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Analysis of high injection pressure and ambient temperature on biodiesel spray characteristics using computational fluid dynamics

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Abstract. Efficiency of combustion engines are highly affected by the formation of air-fuel mixture prior to ignition and combustion process. This research investigate the mixture formation and spray characteristics of biodiesel blends under variant in high ambient and injection conditions using Computational Fluid Dynamics (CFD). The spray characteristics such as spray penetration length, spray angle and fluid flow were observe under various operating conditions. Results show that increase in injection pressure increases the spray penetration length for both biodiesel and diesel. Results also indicate that higher spray angle of biodiesel can be seen as the injection pressure increases. This study concludes that spray characteristics of biodiesel blend is greatly affected by the injection and ambient conditions.

1. Introduction

Fossil fuel shortage and environmental issues from continuously increasing global energy demand has gain concern by automotive manufacturers which resulted the industry to turn to the development of alternative fuels. Biodiesel is one of the promising candidates as alternative fuel for passenger car as it can be produced from many sources of biomass. Different spray and combustion characteristics may affect the mixing formation since many properties of biodiesel are different from the conventional diesel and thus engine performance and efficiency. The lower heating value of biodiesel, compared to that of convention diesel, and higher viscosity and density from long chain chemical formula might affect the injection process [1]. Moreover, biodiesel has higher oxygen concentration, it might yield more complete combustion [2]. Effect of spray behavior, such as the main penetration and spray angle, are influenced by air mixture formation, which related to engine combustion efficiency [3].

The key issue in using biodiesel fuel is oxidation stability, stoichiometric point, antioxidants on the degradation and much oxygen compared to conventional diesel. Although the application of the biodiesel fuel in the diesel engines is more attractive and more economical but it also creates problems of higher emissions compared to conventional diesel. Biodiesel fuel diesel engines still have problem of producing NOx and Particulate Matter (PM) into the atmosphere because of the oxidation stability, cetane number, stoichiometric point, bio-fuel composition and antioxidants on the degradation extremely viscous [4,5,7]. Thus, the improvement of emissions exhausted from biodiesel fuel engines is needed to meet the future stringent emission regulations. Biodiesel has higher cetane number than diesel fuel, no aromatics, almost no sulfur, and contains 10 to 11% oxygen by weight. These characteristics of the fuel decrease the emissions of carbon monoxide (CO), hydrocarbon (HC), and particulate matter (PM) emitted through combustion. In addition, higher viscosity and specific gravity are found to increase the fuel quantity, injection timing, and spray pattern will strongly influence the degree of initial premixing and combustion process.

Computational fluid dynamics (CFD) is a important research tool in order to study and predict the behavior of the injection of fuel spray. CFD is the science of predicting fluid flow, heat transfer, mass transfer, chemical reactions, and related phenomena by solving the mathematical equations which govern these processes using a numerical process. The result of CFD analysis is relevant engineering data such as conceptual studies of new designs, troubleshooting, detailed product development and redesign. CFD analysis complements testing and experimentation is reduces the total effort required in the laboratory [8].

With CFD, it clearly shown the influences of the injection pressure and fuel properties on the variant of spray characteristics of biodiesels and also conventional diesel. Different properties of fuel spray because of their significant influence on the spray atomization and air–fuel mixture affects the engine performance, combustion, and emission. Therefore, the research should investigate the effects of biodiesel on the spray characteristics is apparent and essential. To study the effects of different types of biodiesels on spray characteristics, numerical and experimental studies are carried out [9, 10].

In this study, the effects of high ambient and injection conditions of biodiesel blends on spray characteristics are investigated using Computational Fluid Dynamics (CFD). In this study, only one type of fuel injector is used with orifice 0.12 mm and cone angle of 60º. The ambient temperatures and injection pressures that were used are 850 K, 950 K and 1050 K and 220 MPa, 250 MPa and 280 MPa respectively. Ambient pressure was kept constant at 8 MPa throughout the simulation.

2. Simulation

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 hole with an angle of 60º between each other. Figure 1 shows the simulation flow chart for this study including the simulation of CFD. Figure 2 shows the 3D model of cross section of rapid compression machine (RCM) which can simulated the real behavior of internal combustion engine process. In addition, Figure 3 shows the geometry of injector with six orifice holes drawn using Solidworks. Figure 4 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.

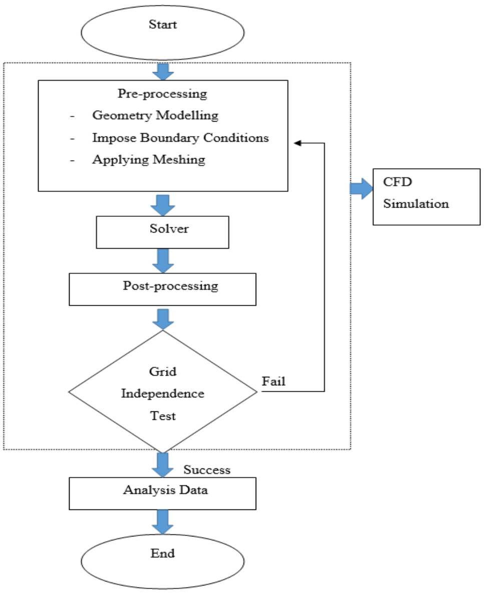

Figure 1. Modelling flowchart in ANSYS Fluent.

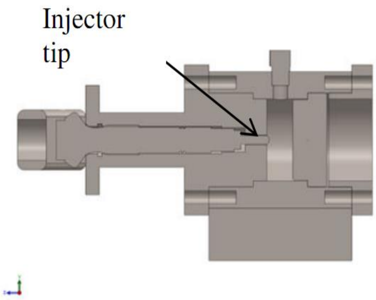

Figure 2. 3D model of cross section in internal combustion chamber of rapid compression machine (RCM).

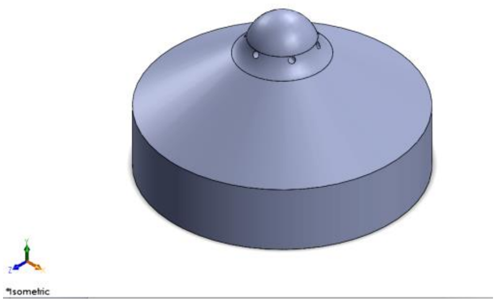

Figure 3. The geometry of injector with six orifice holes.

Figure 4. Geometry of 1/6 part of injector and its combustion chamber.

The meshing used in this can be seen in Figure 5. The boundary conditions used in this study were inlet, outlet and the wall. These boundary conditions are shown in Figure 6 , Figure 7 and Figure 8. Meanwhile, Table 1 shows the boundary conditions used in ANSYS Fluent to conduct the simulations.

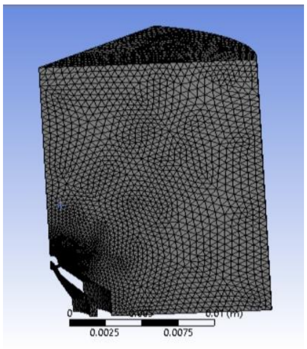

Figure 5. Meshing used on the injector.

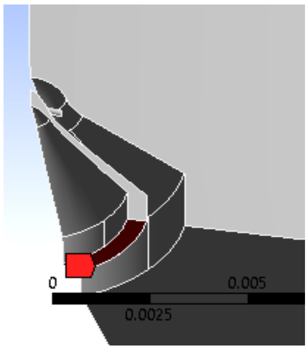

Figure 6. Inlet position at spray injector.

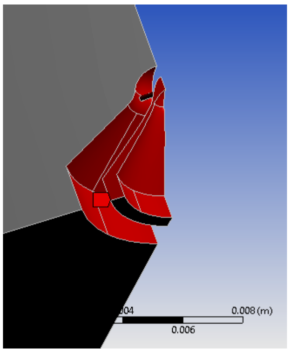

Figure 7. Outlet position at the spray chamber.

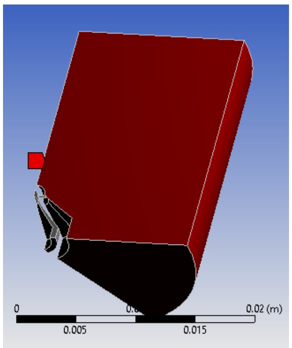

Figure 8. Wall position at injector and spray chamber.

Table 1. Boundary conditions used in ANSYS Fluent.

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

There are mainly three equations we solve in computational fluid dynamics problem. They are Continuity equation, Momentum equation (Navier Stokes equation) and Energy equation. Applying the mass, momentum and energy conservation, we can derive the continuity equation, momentum equation and energy equation as follows.

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a) Continuity equation

$$\frac{D\rho}{Dt} + \rho \frac{\partial U_i}{\partial x_i} = 0 \tag{1}$$

b) Momentum equation

$$\underbrace{\rho \frac{\partial U_j}{\partial t}}_{I} + \underbrace{\rho U_i \frac{\partial U_j}{\partial x_i}}_{II} = -\underbrace{\frac{\partial P}{\partial x_j}}_{III} - \underbrace{\frac{\partial \tau_{ij}}{\partial x_i}}_{IV} + \underbrace{\rho g_j}_{V} \tag{2}$$

Where

$$\tau_{ij} = -\mu\left(\frac{\partial U_j}{\partial x_i} + \frac{\partial U_i}{\partial x_j}\right) + \frac{2}{3}\delta_{ij}\mu\frac{\partial U_k}{\partial x_k} \tag{3}$$

I: Local change with time
II: Momentum convection
III: Surface force
IV: Molecular-dependent momentum exchange (diffusion)
V: Mass force

c) Energy equation

$$\underbrace{\rho c_\mu \frac{\partial T}{\partial t}}_{I} + \underbrace{\rho c_\mu U_i \frac{\partial T}{\partial x_i}}_{II} = -\underbrace{P\frac{\partial U_i}{\partial x_i}}_{III} + \underbrace{\lambda \frac{\partial^2 T}{\partial x_i^2}}_{IV} - \underbrace{\tau_{ij}\frac{\partial U_j}{\partial x_i}}_{V} \tag{4}$$

I: Local energy change with time
II: Convective term
III: Pressure work
IV: Heat flux (diffusion)
V: Irreversible transfer of mechanical energy into heat

3. Results and Discussion

This segment portrays the changes in spray characteristics with both injection pressure and ambient temperature increasing. The close relationship between injection pressure and ambient temperature on the formation of spray is explained in this section. Each injection pressures- 220MPa, 250MPa and 280MPa were simulated with each ambient temperatures- 850K, 950K and 1050K. From the simulation, the result develops from three different injection pressure and ambient temperature.

Figure 9 portrays the image results of different fuels at different ambient temperatures .The size of droplet diameter is usually dependent on the parameters that have been used. Based on the figure it is shown that ambient play a significant role on the changes of the droplet diameter. Based on the figure, it can be seen that the particle diameter of all fuels decreases as the ambient temperature. This is a result of fuel particles breaks to smaller particles as the difference of temperature between injector and combustion chamber is large.

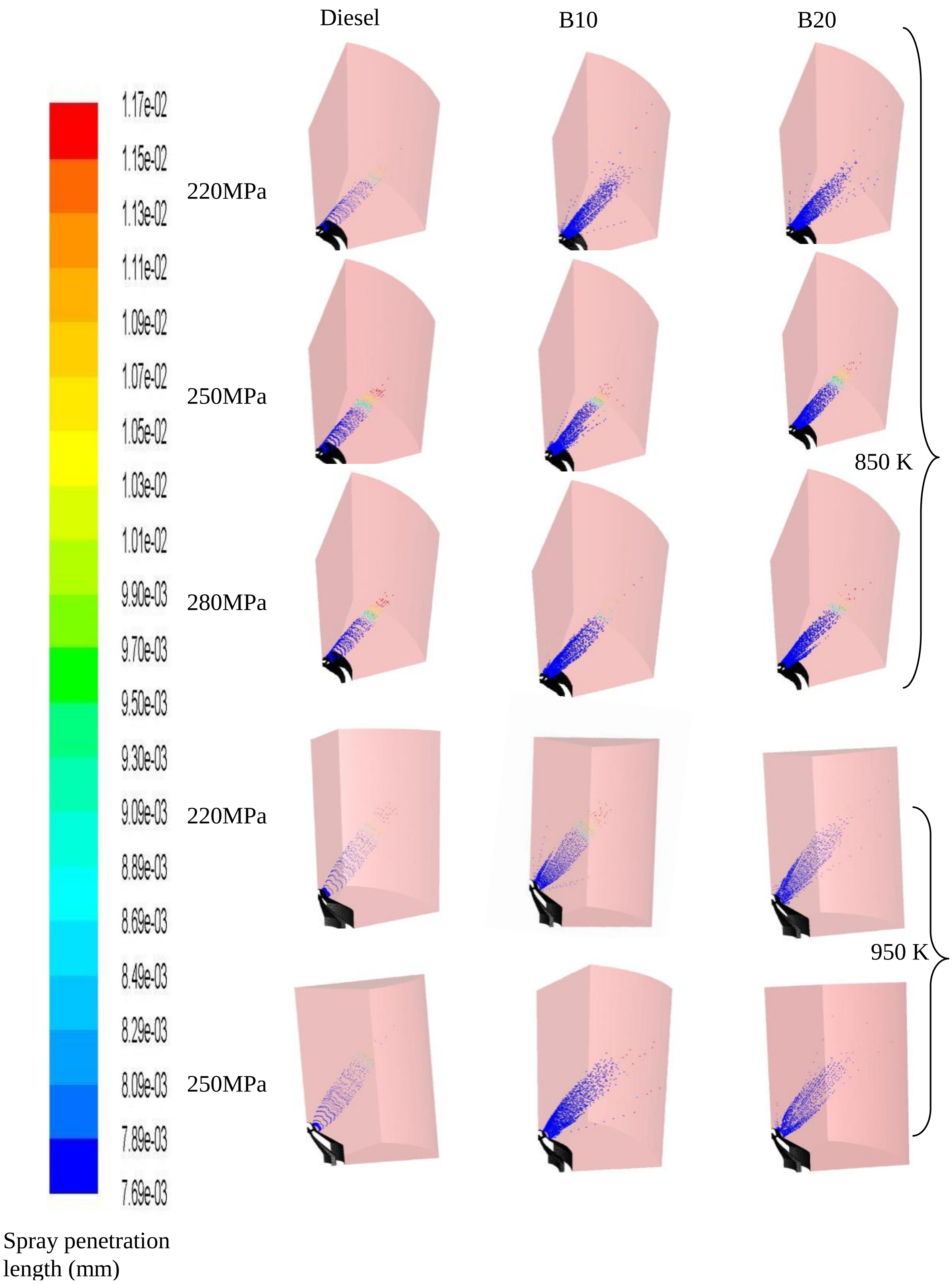

Figure 9. Spray characteristics under different ambient temperature and injection pressure (850 K and 950 K).

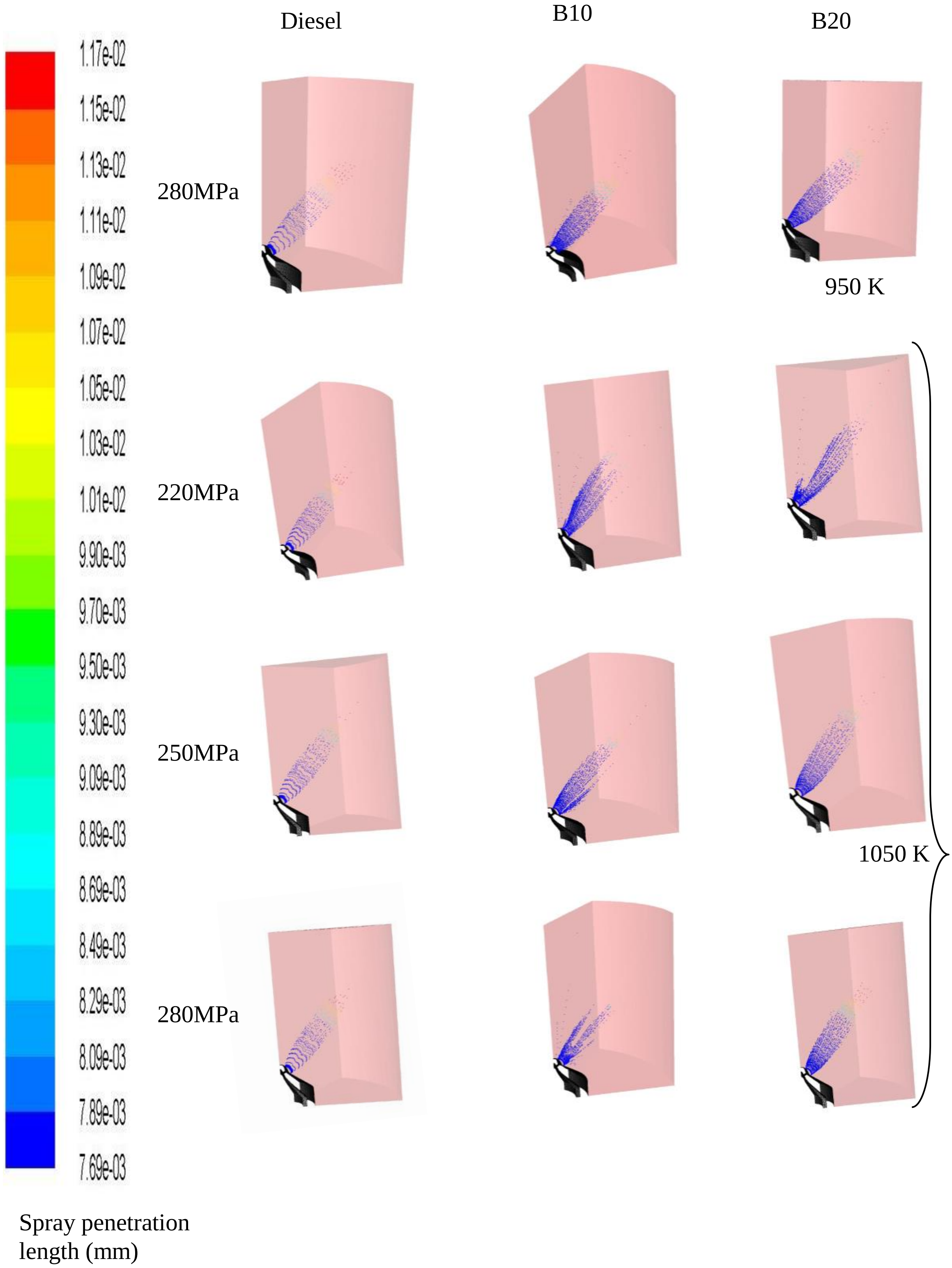

Figure 10. Spray characteristics under different ambient temperature and injection pressure (950 K and 1050 K).

Figure 11 shows the relationship of both ambient temperature and injection pressure and spray penetration length. Steady increase in spray penetration length as the injection pressure and ambient temperature increase. The longest penetration is achieved by B20 at injection pressure 280MPa and ambient temperature 1050K. On the other hand, shortest penetration length can be seen in pure diesel at injection pressure 220MPa and ambient temperature 850K. As for spray angle, the changes in spray characteristics can be seen in Figure 12. Unlike spray penetration, pure diesel has the highest spray angle compared to both B10 and B20 at injection pressure 280 MPa and ambient temperature 1050 K. Lowest spray angle can be seen in B20 at injection pressure 220 MPa and ambient temperature 850K. As the temperature and pressure is increased, a great variation in the spray structure is observed. It promotes mixture formation and distributes larger amount of fuel between sprays thus creates good spray atomization and exhibits a greater amount of fuel-air premixing prepared for combustion. Increment of the ambient temperature promotes the evaporation process or on the other hand, evaporation process is elevated by higher ambient temperature. Increases in the ambient temperature causes the rate of fuel evaporation increased. Fuel droplets with small diameter tend to evaporate easily while those with greater diameter take a much longer time to evaporate.

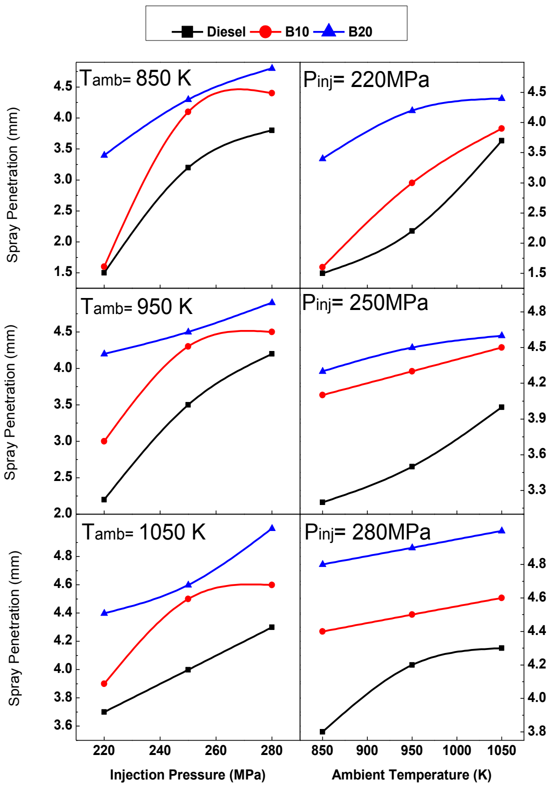

Figure 11. Effect of Injection Pressure on Spray Penetration Length.

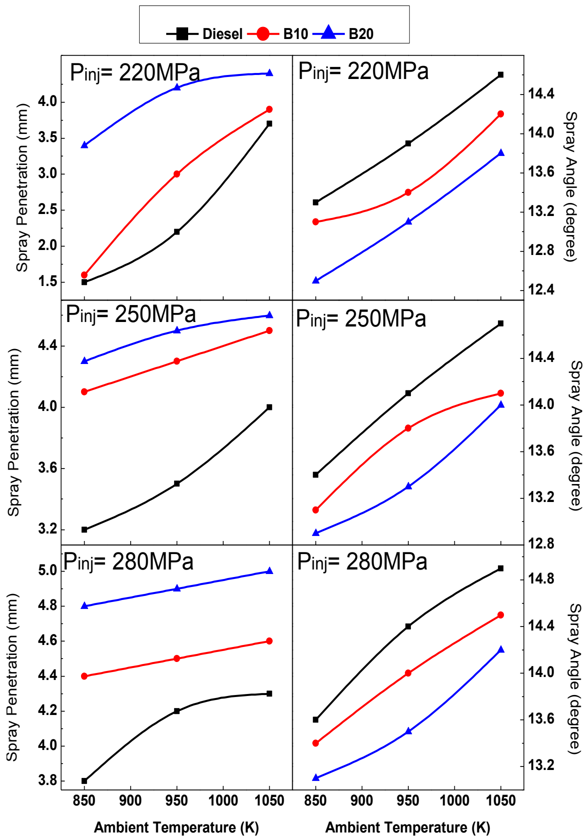

Figure 12. Effect of Injection Pressure on Spray Angle.

4. Conclusion

This study is to investigate the effects of injection pressure and ambient temperature on spray characteristics using constant orifice diameter in the constant volume chamber by using CFD. The results indicate that increase in injection pressure and ambient temperature increases the spray penetration length and spray angle of biodiesel fuel.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 0.12mm. The ambient temperatures inside the chamber is 850, 950, 1050 K, the injection pressures are 220, 250, 280 MPa and the constant ambient pressure at 8 MPa.

Change in temperature affects the droplet diameter of fuel. As the ambient temperature increases, the spray tends to easily evaporate and disperse. This results in wider spray angle of the fuel. Thus, increase in ambient temperature increases the spray angle of the fuel used. In this study, it was found that diesel has a higher spray angle as the ambient temperature increases compared to B10 and B20 blends. This is due to high viscosity of B10 and B20 which causes the droplet hard to break into smaller size and disperse.

Different injection pressure influences the spray penetration length of the fuel. The higher the injection pressure, the longer the spray penetration length of fuel. This is the deduction made from this study. In all conditions, the penetration length of pure 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 diesel.

Acknowledgments

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