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The effect of orifice diameter in constant volume chamber to spray characteristics in diesel engine using computational fluid dynamic

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Abstract. Mixture formation of the ignition process is a crucial part in diesel combustion as it affects the combustion process and exhaust emission. The main focus of this study is to investigate the effects of spray characteristic to the fuel spray in a chamber using Computational Fluid Dynamics (CFD) simulation. However, simulations are done with the discrete phase of injection taken from the outlet of the nozzle hole to spray chamber. The details behavior of spray penetration and spray breakup length were visualized using Computational Fluid Dynamics. This simulation was done in different nozzle diameters 0.12 mm and 0.2 mm performed at a single ambient pressure of 4 MPa, the ambient temperature of 500 K and 700 K with different injection pressure 40 MPa, 70 MPa and 140 MPa. Results showed that the droplet diameter is influenced by high pressure to become smaller, and the penetration length also longer with high injection pressure applied. Besides, smaller orifice diameter gives a shorter length of the breakup. It is necessary to put afford on orifice diameter and ambient temperature conditions in order to improve the formation of spray.

1 Introduction

Internal combustion engine is the heat engines that convert properties of fuel into a mechanical system, and this application is on the rotating output shaft. The fuel injection equipment is one of the sub-systems that have been found to lend itself to development and leads to the improvement in engine performance and emission quality [1]. Fuel injected into the chamber is important to the diesel engine as it influences the performance and emission. Break-up and distribution of the spray are largely determined by the in-cylinder conditions, the injection pressure, and orifice geometry [1-2]. Design of the orifice for fuel injector is important on the performance and emission of diesel engine. All orifices must produce a

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fuel spray that encounters the necessary objectives of performance and emissions into the market for which the engine delivered regardless details of the fuel system design. This simulation study used computational fluid dynamics (CFD); ANSYS version 16.1 Fluent software to study the spray characteristics.

In the most basic sense, a spray is simply the introduction of liquid into a gaseous environment through an orifice such that the liquid, through its interaction with the surrounding gases and by its own unsteadiness, breaks-up into droplets [3]. The formation of a spray begins with the separation of droplets from the outer surface of a continuous liquid core extending from the orifice of injector. Spray characteristic is known to affect significantly the combustion and emission processes in diesel engines. By optimizing spray characteristics, the raw emissions from the diesel engine which are mainly NOx and PM can be minimized [2]. Therefore, investigations into Diesel spray characteristics had concentrated on the effect of spray characteristic on engine performance such as the spray tip penetration, break-up length and droplet size and velocity distributions [3].

More recent investigations by Hiroyasu and Arai [4], Naber and Siebers [5] had shown a strong dependency of spray penetration upon both in-cylinder pressure and fuel injection pressure. The injection pressure has significant effect on spray liquid penetration [5]. The effect of increasing pressure on spray tip penetration is depicted. The spray tip penetration gets longer as the injection pressure increases. This result is related to both higher quantity and higher velocity of the droplets at higher injection pressures [6]. When the spray lost its momentum related to the lower quantity or lower injection pressure, but difference for the penetration lengths which showed longer at the downstream region of spray. Proportional to injection pressure, the spray penetrates faster at higher injection pressures [7].

The break-up length characterizes a point of discontinuity, where the spray changes from a zone of liquid (bulk liquid, or interconnected ligaments and droplets), to a finely atomized regime of droplets [8]. After the disintegration of liquid column emerging from a nozzle, the generated droplets may further break-up into smaller ones as they moved into the surrounding gas [9]. The relative velocity between droplets and gas, and surrounding non-uniform pressure develops, causing the particles to deform. Development of this deformation leads to break-up into smaller droplets. The forces associated with dynamic pressure, surface tension and viscosity control the break-up of a drop [10].

In this research, the characteristics of spray diesel are investigated focusing on manipulate the ambient temperature and injection pressure with different orifice diameter. This study conducted by using Computational Fluid Dynamic simulation which can captured the spray penetration and breakup length.

2 Simulation setup

The modeling flow chart shows in Figure 1 about the flow of simulation. As shown in Figure 1, the first stage is pre-processing which consists of the flow problem in the simulation. Solver stage is complete the calculation of finite element model or solving of governing equation. Post-processing is a process of involving data collect and visualization.

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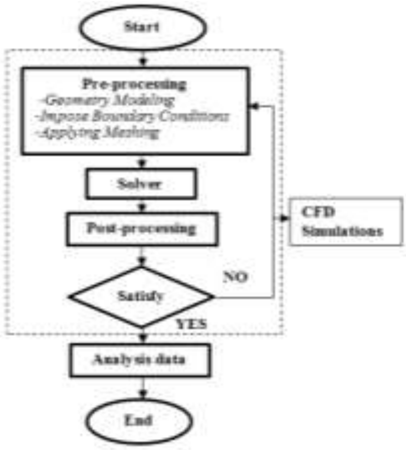

Fig. 1. Methodology and modeling flow chart.

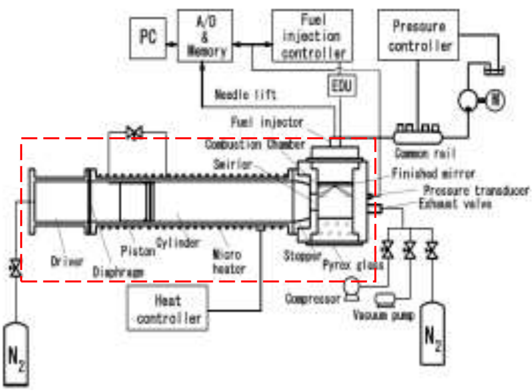

Fig. 2. Experimental setup of RCM.

A rapid compression machine (RCM) was used to generate the actual diesel combustion over a wide range of temperature, pressure and swirl velocities. Figure 2 shows a schematic diagram of RCM, together with an outline of the fuel injection system. Figure 3 and 4 shows the combustion chamber cross sectional drawing with the 3D. The RCM has a disc type combustion chamber with a diameter of 60 mm and width of 20 mm. The design was focused on injector nozzle and spray chamber. The fuel injector has six orifice holes and this design has been saved in IGES format and imported as geometry modeling in ANSYS Fluent 16.1.

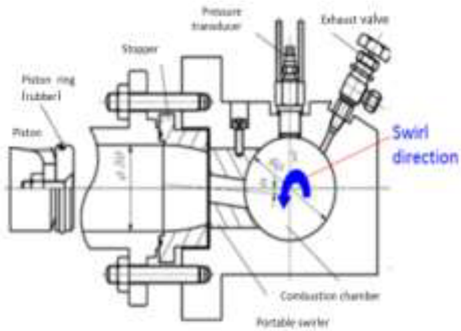

Fig 3. Combustion chamber.

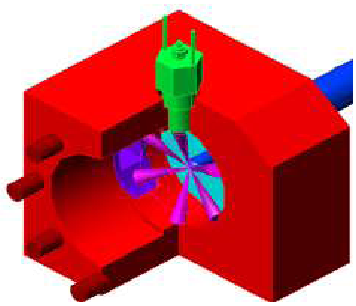

Fig. 4. 3D section view of combustion chamber.

The geometry of injector was modeled by Solid Work software. In this study the combustion chamber is a space where the spray formation occurs. Moreover, model of the injector only considered the tip of nozzle. Figure 5 shows the 3D model of cross sectional area of the injector tip. Figure 6 shows the sections geometry of the combustion chamber. It is 1/6 section from the overall geometry because there are 6 orifices in the actual injector and only one orifice is adequate and considered sufficient for the simulation analysis.

The assigned boundary condition was served as the initiation and direct to motion of the flow. In addition, this simulation carried out with the multiphase model volume of fluid (VOF) and turbulence model of k-ε realizable in transient mode. Besides, a constant mass flow rate of air and diesel are applied as shown in Table 1 which indicates as solver setup of the simulation. Moreover, parameters to investigate are the droplet diameter of particle, penetration length and breakup length.

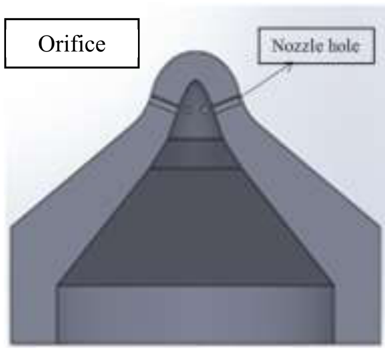

Fig. 5. Cross sectional model of spray injector.

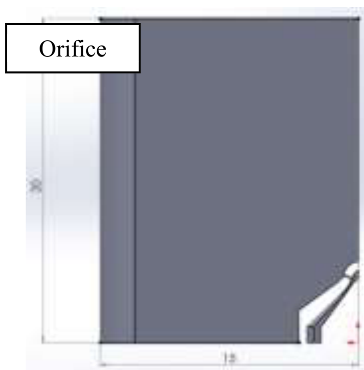

Fig. 6. Hollow model for the combustion chamber.

Table 1. Solver setup.

Options	**Type**
Multiphase Model	Volume of Fluid
Time	Transient
Model	Viscous K-Epsilon Model
K-Epsilon Model	Realizable
Material	Diesel Liquid
Boundary Condition	Injection Pressure = 40 MPa, 70 MPa, 140 MPa
	Temperature Inlet = 313 Kelvin
	Pressure Outlet = 4 MPa
	Temperature Outlet = 500 K, 700 K

3 Results and discussion

This section will explain the result obtained from the simulation. The consideration of this simulation is to make the predictions of spray characteristics located at downstream of injector by using CFD software. This simulation is done by three dimensional modelling in transient state with the multiphase model volume of fluid (VOF). Euler-Euler multiphase approach is applied in this study as it has two phases of materials; air and diesel fuel perform mixing inside the injector and chamber. Two different orifice diameters, 0.20 mm and 0.12 mm are investigated in this study. Meanwhile, this simulation also used several different ambient temperatures such as 500 K and 700 K for every injection pressures are 40 MPa, 70 MPa and 140 MPa. Additionally, 4 MPa is used as the boundary outlet for the ambient pressure in chamber.

Grid sensitivity was tested on the model with different grid sizes. The grid size divided into three levels which are coarse, medium and fine grids. Table 2 indicates the number of elements and nodes for each group of different grid sizes. Besides, the number of elements is ranging from 25888 to 118777 elements. The number of elements is obviously directly proportional to the numbers of nodes by ascending the level of grid sizes from coarse to fine with also level of smoothing from low to high.

Table 2. Grid sizes with number of elements and nodes.

Grid Sizes	Number of Elements	Number of Nodes
Coarse – Low	25888	5182
Coarse - Medium	25979	5234
Coarse – High	26015	5374
Medium – Low	47665	9683
Medium - Medium	47699	9762
Medium – High	48547	9896
Fine - Low	114562	22289
Fine- Medium	115998	22487
Fine - High	118777	22497

3.1 Effect of the ambient temperature, injection pressure and orifice diameter

Ambient temperature is influenced to the spray development which has been investigated throughout this simulation with the parameters of spray droplet diameter, penetration length and breakup length. Orifice diameter is known as one of factor that could influences to the flow inside orifice, while it also can affects to the spray development.

As illustrates in Figure 7, variant parameters influenced the droplet diameter from the qualitative development. At 40 MPa of injection, orifice diameter of 0.12mm with 700 K of ambient temperature shows more droplets with red in colour which represented as bigger droplet size compared to the 0.12 mm at 500 K. These results can be related to the prediction of droplet diameter could be influences by various parameters especially higher ambient temperature and injection pressure is predicted to generate smaller droplet diameter. However, smaller orifice diameter can also produce finer droplet diameter from the spray. Other than that, droplet diameter also depends on the aerodynamic drag in the chamber which can affects the smaller droplet diameter generates when the air collision with fuel. Nevertheless, little fuel injected is assumed to have lower combustion in the chamber as referred from the results prediction.

3.1.1 Penetration length

Ambient temperature has a strong effect on length of penetration, while injection pressure is predicted to have only slight effect on penetration length. However, the effects of most parameters and the mechanisms by which any of the parameters controlling penetration length are not completely understood. Apart from that, Figure 8 shows the visual penetration flow by single orifice simulation. The penetration length is considered from the outer of orifice until the tip of spray. The graphs plotted of penetration lengths against the time with two ambient temperatures of 500 K and 700 K for two different orifice diameters, 0.12 mm and 0.2 mm as shows in the Figure 9 and 10. The graphs showed penetration lengths for both ambient temperatures and also for both 0.12 mm and 0.2 mm orifice diameters increase constantly with the time taken. Besides, the penetration lengths for both

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ambient temperatures were not given much difference. This situation can be assumed as due to not much difference between the ranges of temperature.

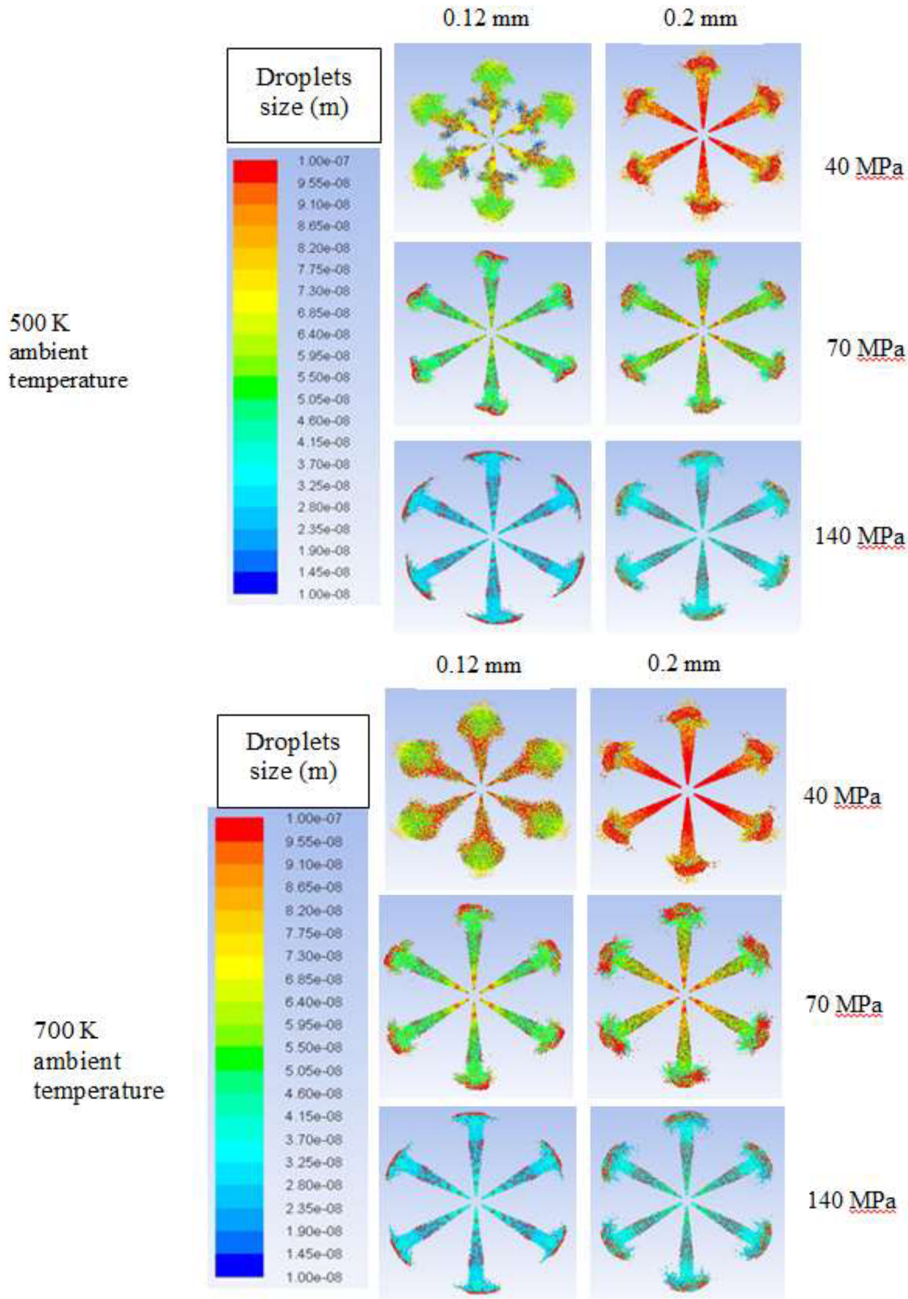

Fig. 7. Spray structure of droplet diameter produced by six nozzles, with colour scale represents the droplet diameter.

However, the injection pressure is also influenced the spray penetration length. The variant injection pressures applied which are 40 MPa, 70 MPa and 140 MPa with ambient pressure 4MPa in the chamber. As the higher injection pressure, the longer length of

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penetration due to the spray was resisted with the ambient pressure. Meanwhile, penetration length for the 0.12 mm orifice diameter performed a longer penetration compare to the 0.2 mm orifice diameter. This result can be explained by the bigger orifice diameter produces larger droplets and spray penetration travel become slower. Nonetheless, the spray will still hit the wall of chamber when it is at the end of injection.

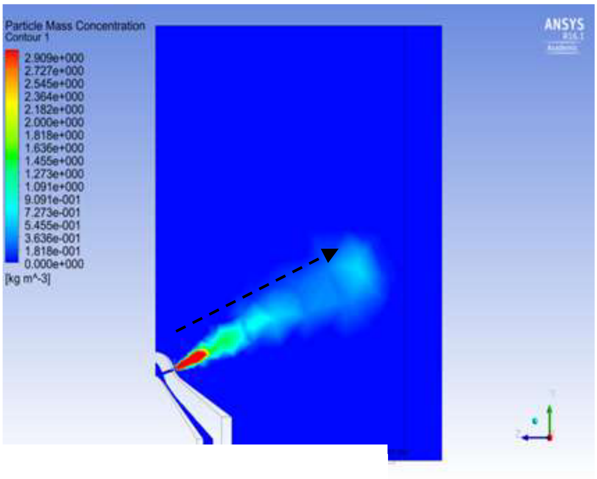

Fig. 8. Visual of penetration flow in simulation.

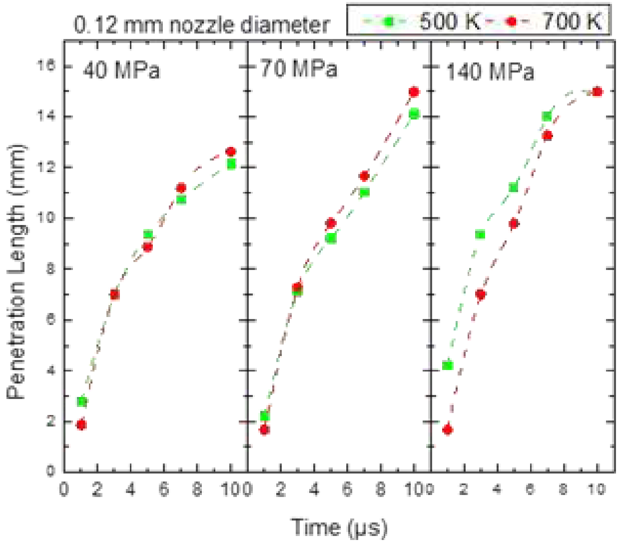

Fig. 9. Graph penetration length with orifice diameter of 0.12 mm.

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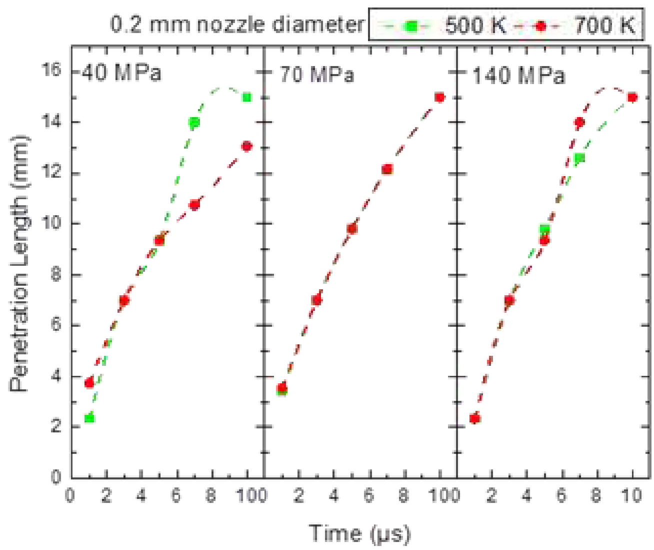

Fig. 10. Graph penetration length with orifice diameter of 0.2 mm.

3.1.2 Breakup length

The breakup length decreased with an increase of injection pressure. The decreased in breakup length could reduce the size of combustion in chamber. Moreover, Figure 11 shows the visualisation of breakup length from a single orifice simulation. The breakup lengths are measured by considering the tip of the spray diesel and the red contour as circuited in Figure 11. Besides, Figure 12 and 13 shows the graphs of breakup length based on the different orifice diameters.

The result of temperature 700 K shows slightly fluctuation, where injection pressure 140 MPa with orifice diameter of 0.12 mm implemented dramatically increases from 0.5 mm stood up to the 1.6 mm. On the contrary, the result of breakup length with temperature 500 K shows almost constant contribution. This phenomena is possibly due to the droplets did not breakup completely and they travelled further while caused the breakup length longer, which also called as the section of ligament. In addition, the breakup length for 140 MPa of injection pressure in orifice diameter of 0.2 mm shows flow steady with the time for both temperature 500 K and 700 K. Thus, it can be assumed that the breakup length could be influenced by ambient temperature used. Other than that the shorter breakup length happened at the core segment. The high injection pressure influenced to the breakup length, where the higher injection pressures caused shorter core of the breakup length which has been identified as shown in the Figure 12 and Figure 13. Nevertheless, diameter of orifice also plays an important role for the spray characteristic to being identified for the better combustion.

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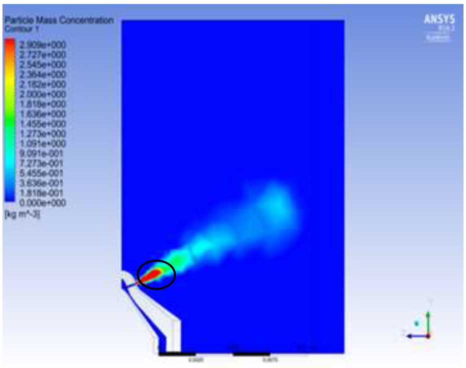

Fig. 11. Visualization of breakup length in simulation.

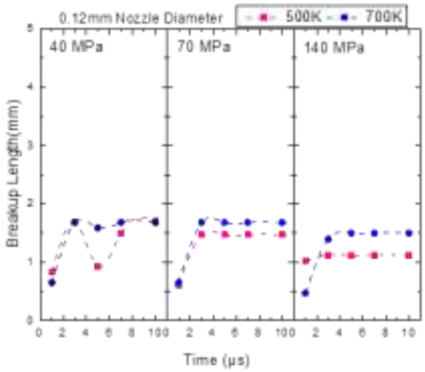

Fig. 12. Graph of breakup length with orifice diameter of 0.12 mm.

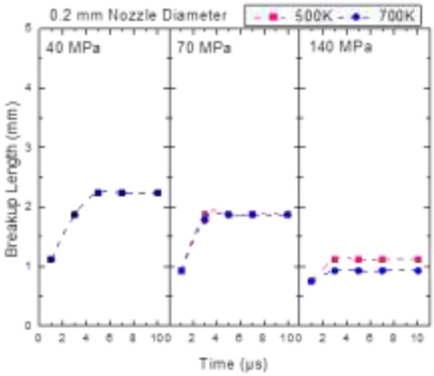

Fig. 13. Graph of breakup length with orifice diameter of 0.2 mm.

4 Conclusions

This study has shown a simulation of fuel-air flow through the orifice of injector to simulate a spray before the step of combustion. This study also found that the injection pressure and ambient temperature used influenced the formation of a spray in the chamber. This simulation was conducted with two different orifice diameters which are 0.12 mm and 0.2 mm. Ambient temperatures 500 K and 700 K are used in this study, while the ambient pressure applied in the chamber is 4 MPa. The results showed that the breakdown of fuel spray is been disturbed at low injection pressures in the chamber. Besides, very fine droplets are needed to start ignition at the fuel injection section. Moreover, temperature changed in the chamber also affected the spray penetration length. At the temperature of 700 K penetration length is predicted shorter than 500 K. For high ambient temperatures, fuel is assumed to evaporate more easily and faster ignition the fuel itself. In this simulation, the diameter of orifice is also predicted to give significant effect to the breakup length of the spray. The breakup length generated by 0.2 mm orifice diameter is longer than the 0.12 mm. Other than that, higher injection pressure also predicted to influence the breakup length of the spray, where the breakup length is shorted when high injection pressure applied. Last but not least, this simulation can be predicted that the injection pressure, ambient temperature and orifice diameter could affect the droplets diameter, penetration length and spray breakup length in the chamber.

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