Simulation of Biodiesel Sprays under High Ambient Temperature using Computational Fluid Dynamics

To cite this article: Muhamad Najib Hassan et al 2019 J. Phys.: Conf. Ser. 1150 012063

View the article online for updates and enhancements.
Simulation of Biodiesel Sprays under High Ambient Temperature using Computational Fluid Dynamics

Muhamad Najib Hassan¹, Amir Khalid*¹,², Norrizal Mustaffa¹, Nofrizalidris Darlis¹, Norrizam Jaat¹, Adiba Rhaodah Andsaler², Akmal Nizam Mohammed²
¹Automotive and Combustion Synergies Technology Group, Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, Jalan Panchor, Muar 84600 Johor, Malaysia
²Combustion Research Group, Centre for Energy and Industrial Environment Studies, Universiti Tun Hussein Onn Malaysia, 86400 Batu Pahat, Johor, Malaysia

*Corresponding Author: amirk@uthm.edu.my

Abstract. Among the numerous alternative fuels for internal combustion engines, biodiesel have promising fuel for use in compression ignition engines due to its properties such as renewable nature, fuel bound oxygen content, non-toxic, biodegradable, no sulphur, good ignition quality and excellent lubricity. The effect of high ambient temperature on spray characteristics of biodiesel was studied by utilizing Computational Fluid Dynamics software. The spray characteristics that are studied are spray penetration length and spray angle. Simulation of fluid flow (Fluent) toolbox was used to simulate and analyze the spray characteristics of biodiesel at various conditions of ambient condition. Simulation results have revealed that the increases of ambient temperature inside the combustion chamber resulting in gain of wider spray angle of all used fuels. Results also show that longer spray penetration length of diesel and biodiesel fuels can be seen as the ambient temperature increases. This study deduces that ambient temperature is a significant variable that plays pivotal role in controlling air fuel mixing in combustion chamber.

Keywords: Biodiesel, Ambient temperature, Diesel engine, Computational fluid dynamics, Spray characteristics

INTRODUCTION

Diesel engine known as a self-ignition engine uses the heat formed from compression air to start ignition from the result of burning the fuel-air mixing inside the combustion chamber contrast to spark ignition engines (SI). Thus, the application of diesel engine has the most fuel efficient internal combustion engine due to high compression ratio but the issue of natural self-ignition of the fuel-air mixing is a major concerned [1][2][3]. Suitability of an oil derived from plants as an alternative to diesel fuel in diesel engines has become more attractive and research in this aspect has gained momentum due to the increase in the crude oil prices, limited world reserve of fossil fuels and increased emphasis on clean environment. Direct usage of vegetable fuel in compression ignition (CI) engines is unattractive due to the higher viscosity, flash point and cetane number. Beside that biodiesel has lower volatility and heating value and also high fuel lubricity and high oxygen content value [4][5][6][7].
Many studies have been carried out to continue the development of diesel engines according to new emissions regulations while at the same time enhancing their fuel consumption and performance. The properties of biodiesel and its blends have been the subject of many investigations experimentally and numerically [8][9][10][11]. It was reported that temperature has a significant effect on diesel and biodiesel properties and combustion [12]. Thus, the implementation of the simulation and modelling to observe the spray characteristics are very important in order to predict the mixture formation under variant ambient condition and operating condition. Adiba et. al. [13] stated that the temperature and ambient pressure had a great influence on spray characteristics of biodiesel combustion, it was concluded that as the temperature of inside chamber increased, the spray area becomes larger while and resulted expands spray angle. It was also stated that by increasing the chamber pressure, it makes reduced spray angle due to the reduction of fuel momentum at the early start of injection [14][15][16].

The objective of this research is to investigate the effects of high ambient temperature of biodiesel fuel on spray characteristics by using the Computational Fluid Dynamics (CFD) software. In this research, fuel injector is fixed at orifice diameter of 0.12 mm and injector nozzle hole angle of 60°. In addition, the ambient temperatures inside combustion chamber were varies which are 850 K, 950 K and 1050 K with ambient pressure and injection pressure kept constant at 8 MPa and 280 MPa, respectively.

![Research and flowchart of Modelling](image)

Figure 1: Research and flowchart of Modelling
SIMULATION

In this research, simulations of biodiesel spray with Ansys Fluent comprised of three main stages such as pre-processing, solver stage and post processing. In addition, the simulations only focused on the injector nozzle, fuel and combustion chamber. Injector nozzle has six orifice holes with an angle of 60º between each other. Figure 1 shows the research and simulation flowchart to complete this research objective. Figure 2 and Figure 3 show the 3D model of cross section of nozzle injector and combustion chamber of rapid compression machine (RCM) and the geometry of injector with six orifice holes, respectively. Figure 4 shows the schematic of section geometry inside combustion chamber. This figure represent 1/6 section from the overall geometry of six nozzle orifices on the injector. The observation of 1/6 section is acceptable and sufficient for the purpose of simulation analysis.

The generated meshed in this simulation can be seen in Figure 5. Thus, the boundary conditions used in this study are inlet, outlet and the wall of combustion chamber and injector as shown in Figure 6 to Figure 8. Meanwhile, the boundary conditions use in ANSYS Fluent in order to simulate the actual engine operations shown in the Table 1.
Table 1: ANSYS Fluent Boundary conditions

| 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                   |

Figure 6: Section of inlet position of chamber and injector

Figure 7: Section of outlet position of chamber and injector

Figure 8: Section of wall position at injector and combustion chamber
There are mainly three equations such as continuity equations, Navier Stokes equation (momentum equation) and energy equation were used to solve the computational fluid dynamics problem. Equation as follows.

a) Continuity equation

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

b) Momentum equation

\[
\rho \frac{\partial U_j}{\partial t} + \rho U_i \frac{\partial U_j}{\partial x_i} = -\frac{\partial P}{\partial x_j} - \frac{\partial \tau_{ij}}{\partial x_i} + \rho g_j \tag{2}
\]

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

Where

I: The local change with time, II: The momentum convection, III: Surface force, IV: The molecular-dependent momentum exchange (diffusion), V: Mass force

c) Energy equation

\[
\rho c_\mu \frac{\partial T}{\partial t} + \rho c_\mu U_i \frac{\partial T}{\partial x_i} = -P \frac{\partial U_i}{\partial x_i} + \lambda \frac{\partial^2 T}{\partial x_i^2} + \tau_{ij} \frac{\partial U_j}{\partial x_i} \tag{4}
\]

Where

I: The local energy change with time, II: The convective term, III: Pressure work, IV: Heat flux (diffusion), V: The irreversible transfer of mechanical energy into heat.

RESULTS

The results illustrate the spray characteristics under the condition of high ambient temperature inside combustion chamber. The biodiesel spray characteristics such as spray angle and spray penetration length were investigated under the range of ambient temperatures of 850 K to 1050 K. The air ambient pressure and fuel injection pressure were constant at 8 MPa and 280 MPa, respectively.

Figure 9 clearly illustrates the result of images for different fuels at varies of ambient temperatures. This simulation reveals that ambient temperature plays a significant role on the changes of the spray characteristics such as spray penetration and spray angle that significant influences on droplet diameter. It seems that the mixture formation area of all fuels increases as the
ambient temperature increased. Increment of ambient temperature during combustion promotes the fuel evaporation process and fuel-air mixing inside the combustion chamber. It seems that the longer spray penetration influences the fuel spray breaks to smaller fuel particles as the variant of ambient temperature is higher.

Figure 9: The spray images at variant ambient temperature

Figure 10 shows the comparison of spray from diesel fuel and B20 fuel. The fuel was injected at injection pressure of 250MPa and ambient temperature of 950K. It shows that the spray produced by both fuels varies from each other where richer fuel particles can be seen in B20 fuel compared to
diesel fuel. The diesel fuel produced slightly wider spray angle compared to B20 fuel. Meanwhile, the spray penetration length is longer produced by B20 fuel. Besides that, due to high injection pressure used in this study, insignificant increase of spray penetration length in both fuels really apparent. Higher injection pressures producing the faster sprays at the nozzle exit. The spray penetration length has a great affected by the ambient temperature and injection pressure. Therefore, better the evaporation and atomization air–fuel mixture were influences from blended fuel at higher ambient temperature and injection pressure.

![Comparison of spray image](image)

**Figure 10: Comparison of spray image**

![Spray penetration at different ambient temperature](image)

**Figure 11: Spray penetration at different ambient temperature**

Figure 11 shows the spray penetration under different ambient temperature depict from the simulation results. The spray penetration lengths of biodiesel blends were compared with diesel fuel at ambient temperatures of 850 K, 950 K and 1050 K, respectively. Figure shows that the spray penetration length of both biodiesel blends and standard diesel are increases with the ambient temperature increases. This is mainly caused by the high injection pressure and higher ambient temperature. The differences between ambient pressure and injection pressure forces the injected fuel particles to travel further into combustion chamber before evaporating. Compared to B20, the penetration length of diesel is rather short as it evaporates easier than B20. Meanwhile, the penetration
length of B10 is longer than diesel but shorter than B20 due to the difference in blending. This is due to the difference in viscosity of the blended fuels and diesel where increase in blending ratio increases the viscosity of the fuel.

The variation of spray angle of biodiesel blends and diesel with different of ambient temperature is illustrated in Figure 12. Results in the figure shows that the spray angle of all three fuels increased as the ambient temperature increases. Spray angle of diesel is the highest compared to B10 and B20. B20 fuel has the lowest spray angle between the fuels used. This is obvious as B20 has the highest viscosity among all three fuels. High viscosity avoids the fuel particle from easily bursting as soon as the fuel is injected into the combustion chamber. It can be seen that the spray angle of both biodiesel blends increases as the injection pressure increase.

![Figure 12: Spray angle at different ambient temperature](image)

**CONCLUSION**

The mixture formation of fuel-air spray under fixed diameter of nozzle orifice and operates in constant volume chamber were investigated using CFD. The results obtained shows that ambient temperature affects spray characteristics significantly. The objective of this research has been achieved by defining the effects of ambient temperature inside the combustion chamber on spray characteristics. The following conclusions were drawn from this study:

1. Different temperature influences the spray penetration length. By increasing the ambient temperature caused lengthening the spray penetration. At higher ambient temperature, fine droplets are produced and promotes atomization thus promotes the evaporation process.

2. When the ambient temperature became higher caused the spray angle expanded which is the spray tends to easily evaporate and disperse. At higher ambient temperature, the vapour phase dominates the spray tip region due to instant evaporation process of the droplets that are exposed directly to the higher ambient temperature inside combustion chamber.

3. Comparison of higher fuel blending ratio of B10 and B20, standard diesel fuel has a higher spray angle but shorter spray penetration length with the ambient temperature increases due to high fuel viscosity of both fuels B10 and B20 which causes the droplet not easily to break into smaller size and disperse.

**ACKNOWLEDGEMENTS**

This research was supported by Fundamental Research Grant Scheme (FRGS) vot. 1054 (Ministry of Higher Education).
REFERENCES

[1] P. S. M. K. Anand, Avishek Ranjan, R.P. Sharma, “Experimental and Simulation Studies of Biodiesel Combustion in a CI Engine”, pp. 1–9, 2009.

[2] Adiba Rhaodah Andsaler, Amir Khalid, Nor Sharifhatul Adila Abdullah, Azwan Sapit and Norrizam Jaat, “The effect of nozzle diameter, injection pressure and ambient temperature on spray characteristics in diesel engine,” Journal of Physics: Conference Series, Volume 822, Number 1, 2017.

[3] Adiba Rhaodah Andsaler, Amir Khalid, Norrizam Jaat and M. Izwan Sukarman, “Effects Of Ambient Density On Flow Characteristics Of Biodiesel Spray Injection Using Computational Fluid Dynamics,” ARPN Journal of Engineering and Applied Sciences, vol. 11, no. 8, 2016.

[4] H. Xie, L. Song, Y. Xie, D. Pi, C. Shao, and Q. Lin, “An experimental study on the macroscopic spray characteristics of biodiesel and diesel in a constant volume chamber,” Energies, vol. 8, no. 6, pp. 5952–5972, 2015.

[5] Amir Khalid, “Effect of Ambient Temperature and Oxygen Concentration on Ignition and Combustion Process of Diesel Spray,” Asian Journal of Scientific Research. Volume 6, no. Issue 3, p. Pages 434-444, 2013.

[6] Amir Khalid, Ridwan Saputra Nursal, Ahmad Syukri Ahmad Tajuddin and Syahrunniza Abd Hadi “Performance and emissions characteristics of alternative biodiesel fuel on small diesel engine,” ARPN Journal of Engineering and Applied Sciences, vol. 11, no. 12, pp. 7424–7430, 2016.

[7] P. Srichai, N. Chollacoop, N. Metal, M. T. Ce, K. Mongkut, and T. Ladkr, “Spray Visualization of Biodiesel and Diesel in a High Pressure Chamber,” October, 2015.

[8] M. Yousefifard, P. Ghadimi, and M. Mirsalim, “Numerical simulation of biodiesel spray under ultra-high injection pressure using OpenFOAM,” pp. 1–10, 2014.

[9] Amir Khalid, Norrizal Mustaffa, Bukhari Manshoor, Hanis Zakaria, Ahmad Jais Alimin, Abdul Mutalib Leman and Azmahani Sadikin, “The Comparison of Preheat Fuel Characteristics of Biodiesel and Straight Vegetable Oil,” Applied Mechanics and Materials, Volumes 465-466, 2013.

[10] Amir Khalid, Azim Mudin, M. Jaat, Norrizal Mustaffa, Bukhari Manshoor, Mas Fawzi, Mohd Azahari Razali and Mohd Zamani Ngali “Effects of Biodiesel Derived by Waste Cooking Oil on Fuel Consumption and Performance of Diesel Engine,” Applied Mechanics and Materials (Volume 534), no. July, pp. 520–525, 2014.

[11] J. A. Bittle, B. M. Knight, and T. J. Jacobs, Interesting Behavior of Biodiesel Ignition Delay and Combustion Duration, vol. 24. 2010.

[12] K. Miwa, T. Ohmija, and T. Nishitani, “A Study of the Ignition Delay of Diesel Fuel Spray Using a Rapid Compression Machine,” JSME Int J, Ser II, vol. 31, p. 166, 1988.

[13] Adiba Rhaodah Andsaler, Amir Khalid, Him Ramsy and Norrizam Jaat “A review paper on Simulation and modeling of combustion characteristics under high ambient and high injection of biodiesel combustion,” vol. 774, pp. 580–584, 2015.

[14] A. C. Pinto, L. L. N. Guarieiro, M. J. C. Rezende, N. M. Ribeiro, E. A. Torres, W. A. Lopes, P. A. P. De Pereira, and J. B. De Andrade, “Biodiesel: An overview,” J. Braz. Chem. Soc., vol. 16, no. 6 B, pp. 1313–1330, 2005.

[15] Y. Wu and C. F. Lee, “Experimental Investigation of Spray and Combustion Characteristics of Soybean Biodiesel in a Constant-Volume,” vol. c, pp. 1–10, 2016.

[16] J. Zhang, W. Jing, W. L. Roberts, and T. Fang, “Soot measurements for diesel and biodiesel spray combustion under high temperature highly diluted ambient conditions,” FUEL, vol. 135, pp. 340–351, 2014.