Study of Laminar Flow Flame using a Coaxial DBD Plasma Actuator

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Abstract

Because the ability to and effective control on high-performance jet by controlling have a wide variety of industrial applications, and has become an important area of research. In this study, an attempt was made to control jet stream diffusion using a coaxial dielectric barrier discharge (DBD) to manipulate an air jet stream and jet flame. The use of a digital flow controller permitted adjustment of the propane and air flow within the combustion chamber where it was fed into the jet flame. The voltages used were 5, 6, 7, and 8 kV. We confirm what kind of influence a flow induced has on the flame by changing the equivalent ratio and the applied voltage. As a result, when gaseous fuel was leaned the flame went out at time of plasma off, but the flame when we applied the voltage was stable. It was able to control the flow. Furthermore, use of the DBD plasma actuator allowed us to raise the central temperature of the burner flame. Moreover, O_3 and chemically active species were produced by the dielectric barrier discharge, so that combustion was promoted.

Keywords: Combustion, Plasma, jet, Laminar flow flame, Induction flow

1. Introduction

Because it is important that we reduce effective inflection of the energy and consumption of the fuel, the development of fuel reduction techniques, as well as other efficiency improvements, is important. Improvements in combustion efficiency and Improvement of the stability of the shape of the combustion region can be achieved by controlling fluid motion [1]. To date, active control of fuel-air mixtures and laminar flow flame combustion using flap type micro actuators has been attempted [2]. In this study, we attempted to control a laminar flow flame using a coaxial dielectric barrier discharge (DBD) plasma actuator in order to form a flame with superior combustion efficiency. The laminar flow flame was manipulated by changing the equivalent ratio and the applied voltage during combustion.

2. Plasma actuator principles

An overview of a DBD plasma actuator is shown in Fig. 1. In our experiments, thin electrodes were placed on the top and bottom sides of a plank which served as the dielectric layer, after which an alternating current (AC) was applied. An insulating material was used to suppress electrical discharge from the electrode on the bottom of the plank. When the AC voltage is applied, the DBD plasma is produced, as shown in Fig. 1. When an external force is applied, the plasma causes a flow induced from the outer (bottom) to the inner (top) electrode. It has been reported that when such a flow is produced near a wall surface, it is effective at influencing the speed distribution of the wall surface shear layer [3].

In addition, the chemical action of the DBD plasma results in O_3 and chemically active species production [4][5][6], which due to its unstable nature, can easily disassociate to product oxygen radicals. It has been reported that these radicals are effective at promoting combustion [7].

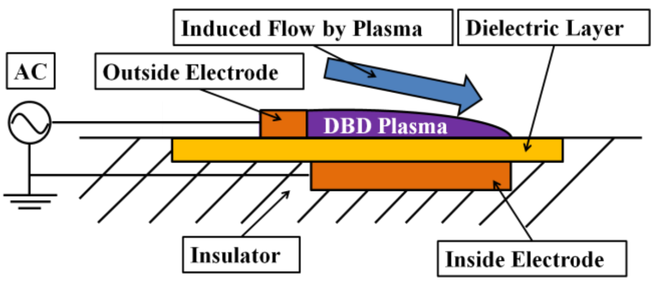
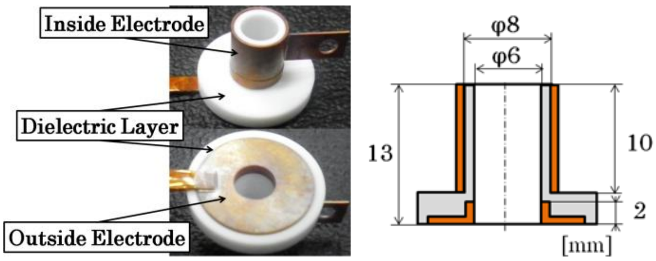


Fig. 1 DBD plasma actuator

3: Experimental device

In this section, we describe the coaxial DBD plasma actuator used for our experiments. As can be seen in Fig 2(a), the DBD consists of a pipe-shaped assembly of two electrodes and a dielectric layer. The dimensions of the actuator are shown in Fig. 2(b). The dielectric was produced from a machinable ceramic since it needs to be heat resistant, while the electrodes were fabricated from copper. The inside diameter of the jet exit is 6 mm, the dielectric layer thickness is 1 mm, and the electrodes are 0.5 mm thick.

Fig. 3 shows a cross-sectional diagram of the DBD plasma actuator attached to the exit of the axisymmetric speed uniformity nozzle, which was also manufactured from a machinable ceramic. As can be seen in the Fig. 3, DBD plasma develops on the wall surface of the actuator when an AC voltage is applied. Due to this plasma, flow induced occurs on the surface of a wall of the nozzle. The Fig. 3 shows fluid exiting the nozzle under the influence of this flow induced.



(a) Assembly Figure (b) Size of DBD PA

Fig. 2 Coaxial type DBD plasma actuator

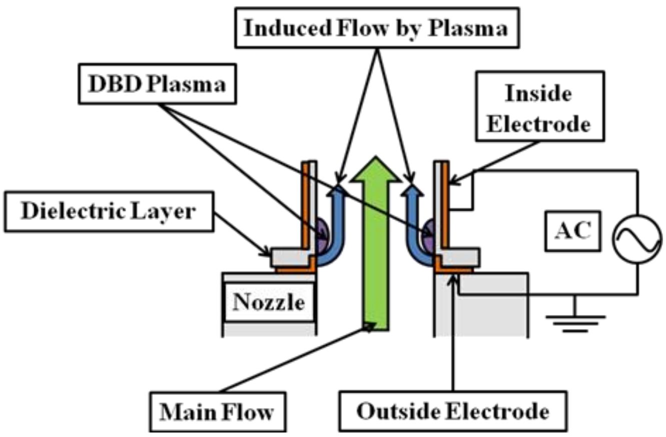


Fig. 3 Overall view of induced flow

4. Experimental method

The shape of the flames was measured using a high-speed camera and the temperature distribution was determined using a thermocouple.

4.1 Flame shape measurements

The experimental conditions for the flame shape measurements are shown in Table. 1, while an overview of the experiment is shown in Fig. 4. Air was provided via a compressor and propane was supplied from a gas cylinder. Flow controllers were used to govern the supply of air and propane to the mixture chamber. After the chamber was filled to capacity, a voltage was applied to the actuator in order to produce a flow induced via the plasma. Upon emission from the converging nozzle, the gas mixture was ignited. we sought to determine the influence of the flow induced by photographing the flame shape using a high-speed camera.

4.2 Temperature measurements

The experimental conditions for the temperature measurements are shown in Table 2, while an overview of the experiment is shown in Fig. 5. The experimental process up to flame ignition was the same as that used in the flame shape measurement a experiment, thermocouple was used to measure the temperature of the generated flame. During these experiments, changing conditions were introduced by turning the plasma on and off and by manipulating the equivalence ratio. Following each change, the flame temperature was measured at positions 3 to 15 mm from the tip of the lower nozzle at 3 mm intervals. The type B thermocouple was 0.1 mm long and was covered with a dimethylpolysiloxane film to prevent platinum catalysis. In the thermocouple using the Pt, SiO_2 exposed to the reducing atmospheres more than 1,100 degrees Celsius by Si. Then thermocouple may change an electrical characteristic.

Table. 1 The experimental conditions 1

Flow rate	3.31 L/min
Voltage	5, 6, 7, 8 kV
Frequency	8 kHz
Fuel	Propane (97%)

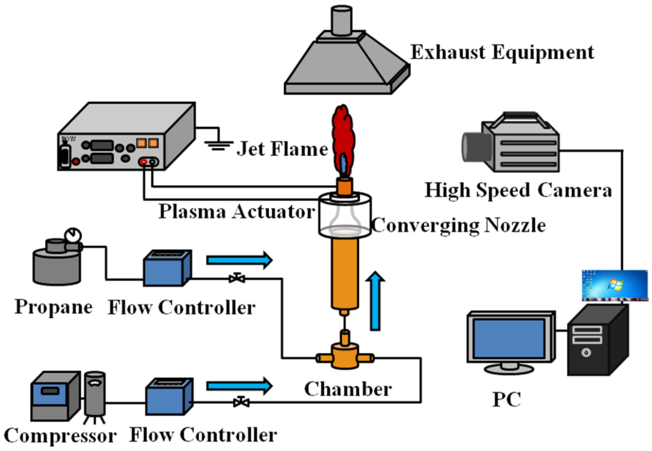


Fig. 4 Experiment method diagrammatical view 1

Table. 2 The experimental conditions 2

Flow rate	3.31 L/min
Voltage	6, 7, 8 kV
Frequency	8 kHz
Fuel	Propane (97%)
Equivalence ratio	1.00, 1.14, 1.28
Thermocouple	3~15 mm

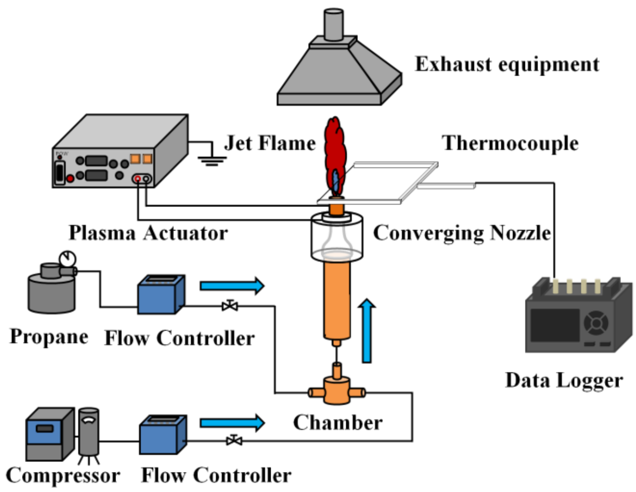


Fig. 5 Experiment method diagrammatical view 2

5. Result and discussion

5.1 Measurement of flame shape

In Figs. 6 to 8, with the flow rate set at Q=3.31 L/min, the photographs show laminar flow flames recorded equivalence ratio were made by varying the voltage.

Figs. 6 shows flame of ϕ = 0.85. The flame went out at time of plasma off, but it was stable in its the flame which applied the voltage. Thus the flame was stable when a voltage was applied, and this is thought to due to the production of O_3 and chemically active species, which leads to enhanced combustion. In addition, a flame vanished when the voltage was 8kV, because a sufficient amount of fuel was provided. The flames of Figs. 7-8 remain for equivalence ratio ϕ = 1 and ϕ = 1.14, and thus continue burning with or without the plasma actuator.

However, the inner flame decreases in size and the shape of the outer flame changes when the plasma actuator is used. In addition, larger changes are found for the 8 kV flame. Specifically, the center becomes hollow and the inner flame assumes a crown shape. It is thought that this is due to a change in speed in the neighborhood of the boundary layer due to the induced flow. The low inner flame is thought to be formed because while the mean speed of the fuel was constant, the speed of the boundary layer increased. Therefore, we can consider it when internal flame lowered by the result that central speed decreased.

In addition, ϕ =1.14 has little influence of the plasma actuator when I compare ϕ =1.14 with equivalent ratio ϕ =1, From this result, the flame size increases with applied voltage, and this change becomes small when the equivalent ratio becomes big.

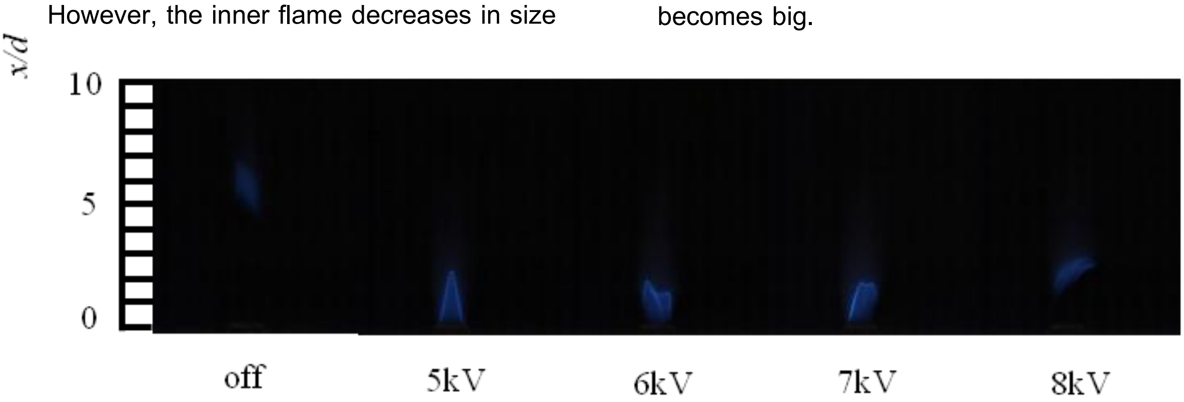


Fig.6 Inner flame form Q=3.31 l/min, 8kHz, ϕ =0.85

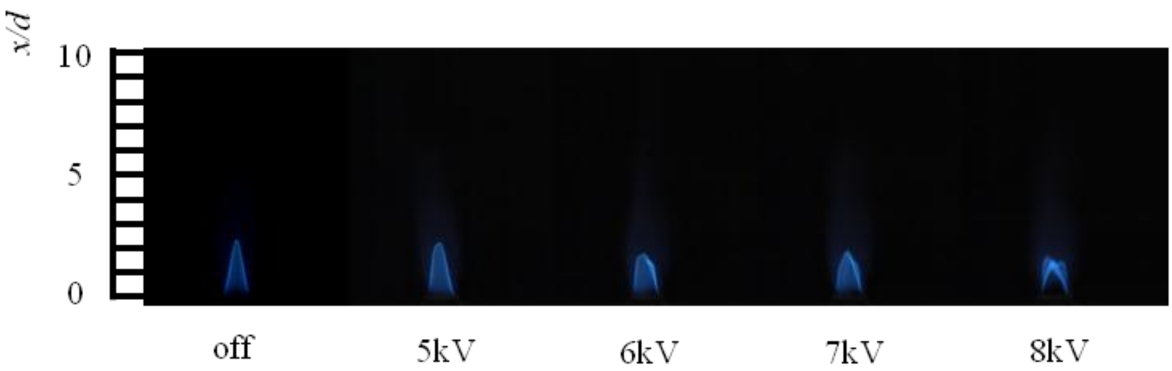


Fig.7 Inner flame form Q=3.31 l/min, 8kHz, ϕ =1

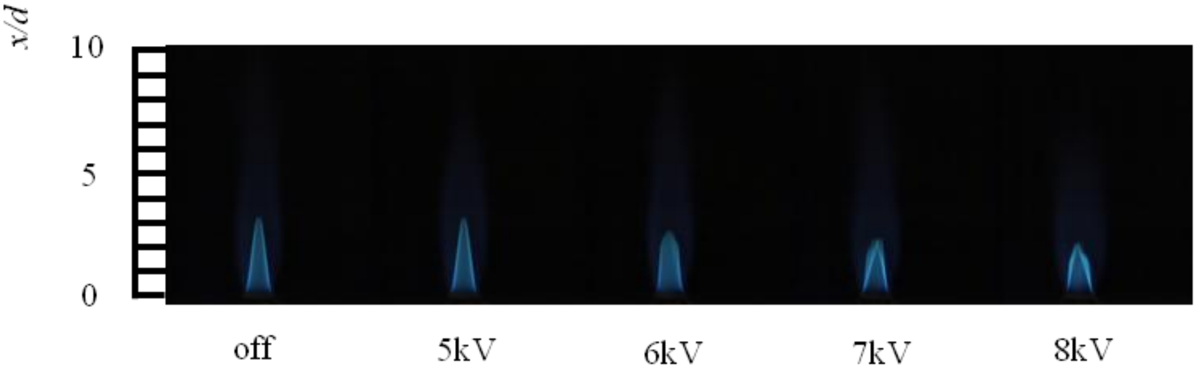


Fig.8 Inner flame form Q=3.31 l/min, 8kHz, ϕ =1.14

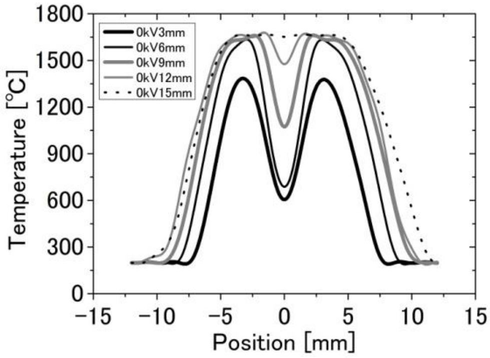
5.2 Temperature profiles

Figs. 9 to 11 show temperature profiles across the flame from the exit nozzle, the flow quantity is constant at Q = 3.31L/m. In Figs. 9 and 10, the equivalence ratio is ϕ = 1.00, and in Fig. 11 it is ϕ = 1.28. In Figs. 9 and 11, the plasma is off, whereas in Fig. 10 the applied voltage is 6 kV. Fig. 12 shows images of the flames under these conditions.

Comparing Figs. 9 and 10, it can be seen that at a position 9 mm from the nozzle exit, the temperature at the center region is higher when the plasma is on than when it is off.

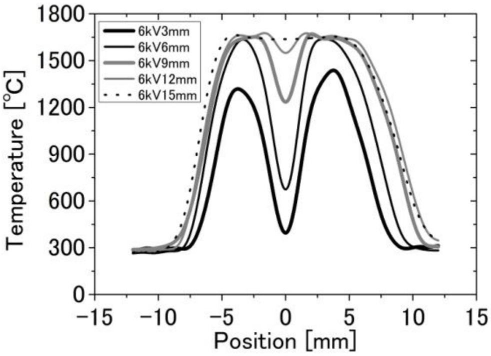
This phenomenon we were thought that temperature high because a central inner flame lowered by the flows induced that occurred on the wall surface of the coaxial type DBD plasma actuator.

The central temperature increases at locations far from the nozzle exit in both Figs. 9 and 11, but the increase is slower in Fig. 11. With the case of ϕ = 1.28, a high inner flame because combustion with rich fuel. This phenomenon is thought that this is because location of measurement was located inside of an inner flame. This is consistent with the image of the flame shown in Fig. 12.



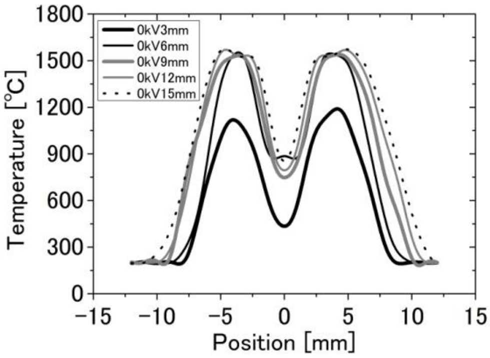
Q=3.31 L/min, ϕ =1.00 Plasma OFF

Fig.9 Temperature distribution of the flame



Q=3.31 L/min, f=8kHz, ϕ =1.00 Plasma 6kV

Fig.10 Temperature distribution of the flame



Q=3.31 L/min, ϕ =1.28 Plasma OFF

Fig.11 Temperature distribution of the flame

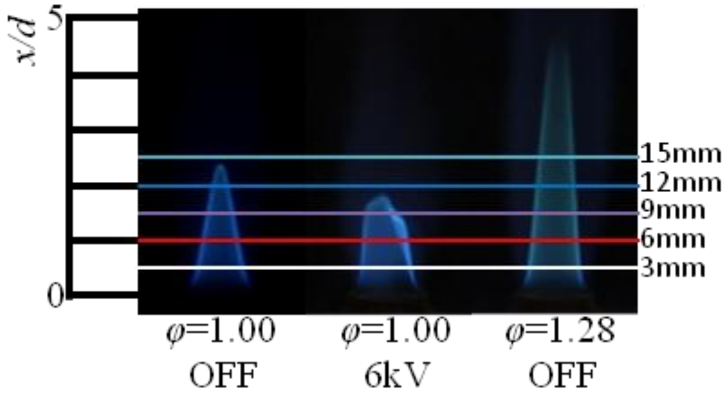


Fig.12 Inner flame form

6. Conclusion

In this study, we experimented at controlling laminar flow flame using a coaxial DBD plasma actuator to produce flames that were superior in terms of shape and combustion efficiency. The following conclusions were reached.

[1] The flow speed in the vicinity of the boundary layer could be changed by the plasma induced flow, causing the inner flame to decrease in size and the shape of the flame to change.

[2] For a fuel-air equivalence ratio of ϕ = 0.85, it was possible to prevent the flame went out using the plasma actuator.

[3] Thermometry measurements showed that for Q = 3.31 L/min and ϕ = 1.00, the induced flow due to the plasma actuator caused the low inner flame in to change shape of the flame.

7. Acknowledgement

This work was supported by Grants-in-Aid for Scientific Research from the Japan Society for the Promotion of Science (JSPS) (C) KAKENHI 22560176 and 25420132

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