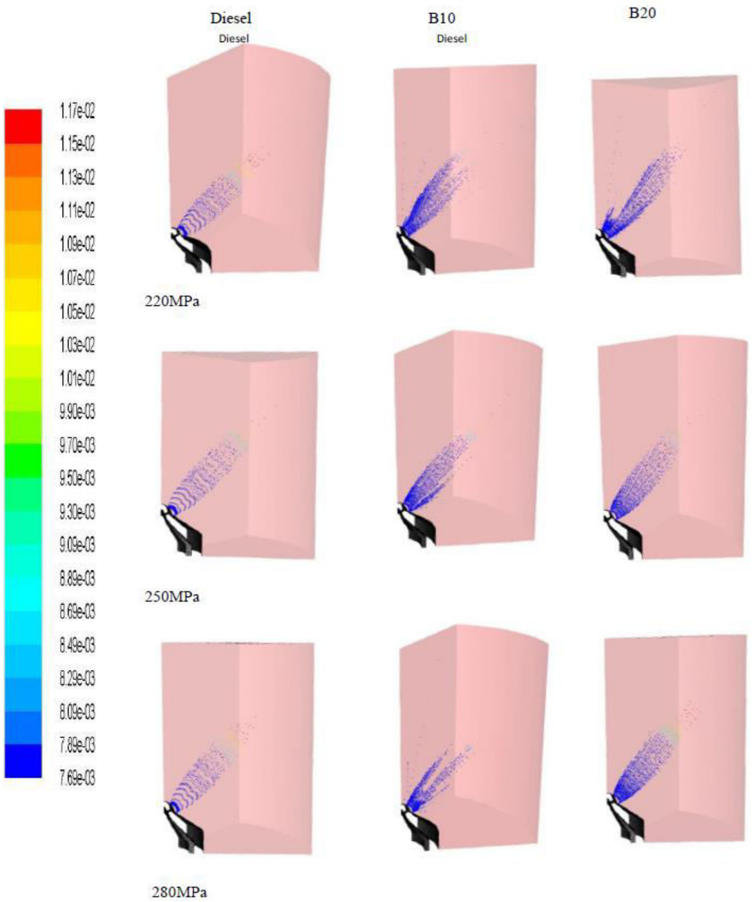

Figure 8: Images of standard diesel, B10 and B20 under different injection pressure (220 MPa, 250 MPa and 280 MPa)

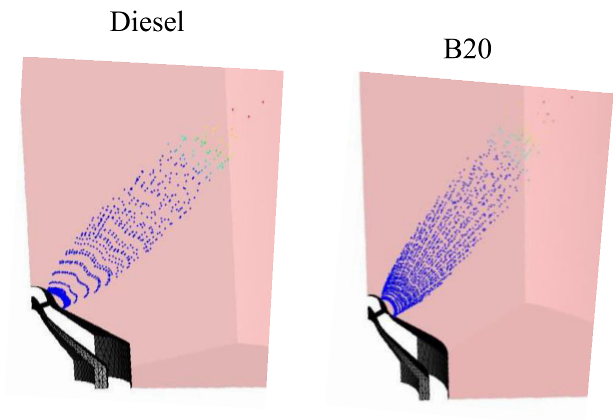

Figure 9: Spray image of diesel and B20 at 250 MPa

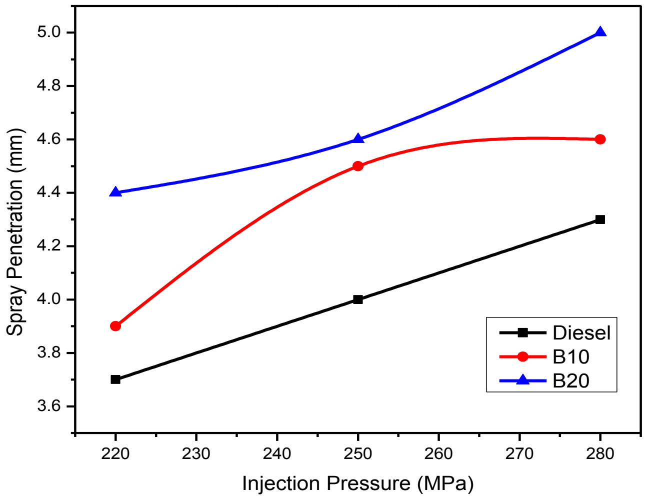

Figure 10: Effect of Injection Pressure on Spray Penetration Length

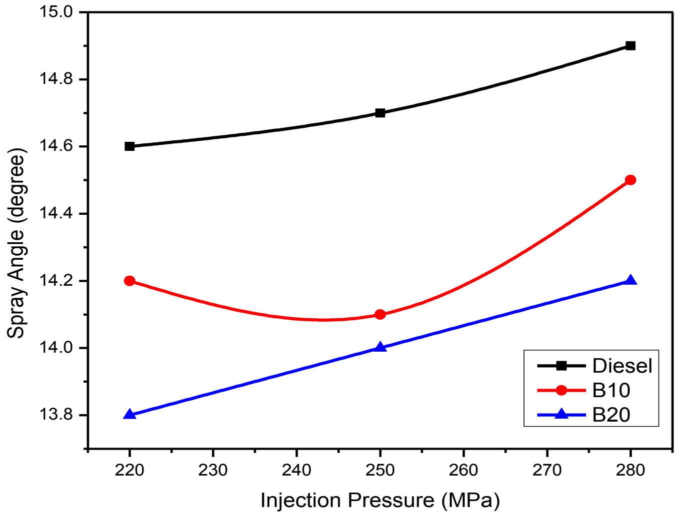

Figure 11: Effect of Injection Pressure on Spray Angle

Figure 11 illustrate the spray angle results under different injection pressure. It seems that the spray angle increases with respect to the increases in injection pressure and plays an important role affecting to the fuel air mixing. Spray angle increases obviously due to effect of ambient temperature on fuel atomization. According to the figure, the spray angle of diesel is higher than both B10 and B20. This is mainly due to high viscosity of B10 and B20 which is higher than standard diesel. Thus, the spray particles of biodiesel blends do not disperse easily due to the opposing ambient pressure of combustion chamber. Meanwhile, this phenomena occurs with the diesel fuel where diesel particles easily disperse as it is injected into the chamber caused in high spray angle.

4.0 Conclusion

The results indicated that increases in injection pressure increases the spray penetration length and spray angle. This study has shown a simulation flow of the fuel flowing in the nozzle spray before combustion process. This simulation was performed on single nozzle orifice diameter which is 0.12 mm. The injection pressures used are 220 MPa, 250 MPa and 280 MPa and the constant ambient pressure at 8 MPa. Different injection pressure influences the spray penetration length and spray angle of the fuel. The higher the injection pressure, the longer the spray penetration length of fuel. In all conditions, the penetration length of diesel, B10 and B20 blends increase as the injection pressure increases. The longest penetration length is achieved by B20 as it has the highest viscosity compared to B10 blend and pure diesel. For spray angle, the widest angle is formed using diesel fuel compared to B10 and B20. B20 records the lowest spray angle due to high viscosity which causes B20 fuel from atomizing as fine droplets.

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