EFFECT OF SOOT PARTICLE DIAMETER TO SOOT MOVEMENT IN DIESEL ENGINE

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ABSTRACT

Soot is one of the end product produced from the combustion of diesel engine. It can adversely affect the performance of the engine. It can cause the lubricant oil to be dirty thus increase its viscosity. These will results to frequent change of lubricant oil. Therefore, the focus of this study is related to the mechanism soot particles movement during the combustion process in the cylinder of diesel engine. The study of the path movement of soot particles from the initial position where it was formed to the last position was carried out. To analyze their movements, the data formation of soot particles was obtained through the simulation of combustion engine using Kiva-3V software which was used in previous investigation. The data that were obtained from the Kiva-3v simulation were velocity vectors of the soot, fuel, temperature, pressure and others. This data is used in the MATLAB routine to calculate the location of soot particles in the combustion chamber. Mathematics algorithm which is used in the MATLAB routine is trilinear interpolation and 4th order of Runge Kutta. In this study, the influence of soot particles diameter with different angular (θ) is included in the calculation to determine its movement. Results from this study shows that if the size of soot particles is bigger, the probability of the movement of soot particles to the combustion chamber wall is high thus contaminating the lubricant oil.

KEYWORDS*: Soot, Kiva-3V software and drag force.*

1.0 INTRODUCTION

In recent decades, diesel engine is among an alternative power source have been widely used for cars due to the efficiency and economically (Lloyd, 2001). In the European Union, diesel engine cars

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have surpassed the market performance of gasoline cars. Besides that, more than half (53%) of the European Union using diesel engine in a new car market share in 2007 (Mahmood, 2011). This rapid growth is because of advantages of modern high-speed diesel engine in terms of fuel economy, remarkable low-end torque and overall performance (Mahmood, 2011). Despite of these advantages, diesel engine has its drawbacks especially from an environmental perspective. During combustion, diesel engines release dangerous and harmful substances including particulate matter (soot), toxic metals, nitrogen oxides that form ozone and nitrate particulate matter, volatile organic compounds, carbon monoxide (CO), carbon dioxide (CO2), and variety of toxic metals and gases such as formaldehyde, acrolein, and polycyclic aromatic hydrocarbons (PAH). In 1994, the limit of particulate matter emission that coming out from heavy duty of diesel engine is (0.1 g/bhp. hr) and become stricter and tighter in the future (Abraham et al., 1996). On the other hand, Clean Air Act stated that emissions from diesel engine contain 40 hazardous air pollutants and known as carcinogen (California Air Resources Board, 2000). Despite of environmental perspective, emission of diesel engine like soot also causes bad effect to the engine itself.

Particulate matter contains solid soot particles which will contaminate the lubricant oil, thus viscosity of the lubricant oil increases. Subsequently the walls of the combustion chamber will not be adequately coated which will increase its wear (Mahmood, 2011). Besides that, when the viscosity of the lubricant oil increases, the interval between oil changes will also increase (Mahmood, 2011). The wear mechanism due to the soot is still not fully understood, therefore fundamental study about this area is needed. Previous researchers investigated on soot distribution in a diesel engine by using the CFD software, Kiva-3v (Abraham et al., 1996). (Hong et al., 2005) carried out a soot particle size prediction along its path using combination of Hiroyasu's soot formation and Nagle and Strickland-Constable soot oxidation rate expression. Meanwhile, (Seykens et al, 2009) also developed a model for soot formation process in diesel engine which follows the conceptual view of diesel spray combustion. On the other hand, this model uses zero-dimensional approach, which makes the model efficient and suitable as simulation tool.

According to (Suhre and Foster, 1992), in order to indentify and understand soot formation, wall deposition mechanisms are important to be explored. The wall deposition mechanisms are electrophoresis, inertial deposition, gravitational sedimentation and thermophoresis. Among these mechanisms, thermophoresis is the most important mechanism. This study is supported by (Rosner et al, 1991). Besides that, (Rosner et al, 1991) stated that to determine soot movement, it is essential to understand some force acts to the particles like drag, electrostatic, gravitational, acoustic, diffusiophoretic and thermophoretic Besides that, (Mahmood, 2011). Focusing more on analysis of soot path in the diesel engine. This study investigated soot particle movement in diesel engine by considering crank angle and applying in MATLAB routine. Soot formation that had been developed was not included wall deposition mechanisms into consideration (Mahmood, 2011). Besides simulation, some researchers did the study by experimental such as (Ping, 2003) and (Mancaruso, 2012). (Mancaruso, 2012) designed and developed an optical engine to investigate the combustion process starting from fuel injection to complete combustion. This study only focusing on combustion energy but not towards soot formation. Ping and Seitzman (Ping, 2003) focusing on measurement of soot concentration. By using Laser Induced Incandescence (LII), soot particle reacts with the high power laser and absorbs the laser heat. Subsequently the incandescence of soot increases. Even though there are numerous study towards soot formation and combustion process but the study towards soot concentration experimentally in a diesel engine is less numerous.

Therefore, the purpose of this proposed research is to investigate soot movement at a certain crank angle in combustion chamber. In this study, the influence of soot particles diameter with different angular (θ) included in the calculation to determine its movement. This investigation represents a first step towards tracking the soot movement path and evolution of particles from nucleation to final mass and form, and to allow future development in order to increase the performance of diesel engine. Furthermore the diesel engines have potential to be used as hybrid vehicles to achieve lower emission target in the future. In addition, this study is aligned with government policy such as Malaysia National Automotive Policy (NAP) which promotes green technology that targeted by 2020, 10% of all cars in Malaysia should be of electric and electric hybrid vehicles (Sustainable Mobility, 2011).

2.0 METHODOLOGY

This study focus on simulation using MATLAB software based on Kiva-3v. Kiva-3v is a modeling platform to investigate soot formation in an internal combustion chamber. Kiva-3v was used in previous investigation to obtain data of in-cylinder soot formation. The data that were obtained from the Kiva-3v simulation were velocity vectors of the soot, fuel, temperature, pressure and others (Mahmood, 2011). The engine has a bowl-in-piston and flat cylinder head face configuration, with a seven-hole injector installed vertically and centrally. The schematic diagram for crown piston configuration is shown in Figure 1.

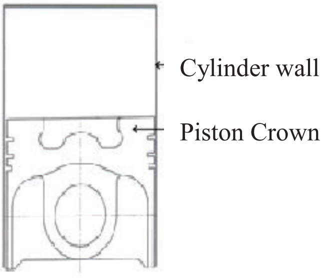

Figure 1. Crown piston Configuration

In Kiva-3V there are two method to determined the formation of soot in a combustion chamber, which is individual tracking and cumulative tracking. This studies focusing on the individual tracking. The starting location of soot can be determined by considering it the velocity same as that particular flow. The combustion chamber mesh is shown in two ways view (side and top) as in Figure 2.

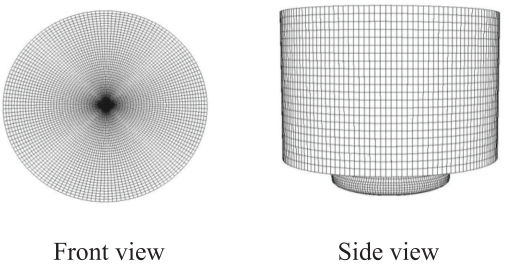

Figure 2. Meshing Model of Combustion Chamber

The simulations were carried out for the combustion system of a 4 valve DI diesel engine from inlet valve closing (IVC) to exhaust valve opening (EVO). The specifications of the engine are bore × stroke: 86.0 × 86.0 mm, squish height: 1.297140330 mm, compression ratio: 18.2:1 and displacement: 500 cm3, speed: 2500rpm. The details of the specification of engine and mesh specification are shown in Table 1 and Table 2 (Mahmood, 2011).

Table 1. Specifications of the Engine

Parameters	Specifications
Engine Type	4 valve DI diesel
Bore × Stroke	86.0 × 86.0 mm
Squish height	1.297140330 mm
Compression Ratio	18.2:1
Displacement	500 cm^3
Piston Geometry	Bowl-in-piston

Table 2. Surface Meshing Specification

Parameter		Surface mesh
Total number of cells		201,900
Number of cells	Azimuthal	150
	Radial	37 (20 bowl area)
	Axial	39 (15 bowl area)
Separation	Azimuthal	2.4°
	Radial (mm)	0.83 – 1.15
	Axial (mm)	0.99 – 3.63

The soot movement starting from its formation which is after combustion process until the exhaust valve is open can be predicted by using numerical method. Euler method or also known as first stage of Runge-Kutta method is an easy way to calculate and determine the soot location. This method takes velocity at a certain location as soot's velocity, and considered distance traveled by the soots. In order to get an accurate value, higher stage of the Runge - Kutta method can be used. And as for this study 4th Stage of Runge-Kutta is used to calculate the soot's location. On top of that, to investigate soot velocity at every condition trilinear interpolation method is used. In this study, the drag force equation is included in the simulation to determine soot movement. The drag force equation is

$$F_d = \frac{1}{2}\rho v^2 C_d A \quad (1)$$

Fd is the force of drag, ρ is the density of the fluid, v is the velocity of the object relative to the fluid, A is the area and C_d is the drag coefficient. To analyze the movement of the soot particles, it is necessary to identify the initial position of the soot particle. This can be found based on the zone of soot distribution with certain crank angle ATDC. After selecting the crank angle and zone, the starting coordinate in radial (rho), angular (θ) and axial direction (z) were also decided. Soot particle movement paths have been studied by considering reasonable crank angle. Data from the simulation is used in MATLAB routine to calculate and identify the soot location. In present paper the reasonable crank angle that is investigated in is at 8° ATDC. 8° ATDC is the intermediate of fuel injection which contains soot particle moves towards the bowl wall. There are a few assumptions done to run the MATLAB routine. Some of the mechanisms are reaction such as thermophoresis, newton respiration, and electrophoresis are neglected. In addition, the soot will not reflect if collided with the combustion chamber wall, instead it will stick to the combustion chamber (Mahmood, 2011).

The locations which are considered in this studies: a) Rho=1.8cm, θ=15º and z=8.8cm, b) Rho=1.8cm, θ=25º and z=8.8cm and c) Rho=1.8cm, θ=45º and z=8.8cm. MATLAB routine will run at 8º ATDC of crank angle by using different diameter size of soot which are 300nm, 3000nm, 5000nm, 20000nm, 30000nm and 40000nm. Data from the simulation is tabulated in graph as shown in the results below, where by the front view and side view of the combustion chamber is displayed. The colors show the different type of soot diameter. This study focusing on the influence of soot particles diameter with different angular (θ) to the soot particle movement path in the cylinder.

3.0 RESULT AND DISCUSSION

The results of MATLAB routine show that soot movement in the diesel are different based on diameter of soot particle. In Figure 4, Figure 5 and Figure 6 show 2 parts of pictures. At left side is respectively top view and right side is side view of a half of combustion chamber of diesel engine. Sensitivity of soot particle location, starting point within each zone in radial (rho), angular (θ) and axial direction (z) should be identified first. This studies consider three part of location which are a) Rho=1.8cm, θ=25º and z=8.8cm, b) Rho=1.8cm, θ=45º and z=8.8cm. From the result, it was found that most of the soot particles move up and then move down when piston moves down.

It can be observed in Figure 3, that big size of soot particle has high tendency to go near to cylinder wall than the small size. Most of the soot particles move in anti-clock wise motion and go near to the cylinder wall which is within 2mm distance. Besides that, it was found that when the diameter is 300nm, 3000nm and 5000nm the soot particle paths are not avaible in the graph. It is because soot particles follow the velocity of air flow in the combustion chamber.

a) Rho=1.8cm, θ=15º and z=8.8cm

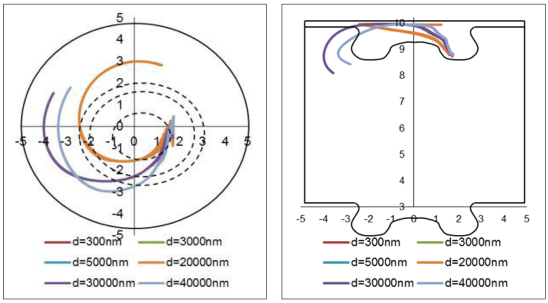

Figure 3. Soot movement during rho=1.8cm, θ=15º and z=8.8cm

Soot particle in Figure 4 are observed to behave almost similar to Figure 1 eventhough the parameter of angular (θ), is different. In addition ,it can be seen that an increase of soot particle size, decreases possibility of soot particle to move closer to the cylinder wall. It can also be observed that most of soot path were moved radially inwards, and axially upwards. This is due to the fuel jet. The effect of fuel jet to the bulk fluid plays a big role in order to move soot particle into squish region (Mahmood, 2011).

b) Rho=1.8cm, θ=25º and z=8.8cm

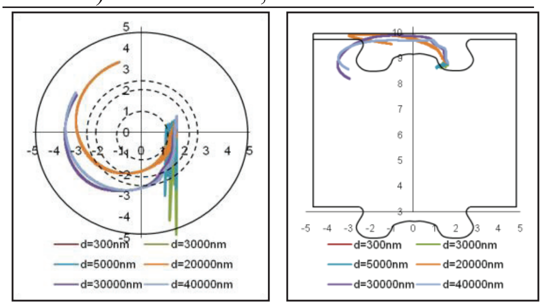

Figure 4. Soot movement during=1.8cm, θ=25º and z=8.8cm

It can be also seen in Figure 5, the bigger size of soot particle goes easier near to the cylinder wall than small size of soot particle. Soot particles which are stick to the cylinder wall will contaminate engine oil. Therefore, it is suggested to improve design of piston or fuel spray angle based on the this result study.

a) Rho=1.8cm, θ=45º and z=8.8cm

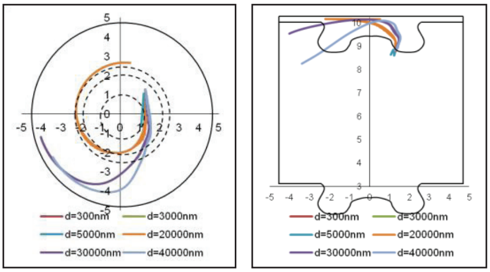

Figure 5. Soot movement during rho=1.8cm, θ=45º and z=8.8cm

4.0 CONCLUSION

In order to reduce lubricant oil contamination is to minimize the transfer of soot particles to the cylinder wall. By understanding the movement path of soot particle in diesel engine, measures to reduce soot particle movement towards the cylinder wall can be identified. Most of the bigger soot particles move upwards and anti-clockwise motion approaching the cylinder wall. Soot particle movement in a diesel engine depends on the diameter of the soot particle. Small size of soot particle has low possibility to go the cylinder wall. The modification of the bowl, piston shape and spray angle is expected to reduce the possibilities of the soot particle moving towards the cylinder wall. This will be investigated further in the future.

5.0 ACKNOWLEDGEMENT

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