The Experimental Study of Atomization Characteristics of Gasoline Spray Impinging on Glow Plug

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In order to reduce the exhaust emissions of a spark ignition engine, it is important not only to improve the catalyst conversion efficiency, but also to directly reduce the engine-out exhaust emissions during a cold starting of the engine and warm up periods. The purpose of this study is to evaluate feasibility of a glow plug for an early fuel evaporator. In order to promote atomization, gasoline is injected on the glow plug with room temperature(20℃) and high temperature(250℃). To analyze the spray behavior characteristics, a PMAS is used to measure the SMD and the dropsize distribution of an impinging spray and a free spray. Results show that the evaporation rate of the impinging spray on the high temperature surface of the glow plug was higher than that of the free spray on the room temperature surface.

Key Words : Glow Plug, Evaporation, SMD(Sauter Mean Diameter), Dropsize Distribution, PMAS(Particle Motion Analysis System), Early Fuel Evaporation

1. Introduction

At a cold-start, HC emissions need to be reduced in order to meet the future stringent standard of ultra low emission vehicles (ULEV). Presence of liquid fuel in the intake port and cylinder of a port-fuel injected SI engine is generally accepted as a major contributor to increased hydrocarbon (HC) emissions during a cold start of the engine and warm-up periods (Cheng, et al., 1993; Crane, et al., 1997; Son, et al., 1999). Excess fuel is injected during an engine start-up to ensure prompt vaporization of the fuel while the engine is cold. A fraction of the injected fuel escapes the combustion process and exits the engine as HC emissions. The problem is compounded by the fact that the catalytic converter has not warmed up sufficiently during a cold start and thus has no effect in reducing the tailpipe emissions. (Takehisa, et. al., 1994; Kimiyoshi, et. al., 1997). It is reported that during cold starting, especially in a gasoline engine, the engine response and the effect of the HC emission can be improved by prompting atomization and reducing the quantity of fuel adhering to the injector tip, inlet port, and inlet valve(Yang, et. al., 1993; Toshihara, et. al., 1987; Oh, et. al., 1999). Accordingly, this study aims to reduce the exhaust emissions by improving the combustion efficiency through promotion of atomization of the fuel before air-fuel mixture in the inlet port and the combustion chamber.

In order to achieve its goal, a detailed examination of the temperature characteristics of a glow plug was made according to the change in its voltage and current. On the basis of this, an attempt was made to promote atomization of fuel by exchanging heat and injecting fuel on the

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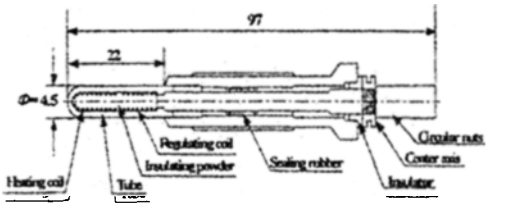


Fig. 1 Detail configuration of the glow plug(metal type)

surface of a high temperature glow plug that is electrified under the conditions of atmospheric temperature and pressure. An optical measuring system, PMAS, is used to find out the levels of atomization and to measure the mean droplet size. Droplet distributions are analyzed according to the measuring point and time.

2. Experimental Apparatus

2.1 Temperature characteristics of a glow plug

Figure 1 shows the appearance of a glow plug of a metal type.

The heated part in the glow plug is 4.5 mm in diameter, 22 mm in length. It has the rated voltage of 12 volts. An experiment on the temperature characteristics was performed to find out if the glow plug can be used as an early fuel evaporator in a gasoline engine.

Figure 2 shows a schematic of the experimental apparatus to measure the temperature of the glow plug. A battery of a gasoline engine for passenger cars generally has a capacity of 12.6V and 45 ~60Ah, and the electric load is 10A. Mightec DR -3030A, which can regulate the amount of voltage between 1V and 30V, and the amount of current between 1A and 30A, was used as a power supply for the glow plug. CHINO such as IR-AL8TB2 or IR-AHS, non-contact infrared radiation thermometer, was used for measuring the temperature. Each of the infrared radiation thermometers can measure a temperature in the range of −50 ~1000℃ (range of the low temp.) and 600 ~3000℃ (range of the high temp.). In this experiment measured temperatures were saved in the form of real time data on a computer by an

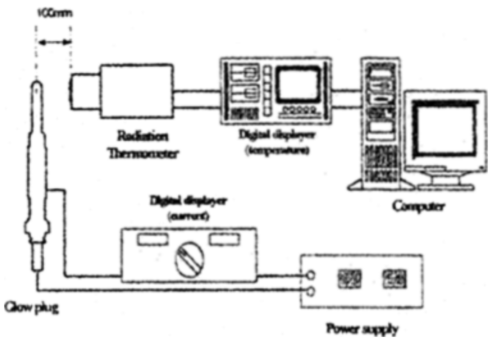


Fig. 2 Schematic diagram of the experimental apparatus

exclusively used program which can correlate with them. For reliability, the measured temperatures were calibrated using a thermocouple of the K-type, the radiation rate was selected on the basis of it, and the temperature was measured again with time.

2.2 Measurement of evaporation rate

Figure 3 shows a schematic diagram of the fuel impinging system for analyzing evaporation characteristics when fuel injected from the pintle-type injector was impinged against glow plug. The fuel was provided by a fuel pump and its injection pressure was maintained at a fixed rate of 250kpa by the pressure regulator attached on the tip of a fuel pipe. The fan(12V, 0.157A) and induction membrane were equipped on the upper part of the injector in order to prevent the evaporated fuel from being liquefied, and they were put into a proper place for the keeping quantity of residual from not being influenced. The quantity of residual was measured using an electronic weighing apparatus which can measure up to 1/100g. Considering the injection period (ti) of commercial passenger cars, which is 2.5 ~10ms, and the early injection period during a cold starting, that of the injector(t_i) was made 5ms in this injection experimental system. Injection pulse(t_p) was made 500ms and the mean value of the quantity of the injection for 240 seconds(480 times) was selected as the basic injection flow, regardless of the maximum value

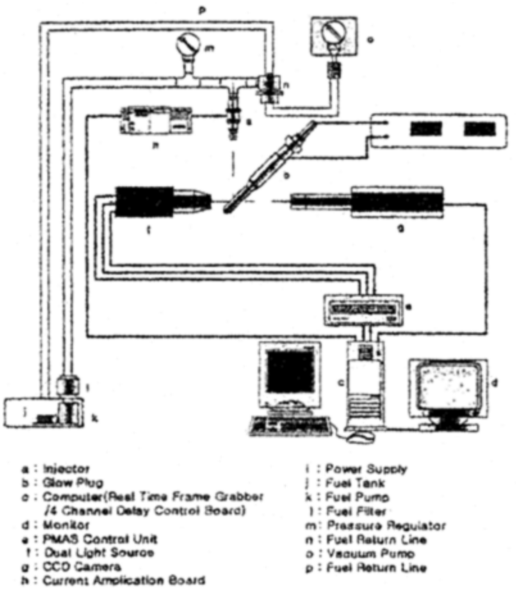


Fig. 3 Schematic diagram of the fuel impinging system

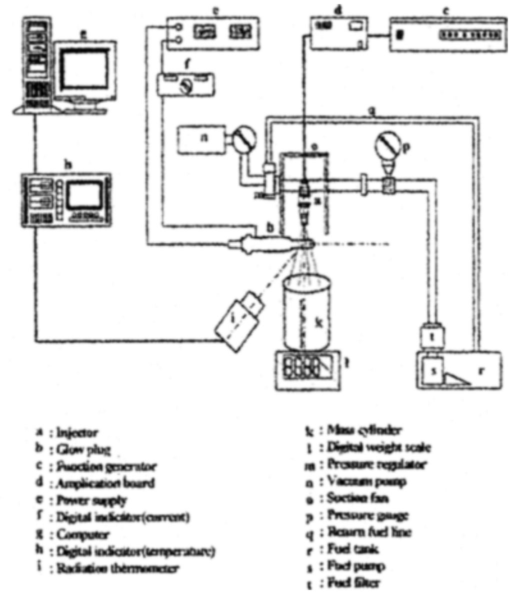


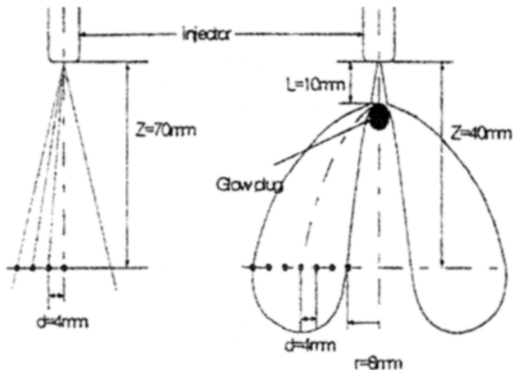
Fig. 4 Schematic diagram of the dropsize analysis system

and minimum value. This process was repeated five times to find an accurate mean value. The injection time was controlled by the function generator. Because its voltage and current are too low to work the injector, an amplifier was made of our own.

2.3 Measurement of SMD and droplet distribution

Figure 4 shows an experimental apparatus for measuring the droplet distribution and SMD when the fuel was impinged against the glow plug evaporates. Dropsize was measured using PMAS, which can convert the brightness and the luminance of the image into a digitalized quantity and deals with the quantity quantitatively by quantizing it. PMAS consists of a dual discharge light source, which has the duration of light of 50ns, CCD camera(the range of observation 3×3mm), lens, ND filter, frame grabber(image recorder, 512×480, 30frame/s), 4-channel control board, and PC. This measuring apparatus can an establish accurate mutual relationship between the image and droplet because it gains data from a photographed image, and its reliability can be improved by correcting data. The adjusted ratio of expansion and correction is 1.87 and 0.4 respectively.

Figure 5 shows the measuring position of an atomized droplet situationally after injected fuel was impinged against the glow plug. Figure 5 (a) shows the measuring point of the free spray of the fuel injected from the injector of the pintle type, and it was made Z=70mm considering the distance between the injector and the inlet valve in a commercial engine. In the whole process, the measurement droplet was measured in various positions considering the main spray(t=9ms), and the droplet distribution and SMD were analyzed according to the change of time after selecting one point of the gathering droplet as much as possible on the tip of the injector. Figure 5 (b) shows the measuring position of a droplet when the fuel was impinged against the metal type glow plug at a distance of L=10mm. The spray couldn't be observed at a distance of more than 45mm from the injector tip because the penetration from the impinging got much shorter than that of the free spray. So the measuring position was set at t=9ms and Z=40mm in order to observe main spray better.



(a) Free spray (b) Impinging spray

Fig. 5 Measuring position of the dropsize

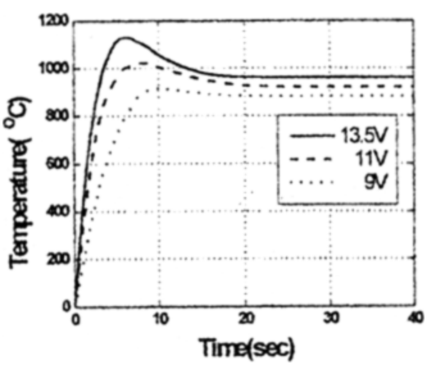


Fig. 6 Temperature characteristics according to the metal type glow plug(9V, 11V, 13.5V, 20A)

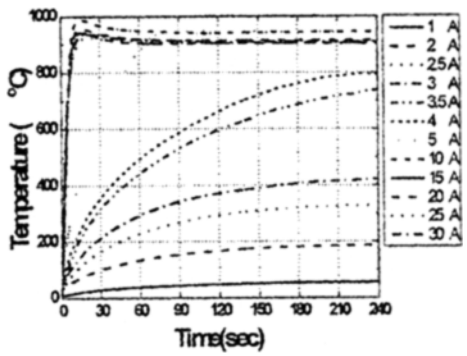


Fig. 7 Temperature characteristics according to the glow plug of the metal type(12V, 1~30A)

3. Results and Discussions

3.1 Temperature characterustics of glow plug

Figure 6 shows the temperature change according to the electrified time in case of increasing or dropping voltage of the metal type glow plug under a constant current. Considering the temperature changes according to the change in the account of the voltage and current, the change of temperature was measured according to electrified time after the amount of voltage and current were fixed at 9V, 11V, 13.5V and 20A, respectively, in order to find the temperature characteristics of a glow plug and to decide the experimental situations. During the first 15 seconds, the temperature changed rapidly up to 900~1100℃ and afterwards it was maintained constantly by each voltage between 800℃ and 1000℃.

Figure 7 shows the temperature change according to the electrified time when the current of the metal type glow plug was changed under a constant voltage. The graph shows that the temperature rose slowly when the amount of current was between 2A and 4A, and it was kept constant after 240 seconds. For this experiment, the amount of voltage was fixed at 12V and a variety of changes were given to the amount of the current. Especially up to 2~3A, the temperature was maintained between 200℃ and 400℃, and around 30 seconds after being electrified. Between the amount of current 3.5A and 4A, the axis of the temperature rise was increased, and after 240 seconds the temperature rose up to 700℃~800℃. Between the amount of current 10A and 30A, there was a similar tendency, compared with the case of between 3.5A and 4A. The temperature went up rapidly to more than 800℃ in the first three seconds, began to fall around 1000℃, and stabilized at a level of about 900℃ after 60 seconds. The above experiment on the basic temperature characteristics of a glow plug shows that the ideal evaporation condition of gasoline fuel lies in a temperature under the self-fire ignition of between 100℃ and 300℃. And also it shows the best temperature for a glow plug is between 200℃ and 400℃ considering the surface temperature of a glow plug can be cooled by the exchange of heat between the air and injected fuel. For a glow plug of the metal type, the injected fuel can be

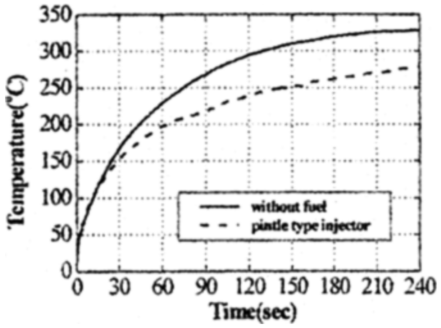


Fig. 8 Cooling characteristics of the glow plug by fuel evaporation

evaporated best if the amount of voltage is 12V and the amount of current is 2A and 2.5A. After the analysis of the temperature characteristics, the temperature for the spray experiment was limited within 200℃~400℃ expecting that the early evaporation ratio would be improved. The range of the temperature considered that it is cooled down by the heat exchange made by the injected fuel and be made an abnormal combustion such as pre-firing caused by surface temperature of a glow plug when gasoline fuel is injected in a commercial engine. Another experiment was carried out to compare the evaporation effect at a proper temperature with the evaporation effect at a high temperature between 700℃ and 800℃ as well.

Figure 8 shows the cooling characteristics of a glow plug when fuel was injected into the glow plug from an injector under the current condition of a glow plug takes the best evaporation effect. If the temperature of a glow plug put in the inlet port of engine can be set in advance after finding out the cooling characteristics of a heated glow plug by the continuous impinging of fuel under the amount of 12V and 2.5A according to the types of glow plus, it will prevent fuel from making an abnormal combustion such as pre-firing. The experiment resulted in a cooling rate of 20%, 30 seconds after it began.

3.2 Evaporation rate

Figure 9 shows a change of residual amount except for the evaporation rate in the mass cylinder according to various impinging distances

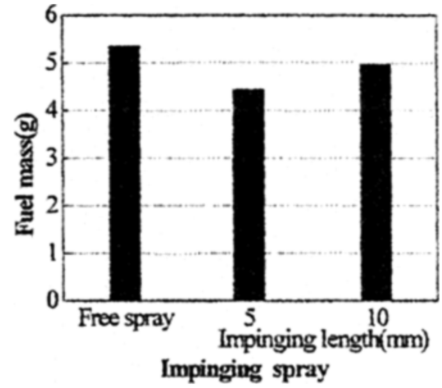


Fig. 9 Residual fuel amount of impinging spray at various distances (Injector of pintle type, p=250kpa)

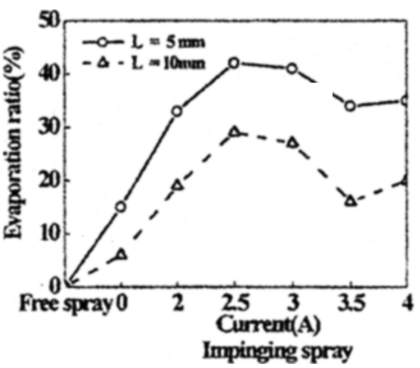


Fig. 10 Evaporation ratio of spray at various currents in the glow plug (Injector of pintle type, p=250kpa, 12V)

in the case of free spray and impinging spray. The evaporation amount is obtained by subtracting the residual amount from the total injected amount, and the larger the evaporation amount is, the less the residual amount is.

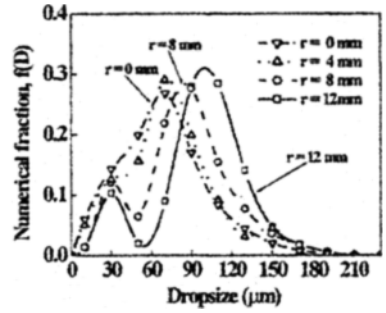
Figure 10 shows the evaporation ratio at various impinging distances in the case of an impinging spray after changing the electrified current in the glow plug. The distance between the glow plug and the injector was set at L=5mm and 10mm, and the fuel was sprayed according to the various electrified currents in the glow plug.

The maximum evaporation rate of 42% was observed in the case of L=5mm and an electrification of 12V and 2.5A. During early electrification, the fuel was atomized by the impinging and after 15 seconds, the fuel evaporated actively by a heat exchange caused by the rising of surface temperature of the glow plug. But the higher the current became, the higher the surface temperature of the glow plug became and it went up to about 800℃～1100℃. The high temperature can make the temperature of the evaporated fuel higher than that of self-firing inside the sealed inlet port in a commercial engine and cause an abnormal combustion such as pre-firing. And therefore, the temperature in this experiment was limited within 300℃.

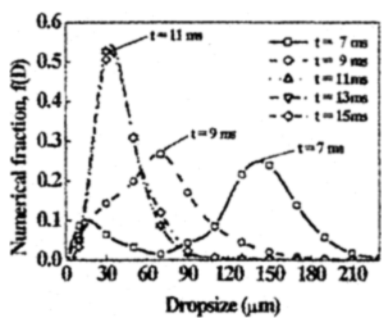
3.3 SMD and droplet distribution

In order to find out the mutual relationship between the SMD, droplet distribution and the change of the evaporation rate obtained in the above experiment, the SMD and droplet distribution were analyzed in the case of the impinging spray under the free spray and barometic temperature and of fuel impinging against the glow plug which had the surface temperature of 250℃. For this experiment, an injector of the pintle type was used and its injection pressure was kept constantly at 250kPa.

Figure 11 shows the droplet distribution according to the change of the measuring point and time when the free spray occurred by a pintle type injector. Figure 11 (a) shows, when measuring points were r=0, 4㎜, the size of the droplet was small or medium, but when it went towards the radial direction(r=8, 12mm), the size of the droplet became large and the graph had bi-mode distribution characteristics of having dual droplet distribution curves. The set of conditions for this experiment were Z=70㎜(from injector tip), t (measuring time)=9ms, and r(radius)=0, 4, 8, 12㎜. Figure 11 (b) shows the droplet distribution when the radius was 0mm and the measuring time(t) of the main spray was 7, 9, 11, 13, and 15ms centering around 9ms at intervals of 2ms. When the measuring time(t) was 7ms, the droplets began to be observed forming large ones and became larger afterwards, and after it was 11ms there was no change in the droplet distribution forming small droplets, which had the peak at 35μm.



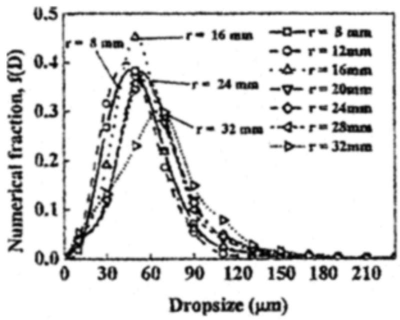
(a) As to radial direction(t=9ms)



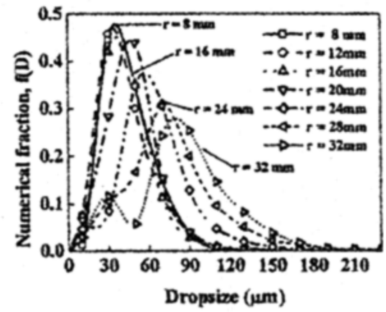
(b) As to time(r=0mm)

Fig. 11 Drop size distribution of the free spray(p=250kPa, L=70mm)

Figure 12 shows the frequency according to the various spray dropsizes when the fuel was impinged against the metal type glow plug. Figure 12(a) shows the result when the measuring time(t) was kept constantly at 9ms, and measuring position mean dropsize distribution of the impinging in barometric temperature. was compared with that in high temperature. Comparing the impinging in the surface barometric temperature with impinging in surface high temperature, in the latter case, the dropsize having the maximum peak value became smaller near the center of the spray, and the peak value got larger. On the contrary, the peak dropsize became larger than that of the impinging spray outside the center of the spray, and the curve of distribution became gentle. It's because steam film was formed on the surface of the glow plug when the fuel was impinged against the surface of high temperature on the glow plug. The steam film stopped the glow plug from exchanging heat with its surface, and the droplets bounded outside.

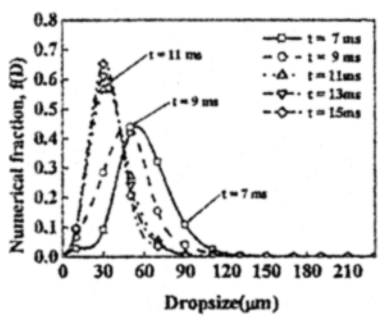


No heating (T=20℃)

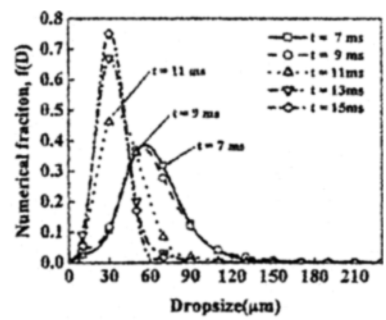


Heating (T=250℃)

(a) As to the radial direction (t=9ms)



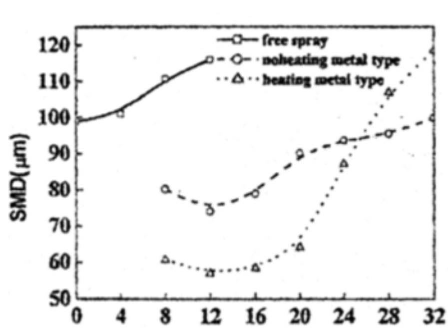
No heating (T=20℃)



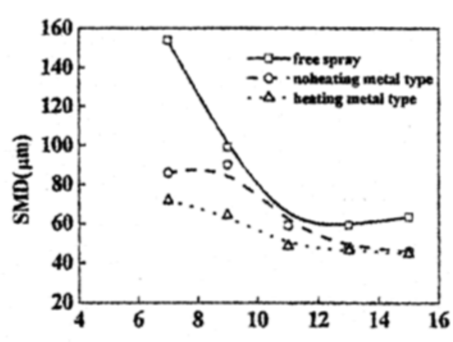
Heating (T=250℃)

(b) As to the time (r=20mm)

Fig. 12 Dropsize distribution (p=250kpa. L=0mm, Z=40mm, glow plug of the metal type)



As to the radial directions



As to the various times

Fig. 13 SMD distribution (p=250kpa)

Figure 12 (b) shows the droplet distribution at r=20mm according to the various change of time. When the fuel was impinged and sprayed against the surface with a high temperature, as time goes on, the droplet showing the maximum peak value became smaller than that of the impinging spray.

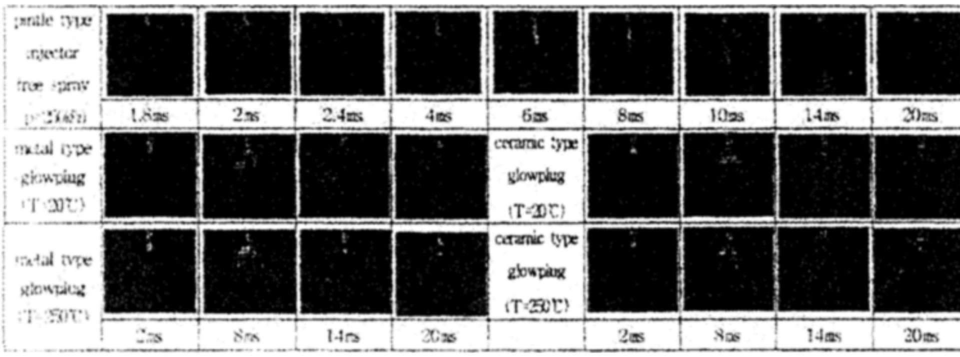


Fig. 14 Spray formation in the various condition(p=250KPa)

Figure 13 shows SMD distribution made by analyzing the conditions of Figure 11 and Fig. 12. Figure 13 (a) shows the SMD distribution according to the impinging distance, and SMD becomes much larger as the impinging distance becomes far from the center of the spray. In the case of the impinging spray against the high temperature surface, the SMD was small within a certain radius, but it became large beyond it. Figure 13 (b) shows the SMD distribution according to the changes of time. In the case of the impinging against the high temperature surface of the glow plug, during the early spray, the SMD was smaller than that of the impinging spray, but there was no big gap between the values as time went on.

Figure 14 shows the process of the spray development of the free spray and the impinging spray. Atomization in an impinging spray was much better than in a free spray. When the fuel was impinged and sprayed against the high temperature surface, it atomized better, compared with impinging spray.

4. Conclusions

In order to use a glow plug for early fuel evaporation in a gasoline engine, the temperature characteristics of the glow plug were examined and the gasoline fuel was impinged by spraying against the electrified glow plug. The SMD of the atomized fuel droplets was measured, and the droplet distribution was analyzed to find the results of this experiment.

The results are as follows.

(1) In the case of t_i=5ms(injection time) and t_p=500ms(injection pulse), a higher evaporation rate was observed when the fuel was impinged and sprayed against the glow plug, and the impinging distance was 5mm, compared with 10mm. When the constant voltage was 12V and current was 2.5A in metal type glow plug, the highest evaporation rate of 42% was observed as well.

(2) An analysis of the droplet distribution of a free spray and an impinging spray according to the measurent positions, when the fuel was injected from an injector shows that the dropsize having maximum peak value became larger, but the peak value became smaller as it went from the center of the spray to outside. In the case of the impinging spray and impinging spray against the high temperature surface, the distribution curve in the form of bi-mode was observed.

(3) When the measuring position was changed, the SMD of the impinging spray was much smaller than that of the free spray. In the case of the impinging spray, according to the types of glow plugs, the SMD of the impinging spray against the high temperature surface was smaller than that of the impinging spray, but beyond a certain distance it became much larger.

(4) When the SMD was changed according to a change of time, during the early spray, the SMD of impinging had a smaller value than that of the free spray, but after t=11ms or so it was

maintained constantly according to the conditions.

(5) The evaporation rate of the impinging spray was higher than that of the free spray, and the higher the evaporation rate was, the smaller the peak dropsize was. Especially during the early spray, SMD of the impinging spray was still smaller than that of the free spray.

On the basis of the results, we will design a glow plug which can be attached to the engine easily without making a big modification to the MPI engine in the near future, and experiment on the emission of exhaust gases and engine characteristics.

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