Analysis of Spark Plug Gap on Flame Development using Schlieren Technique and Image Processing

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Abstract. Gasoline spark ignition system in cars remains one of the main consumption of fuel in the world nowadays. During combustion process, spark plug is one important key features in a gasoline engine. The incompatibility of spark plug gap width and the fuel used causing backfire and knocking in the combustion engine. Thus, the spark plug gap was studied with focussing in controlling the combustion process to improve the performance of the engine. The main purpose of this research is to investigate the effect of spark plug air gap on flame development. The parameters studied in this research include spark plug air gap width (1.0 mm, 1.2 mm, 1.4 mm, 1.6 mm and 1.8 mm), injection pressure (0.3 MPa, 0.4 MPa, 0.5 MPa and 0.6 MPa) and flame characteristics such as flame front area and the flame intensity. The flame front area of different spark plug gap and injection pressure were investigated through Schlieren photography method. The Schlieren images taken were analysed with the time changes. The experiment results proved that the increase of spark plug gap width will led to better flame development in shorter time while increased the chance of misfire.

Introduction

Generally, combustion in spark-ignition engines varies considerably from cycle to cycle [1-2]. Many studies have been carried out in order to find the main causes of this effect [3,4]. Over the past few decades, a number of studies have been conducted to understand the effects of spark plug design on spark-ignition engine performance in various aspects such as number of electrodes, shape, size, material, gap projection, and orientation are the main parameters under investigations [3]. The design of spark plug will greatly affect the ignition process and its subsequent combustion at the early stage of the combustion process,

By the end of 2012, there are only 235.8 million tonnes of proved oil reserve in the world. Therefore, it have become more concerned for the energy resources [5]. The main consumption of these energy resources are the vehicle. The electric powertrains is one of the substitute products for internal combustion (IC) engine. However, it still face many technological challenges and it is still are not widely used. In order to overcome the crisis of energy resources, IC engine need to be researched so that it can maximize the performance without exploiting the fuel [6-7]. Studies on automotive fuels are extensive but far from exhausted because fuel formulations and engine designs are evolving with technological advancement [8-9].

Meanwhile, it was believed that less amount of material near the gap is a major contributing factor for more rapid growth of the flame kernels [5]. This means that larger size of electrodes increase the heat loss from the initial flame kernel while the rate of initial flame kernel development is adversely affected. Some of previous researches indicated that reducing the contact areas between the flame kernel and the spark plug achieved by reducing the electrode diameter or increasing the gap leads to a faster flame kernel development [9-11]. Furthermore, the other ways to study the combustion phase of the engines is by using Schlieren optical visualization technique.

Therefore, a study on analysis of spark plug gap on flame development using Schlieren technique and image processing were conducted. The scope of this research is to study the flame characteristics during flame development process with spark plug gap width 1.0 mm, 1.2 mm, 1.4 mm, 1.6 mm and 1.8 mm with different injection pressure which is 3 bar, 4 bar, 5 bar and 6 bar. The spark plug gap width and the flame characteristic such as flame front area and intensity were investigated as it is the important parameter that will influence the combustion process. Moreover, the experimental method used to evaluate the detail of mixture formation process is schlieren optical visualization method. The basic principle of this technique is to combine the optical projection of an object with an indication of its light deflection. With the help of the Schlieren photography technique, the fluctuation in optical density of combustion phase can be observed [12-13]. Schlieren photography technique remain one of the most powerful technique to visualize the flow and it's relatively easy to implement.

Experiment set up

During the operation, RON 95 fuel was filled into the fuel injector machine. Next, the fuel will be pumped by the machine through an injector to the combustion chamber. The injector used having 8 holes with 1 mm diameter. The machine can controlled the fuel pumped by its pulse injection, pressure and also the rotation per minutes.

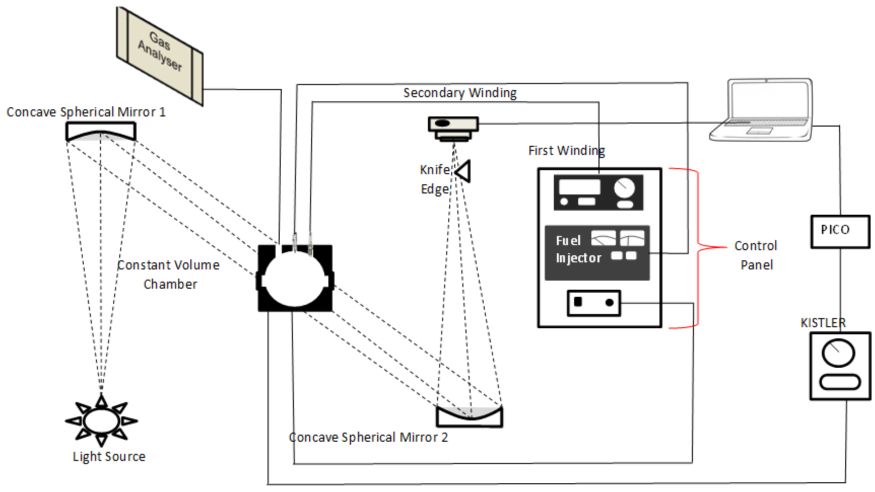


Figure 1: Schematic diagram of the Schlieren optical setup

Based on Figure 1, it illustrates the schematic diagram of the Schlieren experimental setup. The Schlieren apparatus consists of two concave mirror with a focal length 5 feet each. A LED light source was projected to a concave mirror with focal length of 5 feet. The light will deflected by the mirror to an acrylic placed in front of chamber. Here, a straight and equal intensity of light is maintained by the LED light source. The light will then pass through the test subject and reach the second concave mirror. Then, the parallel light of LED will deflect again by the second concave mirror. A knife edge with a diameter of 2.5 mm was used as a Schlieren stop and was set at the focal point of the LED light deflected by the 2nd concave mirror. After the knife edge cut the LED light, it will then reach to camera lens and the image will be taken.

The combustion process of the experiment can be observed through the camera behind the knife edge. The camera used in this experiment is a high speed camera (Nikon 1 J1). The image is captured at a resolution of 640 x 240 pixels with 400 fps at 30 p. It uses a NIKKON lens with aperture of 4.5, ISO setting of 1600 and focal length of 60 mm. The shutter speed is set to 1/13000 to record slow motion of the flame development. Table 1 shows the experimental parameters for this experiment. The RPM and the temperature of this experiment is set to 2000 and 300 K respectively.

Table 1: Experimental Specification

Temperature	300K
RPM	2000
Spark Plug Gap (Width)	1.0 mm – 1.8 mm
Injection System	Electronic Control
Injection Pressure	0.3 – 0.6 MPa

Result and Discussion

The effects of injection pressure on flame intensity was firstly investigated. Figure 2 shows the Schlieren images taken from the experiment of spark plug gap width 1.0 mm with time changes. The time sequences in Figure 2 based on time when ignition starts. The flame intensity increased as the time passed due to the increment of the heat energy. Meanwhile, at high injection pressure 5 and 6 bar, orange color flame can be observed earlier at 0.241 s. This indicates that more heat energy can be observed at higher injection pressure in shorter time. This phenomenon occurred because of high injection pressure form better spray atomization which promotes to combustion. Thus, we can conclude that as the injection pressure increase, the flame intensity will also increases. Next, the flame front area of the image will be investigated. The red line in the image illustrates the progression of the flame front until it fully occupy the observed area. The line for each time sequences have been combined in an image with white background for the clarity to identify the flame front area as shown in Figure 3.

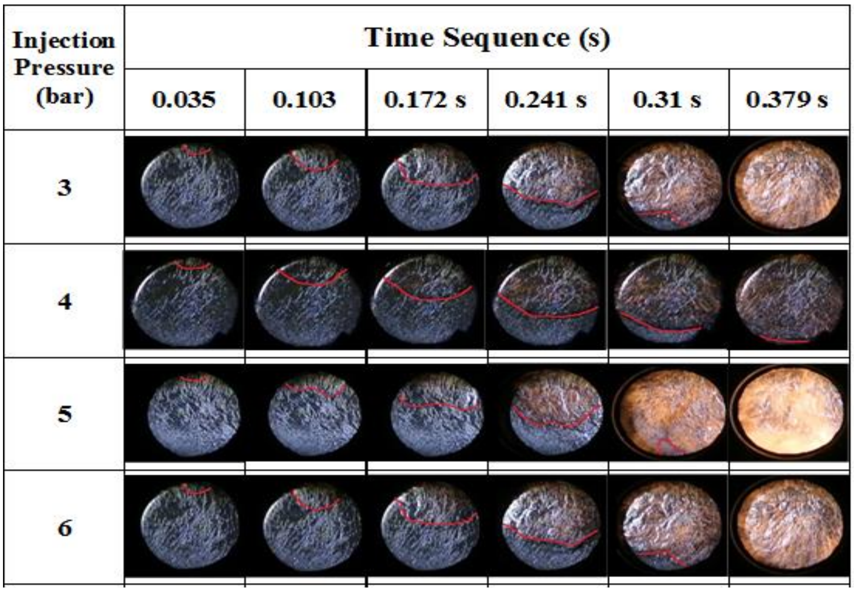


Figure 2: The effect of injection pressure on flame intensity for gap 1.0 mm

Each color line represents different time sequence with minimum of 0.035s to maximum of 0.379s. The small square near the top of the circle represents the location of the spark plug. The flame front images shown on the first rows revealed that the increased of spark plug air gap width, the greater the flame front area with a more constant value. The analysis data from the figure shows a smaller upturn in flame front area at first but increase in a rapid manner after 0.172 s. This phenomenon occur due to the burning of the air –fuel mixture that leads to the increase of heat energy. Furthermore, the area of interest of this study is to focus the ideal shape of the flame front which is circle or oval shape until it reach the combustion process. As shown in the first row, the gap width 1.2 mm to 1.6 mm shows a better shape pattern and more constant area until the combustion happen. However at 1.8 mm, the flame did not fully occupy the observed area at 0.379 s and show more distorted shape. This is probably due to misfire that causes the flame improperly established. As the park plug air gap width increased, the probability of misfire to occur is also increases as the flame distributed to surrounding and contribute in the loss of energy. The analysis data on Figure 3 also shows the comparison between the flame patterns from lower to higher injection pressure. For the first column (1.0 mm), the effects of injection pressure shows almost constant flame front area but increases the shape of the flame front to a better manner. For the second column (1.2 mm), the injection pressure also increase the shape of the flame front but also almost constant flame front area for the first 3 pressure. Meanwhile, at injection pressure of 0.6 MPa, the pressure lead the flame to occupy more area at 0.31s. Thus, a high injection pressure can distributes larger amount of fuel between sprays and it creates better spray atomization. Therefore, the flame front will progress in a more stable manner and combustion process will occur in a shorter time. For the last column (1.8 mm), the flame patterns show distorted shape in first 2 pressure. As the pressure increases after 0.4 MPa, the flame front show better shape and manage to occupy the entire observed area. Thus, higher spark plug gap width require a high injection pressure to establish better shape flame front.

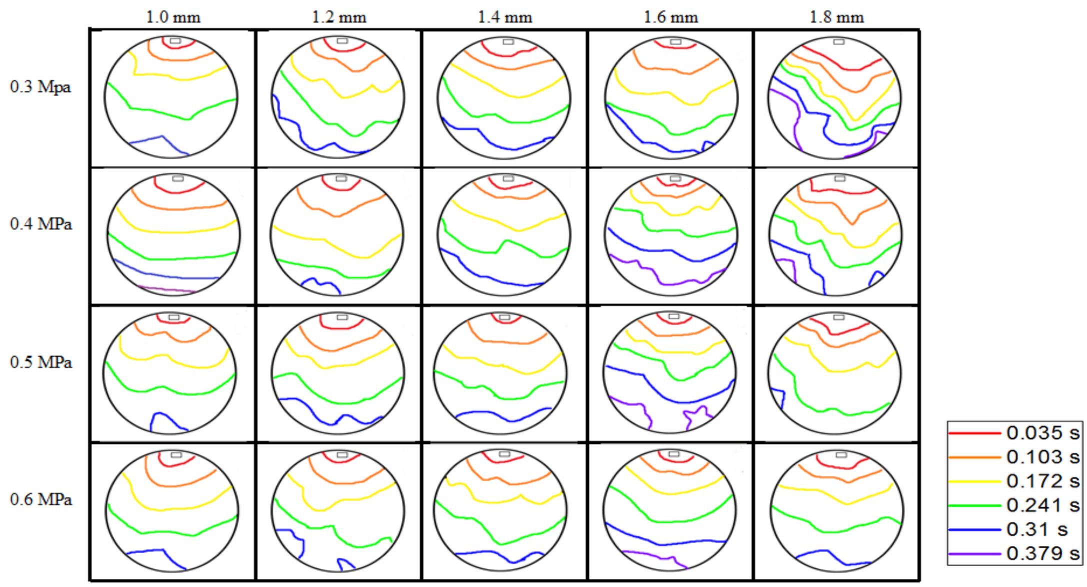
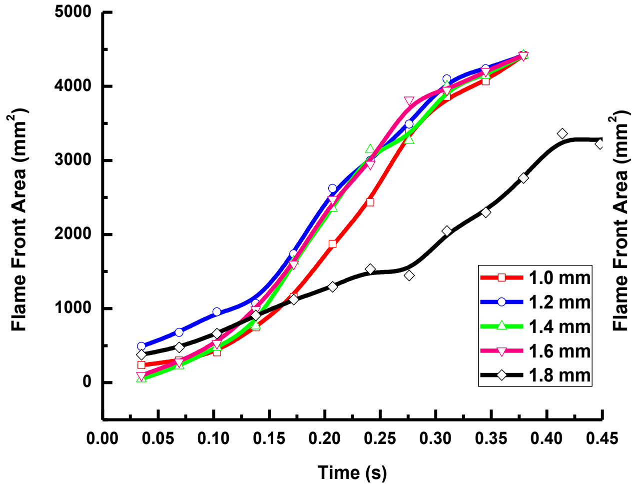
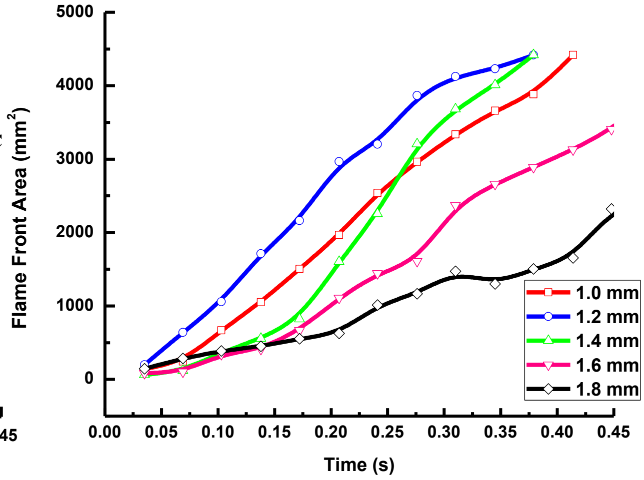


Figure 3: The effect of injection pressure and spark plug gap width on flame development

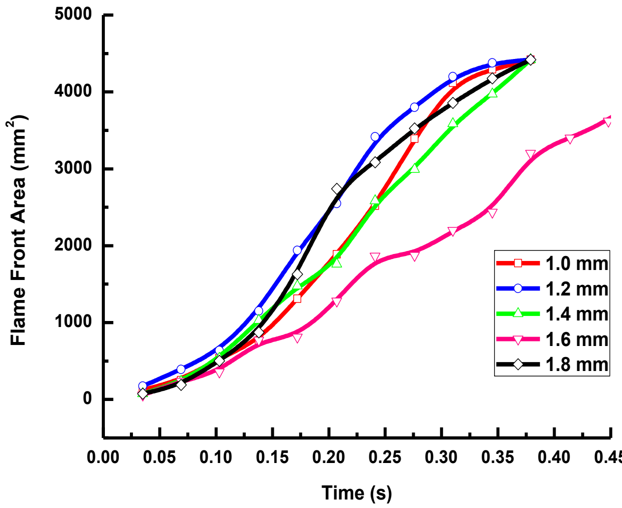
The graph trends of the flame front area shown in Figure 4 were analyzed by the image processing technique presented in Figure 3. Based on the Figure 4, it shows the graph of flame front area against the time sequence for all spark plug gap that have been conducted. The analysis data shown in the first graph compared the flame front area between the gap widths 1.0 – 1.6 mm at injection pressure 0.3 MPa shows almost consistent flame pattern. This explain that low injection pressure doesn't have significant effect on the flame front area. However for gap width 1.8 mm, the time require to fully occupy the observed area require longer time due to misfire causing flame improperly established. This behaviour can also be seen in 0.4 MPa for gap 1.6 mm and 1.8 mm. Both 1.6 mm and 1.8 mm gap width required more than 0.43 sec to occupy the observed area compared to other 3 gap width at the second graph. It seemed that the fire was not established at lower injection pressure for bigger gap width. When the injection pressure was set to 0.6 MPa, the trends of the graph were more consistent which less fluctuation.



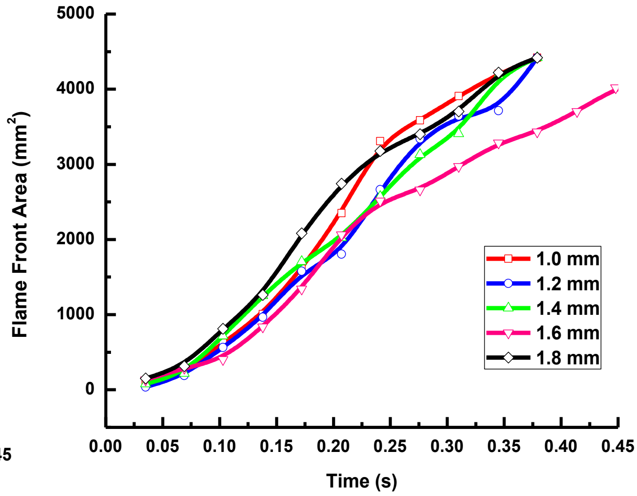
(i) 0.3 MPa



(ii) 0.4 MPa



(iii) 0.5 MPa



(iv) 0.6 MPa

Figure 4: Effects of injection pressure on spark plug gap

This indicates that the larger spark plug gap width require a higher injection pressure to fully established the flame. Meanwhile, in the last graph (0.6 MPa), the gap width of 1.8 mm shows a higher flame front area earlier compared to other gap width. This phenomenon indicates the shorter self-ignition time occurred causing the heat energy to rapidly increase. This behaviour also shown in the third graph (0.5 MPa). The flame front area of all the gap width shows greater compared to lower pressure graph. Thus, high injection pressure will lead to better flame front progression and sometimes self-ignition as in the 1.8 mm at the last graph.

Conclusion

As conclusion, this research on the effect of spark plug gap width was carried out using Schlieren technique by varying the injection pressure. The results obtained in this study are summarized as follows:

i. Smaller spark plug air gap width can produce good combustion with high injection pressure but self-ignition might occurred and damages the engine.

ii. Higher spark plug gap width increases the chance of misfire. However, higher spark plug gap will reduce the chance to ignite the fuel in low injection pressure.
iii. High injection pressure will make the flame front progression of the combustion more smoothly

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