THE EFFECT OF DIESEL AND BIO-DIESEL FUEL DEPOSIT LAYERS ON HEAT TRANSFER

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ABSTRACT: The adhesion of deposits on the combustion chamber wall surface affecting the heat transfer process in an engine that cause engine knock, increase NO_x and increase soot generation during the combustion process. The effect will be more significant when utilizing bio-diesel fuel due to its higher density and viscosity. Thus, this study is intended to investigate the effect of diesel and bio-diesel fuels deposit layers on heat transfer. In this study, deposit layer of diesel fuel (DF) and 5% palm oil based bio-diesel fuel blends (B5) were prepared for surface temperature at 250°C and 357°C by using a hollow cylinder heater. Then, the hollow cylinder covered with deposit layer in its inner surface was inserted in a heat transfer chamber apparatus to investigate its effect on heat transfer to surrounding. Deposit layer for DF that was prepared at surface temperature of 357°C was able to act as insulator which prevents the heat from transferring to the surrounding compared to deposit layer formed at lower surface temperature. However, deposit layer of B5 prepared at surface temperature of 250°C have better insulator properties compared to DF at the same surface temperature.

KEYWORDS: *Fuel Deposit Layer; Heat Transfer; Bio-Diesel; Fuel Spray; Heater*

1.0 INTRODUCTION

Deposits or carbon deposits may be defined as heterogeneous mixtures made up of carbon residue (ash), carbonaceous mixtures (soot) and oxygenated resinous organic material that bind together as mixtures [1]. It can also include any number of materials, excess, or residue that is gradually grown or accumulated on critical parts of an internal combustion engine [2]. Deposits on the various parts of an engine cause substantial impact on engine performance, fuel economy, cold-start, warm-up drivability, and exhaust emission through various problems such as lowering the fueling rate, restricting air flow, increasing compression ratio, altering spray pattern, inducing knock, degrading thermal conductivity, and reducing catalyst reactivity [3]. In modern engine design, deposit formation in the engine increases unburned hydrocarbon (HC) due to adsorption and desorption of HC by the deposits. NO_x emissions also increase due to the insulation effect and heat storage of the deposits that increase the gas temperature in the combustion chamber.

In general, the highest heat flux occurs in the center of the cylinder head and near the exhaust valve seat, and at the center of the piston crown [4]. The greater amount of deposits usually accumulated on the piston which is the most highly stressed part [5] and also on the area closer to the fuel injection nozzle [6]. The highest thickness of deposit layer was found on the edge of the piston bowl where the average temperatures are relatively lower. The lower deposit mass with rising piston temperature is evident as mentioned by Eilts [7]. The combination of low wall temperature and unburned fuel cause greater deposit formation in a combustion chamber. Hence, the area where fuel spray was expected to be impinged obtained a greater amount of adhered deposits as mentioned by Yamada [6] and Akop [8-9], Zhou [10] and Yang [11].

Unburned fuels that adhere on the combustion chamber surface are involved in heating and vaporization processes that form deposits on its surface. The deposit layer will act as a thermal insulator where it affects heat release in the combustion chamber. Yamada [6] and Ishii [12] found that the variation of instantaneous surface temperature and heat flux was caused by the amount of deposit adhered on a wall surface. Low thermal conductivity of deposits cause conduction rate reduction and retards the capability of heat release from the combustion chamber. The increased surface temperature of the deposits leads to a reduced temperature gradient in the gas as mentioned by Lepperhoff [13]. As a result, an overheating of the cylinder wall occurs in the combustion chamber, which can further cause engine knock and fuel degradation which will cause more deposits, increase in combustion flame and exhaust gas temperature as mentioned by Ye et al. [3].

Combustion chamber deposits (CCD) that form on both piston tops and cylinder heads could adversely affect the operation of an engine. The CCDs affect ignition not only due to the variations in heat transfer during intake or compression, but also produce an additional strong effect on bulk burning due to altered near-wall boundary conditions [2]. Such effects can lead to various forms of abnormal combustion such as the existence of hot spots that cause uncontrolled surface ignition which leads to knocking [14]. Another form of abnormal combustion can result from heat regeneration and thermal insulation effects leading to auto-ignition knock that results in octane requirement increase (ORI) [4] and loss of engine power through spark advance reduction [14].

These clearly explained that how significant the effect of deposit layer on heat transfer in an engine. Thus, it is important to investigate this phenomena especially when it involves the utilization of bio-diesel fuel that have greater tendencies in deposit formation compare to the typical diesel fuel. Currently, there two type of investigation available. First is a real engine deposition investigation which concentrate more on critical part of the engine such as piston head, valves and injector [4-6] and only few of them investigate combustion chamber wall deposit effect in a real engine [6, 12-13]. Secondly is a fundamental research on deposit formation on a flat and curve surface, which try to understand the mechanism of deposit formation on a hot wall [15].

Based on previous research, there is a lack of fundamental study for deposit formation on combustion chamber wall due to fuel spray impingement. Due to these reasons, this study intends to investigate the effect of diesel and bio-diesel fuels deposit on heat transfer due to secondary fuel spray impingement on a combustion chamber wall. By introducing hollow cylinder heater which represents the hot combustion chamber wall, the understanding of the effect is significant for further investigations that involve with deposit in an engine.

2.0 METHODOLOGY

In this study, there were two parts of experiment were introduced. First, the experiment involved the formation of deposit layer for different type of fuel at different surface temperature condition by using a hollow cylinder heater in a spray chamber. Second, a heat transfer investigation was conducted where the hollow cylinder from the first experiment with deposit layer on its inner surface was moved into a heat transfer chamber apparatus. Thus, further investigation on the effect of the deposit layer on the heat transfer to surrounding could be made.

2.1 Deposit Layer Formation

Figure 1 shows the schematic diagram of a hollow cylinder heater apparatus. The apparatus consists of a heater support, hollow cylinder, flat plate, cartridge heaters, heater body, heater base and thermocouples. The apparatus was used to develop a fuel deposit layer on the inner surface of the hollow cylinder. The hollow cylinder is made from an aluminum alloy which is placed inside the heater. There are six units of cartridge heaters inserted in two different parts of the heater body with a power of 1000 Watts each. One thermocouple was located at both part of the heater body which is inserted very close to the hollow cylinder outer surface. Both thermocouples were connected to the temperature controller in order to maintain the temperature of both part of the heater body at the specific value needed. However, there was also a thermocouple located at the based of the heater to measure the hollow cylinder temperature.

A flat plate was located at the center position of the heater to make sure the fuel spray that impinge on the plate surface will produce secondary spray to create the deposit layer on the inner surface of the hollow cylinder. The temperature of the heater is set at a constant temperature and the temperature is controlled by a temperature controller. The temperature of the heater was set at 250°C and 357°C. These temperature are represent the temperature that far from and close to the maximum evaporation rate point (MEP) of fuel tested [15], respectively. The different temperature used in this study is to obtain different features of deposit layer for the fuel tested.

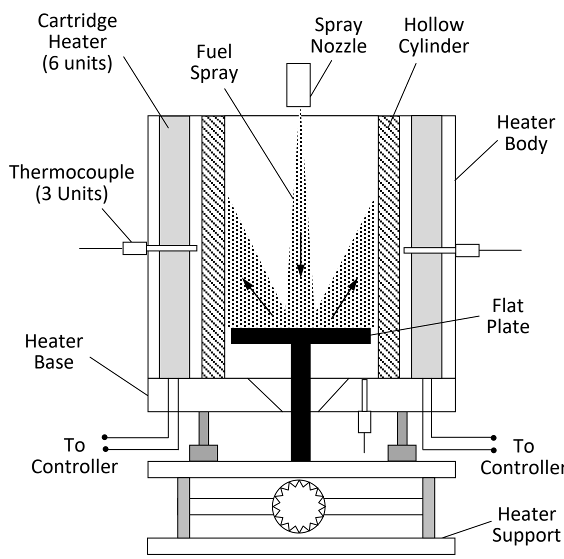

Figure 1: A hollow cylinder heater apparatus

In order to develop a fuel deposit layer in the inner surface of the hollow cylinder, the heater apparatus was combined with a fuel spray system. The combination of fuel spray system and the hollow cylinder heater apparatus was called fuel deposit layer apparatus. The fuel deposit layer apparatus consists of temperature controller, fuel injection system, hollow cylinder heater apparatus and fuel vapor trap system. During the experiment, fuel vapor was filtered by the fuel vapor trap system before it was released to the surrounding.

After all the equipment and safety procedure were set up, the hollow cylinder heater switches were turned on and the temperature was set gradually with an increment of 100°C until the temperature of the heater reached 250°C by controlling the temperature controller. After the temperature was set, the fuel spray was introduced in the holow cylinder heater for 15 minutes. Fuel spray impinged on the flat plate surface to produce secondary fuel spray impingement on the inner wall surface of the hollow cylinder.

Layer of fuel covered the surface causes the formation of deposit layer after it remained on the hot surface for certain period of time. After the 15 minutes of fuel spray completed, all the heater switches was turned off. The hollow cylinder was allowed to cool down to the ambient temperature before it was removed and inserted into the heat transfer chamber apparatus. Photograph of the deposit layer were captured at four different locations as shown in Figure 4. This is important to understand the effect of deposit layer on heat release from the center of the hollow cylinder to surrounding. After the deposit layer preparation was completed, the hollow cylinder covered with the deposit layer on its inner surface was inserted into a heat transfer chamber apparatus. The hollow cylinder must be marked at first so that when the cylinder was inserted in the heat transfer chamber apparatus, it will be inserted at the same position to make sure the consistency of the data obtained.

2.2 Heat Transfer Test

The heat transfer chamber apparatus was designed to insert the hollow cylinder in it. The purposed of the chamber is to test the deposit layer effect on heat transfer through the hollow cylinder. Figure 2 shows the heat transfer chamber and its components. The system consists of a chamber, a data logger, thermocouples and a control panel which is to control the temperature of the cartridge heater at the center of the chamber.

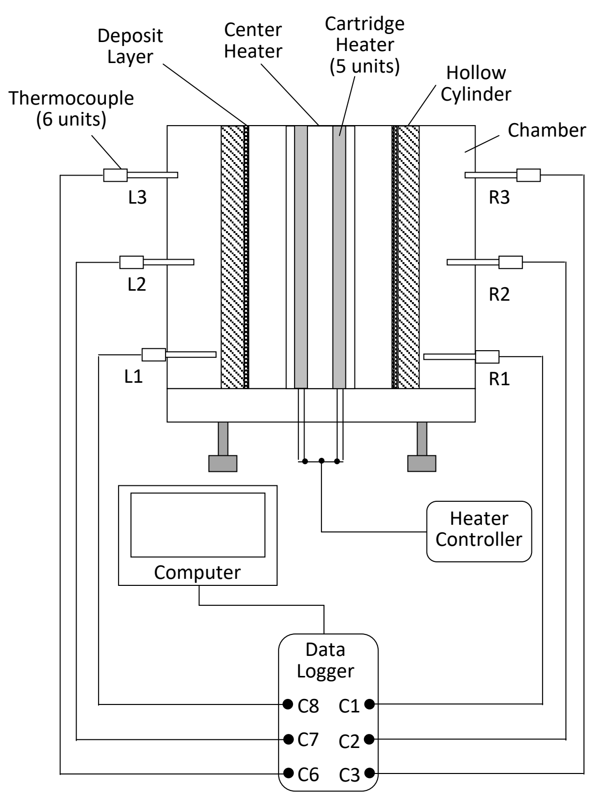

Figure 2: Heat transfer chamber apparatus

The hollow cylinder that was covered with deposit layer on its inner wall surface was tested in the heat transfer chamber to investigate the deposit layer effect on the heat transfer. The test took place in a closed chamber and the time taken for the heat loss in term of temperature difference is measured for 30 minutes. The cartridge heater was used as a heat source at the center of the chamber. The center heater was heated by the cartridges until its temperature reached 200°C. After the temperature was reached, the condition was kept for approximately 10 minutes to stabilize the temperature condition. Then, the hot hollow cylinder with the deposit layer on its surface was inserted in the chamber for the heat transfer test. The chamber body temperatures were measured continuously for 30 minutes. The temperatures were measured by six thermocouples which were inserted in the chamber body at different wall thickness. The heat transfer chamber apparatus was connected to the data logger which was used to record the temperature measured by the thermocouples. In this experiment, there were six thermocouples used by the data logger which connected to six different channels (C1, C2, C3, C6, C7 and C8). These channels were connected to the thermocouple positions which labelled as R1, R2, R3 for the right side position and as L1, L2, L3 for the left side positions.

3.0 RESULTS AND DISCUSSION

This section presented data and analysis in terms of deposit layer features and temperature difference profile for each case in order to investigate the heat transfer from the center of the heat transfer chamber to surrounding. The data and analysis are presented for deposit layer of DF and B5 that prepared at surface temperature of 250°C and 357°C.

3.1 Fuel Deposit Layer Features

Figure 3 shows the features of fuel deposit layer obtained from the deposit layer formation experiment. The results are for deposit layer of DF and B5 prepared at surface temperature of 250°C and 357°C. Four different locations were chosen for observations which are referring to location No. 1 until No. 4. Figure 3(a) shows the deposit layer for DF prepared at surface temperature of 250°C. It seems that most of the deposit layer formed at location No. 4 followed by location No. 3 and No. 1. Lowest deposit formation was at location No. 2. These conditions occurred due to the spray pattern for secondary spray after the first spray impinged on the flat plate. Based on the result, it shows that more secondary spray impingements [8] at location No. 4 and less spray at location No. 2. The location with greater deposit layer covered has higher potential to become an insulator to prevent heat transfer [6] through the hollow cylinder wall. The yellowish color of the deposit layer shows that the deposit layer was in the form of liquid fuel film. The surface temperature of 250°C and the short time of liquid fuel remaining on the wall during the deposit layer formation process cause the deposit layer to still be in liquid film form.

Figure 3(b) shows the deposit layer for DF prepared at surface temperature of 357°C. The surface temperature at this condition was the temperature where the DF has maximum rate of evaporation [15]. This means the condition that left less deposit remain with higher possibility to have solid deposit layer formation. According to Figure 3(b), location No. 4 and No. 1 have similar features with greater area of deposit layer formation compared to location No. 2 and No. 3 with lesser area of deposit layer. The result is quite different from that in Figure 3(a) when the deposit layer of DF prepared at 250°C. The deposit layer prepared at 357°C covered almost all areas on the inner surface of the hollow cylinder. These areas covered the bottom, middle and most of the upper parts of the inner surface. This phenomenon is probably due to the effect of the higher evaporation rate at surface temperature of 357°C [15] and thus less fuel adhered at the upper part of the inner surface. The black color of the deposit layer shows that the deposit layer formed was a carboneous solid deposit layer. The surface temperature of 357°C is the highest evaporation rate point for DF. Thus, most of the liquid fuel evaporates, leaving behind the solid remains on the wall surface.

Figure 3(c) shows the deposit layer for B5 prepared at surface temperature of 250°C. Generally, all locations have less deposit layer formation compared to the result obtained for DF at the same surface temperature. It seems that greater area of deposit layer covered the inner surface for location No. 3, followed by location No. 1, No. 4 and No. 2. According to Arifin [15], at the surface temperature of 250°C, B5 has longer evaporation lifetime compared to that of DF. This means that, it is supposed that B5 will have more deposit layer in liquid film form compared to DF.

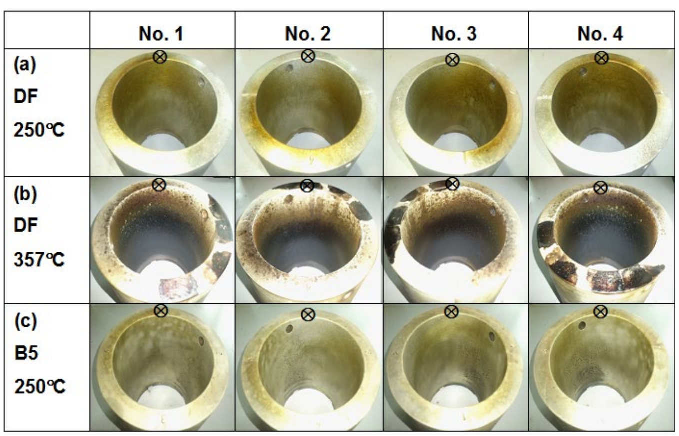

Figure 3: Deposit layer formations for (a) DF at surface temperature of 250°C, (b) DF at surface temperature of 357°C and (c) B5 at surface temperature of 250°C

3.2 Heat Transfer Profile

Figure 4 shows the location of photograph taken and thermocouple locations from the top view of the heat transfer chamber apparatus. However, Figure 5 shows the dimension of the hollow cylinder and the chamber body from the side view. Figure

5 also shows the exact location of the thermocouples that were inserted into the chamber body which was used to measure the temperatures recorded by the data logger. Three units of thermocouples were used to measure the right side of the chamber and another three units on the left side of the chamber. The depth of the thermocouple inserted into the chamber body are at different depth which were 7 mm, 15 mm and 27 mm for both sides which represent the upper, middle and bottom parts of the chamber, respectively.

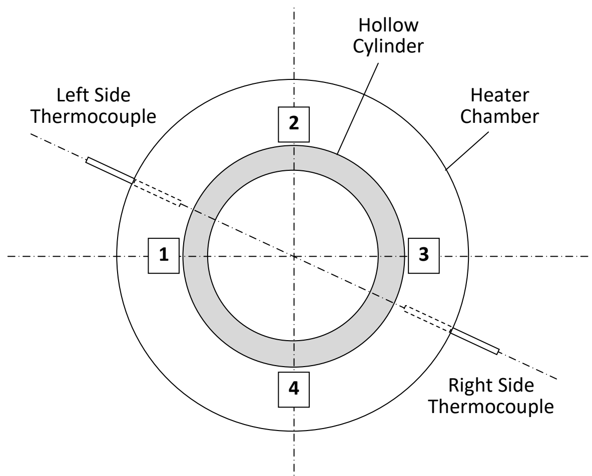

Figure 4: Photograph taken and thermocouple locations

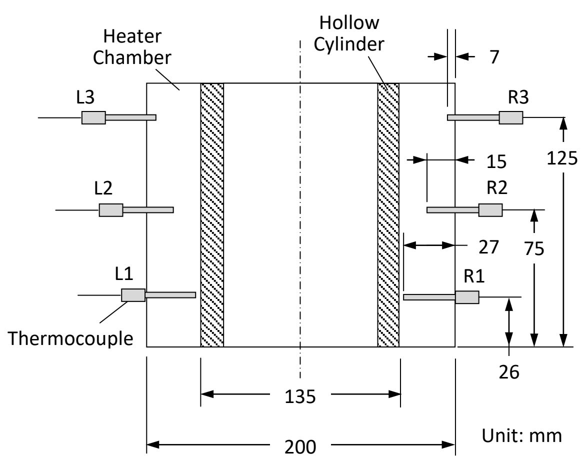

Figure 5: Dimension of the hollow cylinder and the chamber body

Figures 6 and 7 show the results of temperature difference between initial temperature (T_i) at the beginning of the heating process and final temperature (T_f) after 30 minutes of heating process completed for both sides of the chamber body. In this experiment, it is important to understand that the higher the temperature difference for each thermocouple location, the lower the heat transfer rate to surrounding. This mean that at higher temperature difference, the deposit layer tend to keep the heat in the chamber because of the deposit layer act as an insulator to prevent the heat from transferring through the hollow cylinder and the chamber body to surrounding.

As for Figure 6, generally the highest temperature difference at all thermocouple locations was obtained by the hollow cylinder with deposit layer for DF prepared at surface temperature of 357°C. At L2 and L3, the temperature difference for deposit layer of B5 prepared at surface temperature of 250°C was slightly lower than deposit layer of DF prepared at 357°C, followed by DF at 250°C. However at location L1, the temperature difference for deposit layer of DF at surface temperature of 250°C was similar with deposit layer of DF at 357°C, followed by B5 at 250°C.

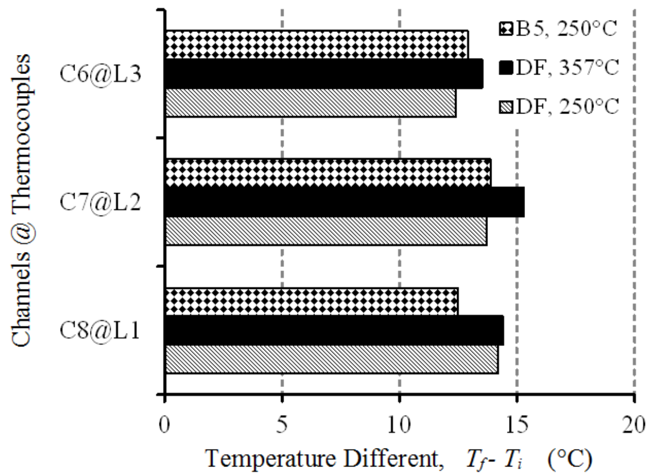

Figure 6: Temperature difference measured by left side thermocouples

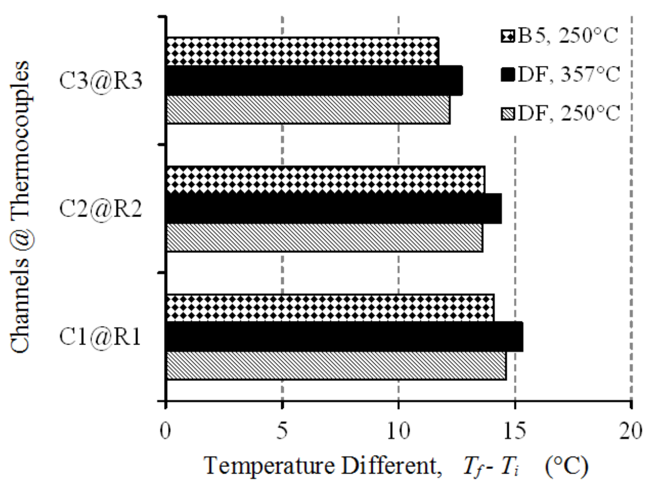

Figure 7: Temperature difference measured by right side thermocouples

Similar to the result obtained in Figure 6, Figure 7 generally shows the highest temperature difference at all thermocouple locations obtained by the hollow cylinder with deposit layer for DF prepared at surface temperature of 357°C. At R1 and R3, the temperature difference for deposit layer of DF prepared at surface temperature of 250°C was slightly lower than DF at 357°C, followed by B5 at 250°C. However at location L2, the temperature difference for B5 at surface temperature of 250°C was similar to that of DF at 250°C, but both are lower than DF at 357°C.

The inconsistency of result obtained at each location of thermocouples depends on the area that is covered by the deposit layer. By referring to the location of the thermocouples and the deposit layer features at different location, estimation of the dominant area covered by the deposit layer for DF and B5 prepared at surface temperature of 250°C and 357°C on the inner lateral surface of the hollow cylinder were summarize in Figure 8. Figure 8 shows the estimated dominant area that covered with deposit layer formation. The intensity of the dots in the deposit area represent the darkness of the deposit color. This information is very useful to explain the result of temperature difference obtained from the heat transfer chamber apparatus.

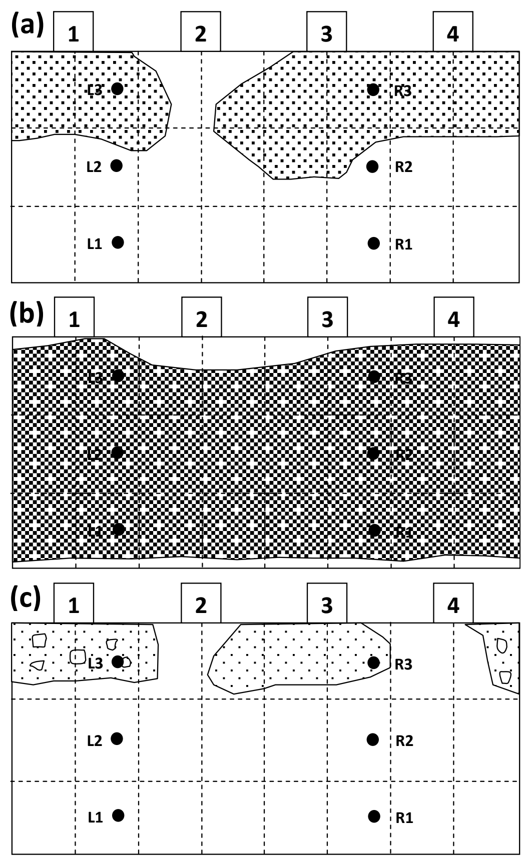

Figure 8: Dominant area covered by deposit layer on inner lateral surface of hollow cylinder for (a) DF, 250°C, (b) DF, 357°C and (c) B5, 250°C

From Figure 8(b), clearly can be seen that the inner surface of hollow cylinder was almost fully covered with deposit layer for DF prepared at surface temperature of 357°C. All location where the thermocouples are located were covered by the deposit layers. This features explain why the temperature difference for deposit layer of DF prepared at surface temperature 357°C was highest compared to others. However for deposit layer that form for DF at surface temperature of 250°C as shown in Figure 8(a), it covered almost all of the upper part of the inner hollow cylinder surface and a small area of the middle part of the surface. For this case, only area where thermocouples L3 and R3 were covered with deposits layer. These probably explained the results for temperature difference at L3 an R3. The other parts were seem to have no deposit layer or minimum deposit layers formed. The lower area covered by the deposit layer was for deposit layer of B5 at 250°C as shown in Figure 8(c). Only few area at upper part of the inner surface was covered with deposit layer which also covered the area of thermocouple at L3 and R3. The other areas seemed like free of the deposit layer formation.

When compared the result of temperature difference at L3 and R3 for deposit layer of DF prepared at surface temperature of 250°C and B5 at surface temperature of 250°C, both location covered with deposit layer, the difference in results for both was probably due to deposit layer properties of different type of fuel [15]. Probably the thermal conductivity [3] for deposit layer of B5 is lower than DF at this condition. However, similar result of temperature difference for both conditions at location L2 and R2 are because both locations are not covered or minimally covered with deposit layers.

4.0 CONCLUSION

This study intends to investigate the effect of diesel (DF) and bio-diesel fuels (B5) deposit on heat transfer due to secondary fuel spray impingement on a combustion chamber wall. In order to investigate the fuel deposit layer effects on heat transfer of a chamber wall, temperature differences for DF and B5 deposit layers that were prepared at surface temperature of 250°C were compared. There are no obvious difference in term of temperature difference for both cases. Thus, the deposit layer of B5 probably has similar properties of insulation with DF as shown by the type of deposit layer formed for both cases which are in liquid film form. In term of surface temperature effect, temperature difference for DF deposit layers prepared at surface temperature of 250°C and 357°C were compared, the deposit layer prepared at 357°C covered most area on the inner surface of the hollow cylinder with a carbonecous solid deposit layer. Different with the deposit layers that were prepared at surface temperature of 250°C, deposit layer formed is in the form of liquid film deposit layer. Generally, higher temperature difference at all thermocouple locations obtained by hollow cylinder with deposit layer for DF that prepared at surface temperature of 357°C compared to deposit layer of DF at surface temperature of 250°C. From the results obtained, deposit features in term of deposit layer type (liquid film deposit or carbonecous solid deposit) and deposit features such as deposit thickness are affect the heat transfer process. Carbonecous and thick deposit layers act as insulator to prevent the heat transfer from the heat source to the surroundings. It is important to prevent this type of deposit layer from adhere on the inner surface of a combustion chamber. As the smooth heat transfer process to surroundings after the combustion occurred is a requirement for a real engine, the finding in this study is significant. High wall surface temperature will produce less deposit layer that cause better heat transfer through the chamber's wall.

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