Influence of Nozzle Exit Velocity Distribution on Flame Stability Using a Coaxial DBD Plasma Actuator

M. Kimura and K. Okuyama

Abstract In this study, a coaxial dielectric barrier discharge plasma actuator (DBD-PA) is applied to control the flame shape, the control to maintain excellent flame stability is attempted. DBD-PA consists of an exposed electrode, an insulated electrode, and a dielectric layer. In a convergent round nozzle having an exit inner diameter of $d = 6$ mm, the electrode set was arranged coaxially with the nozzle. DBD-PA is applied to the control of the flame stability on condition equivalence ratio: $\phi = 0.85$, 1.00. Premixed gas of air and propane was used for fuel. The applied voltage is 5–8 kV and OFF, and frequency is 8 kHz constant. Flame stability limit is taken with a high speed camera. The center of inner flame assumes a crown shape. It is thought that this is due to a change in velocity distribution in the free boundary layer by the effect of the DBD-PA induced flow.

Keywords Jet · Flow control · DBD plasma actuator · Instability · Flame

1 Introduction

In the control of a current jet flow, various researches on the control that have been used many control methods; sound wave, flap type actuator, controlled coaxial flow, MEMS actuator etc. Recently, dielectric barrier discharge plasma actuator (DBD-PA) (Corke et al. 2010) has been applied to flow control. DBD-PA has been investigated as a device for separation control on wings by many investigators (Post ML and Corke TC 2004). And also it was applied to the jet diffusion control

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(Kimura M et al. 2013). On the other hand, control of the jet is that the performance of controlling the mixing of combustible gas and airs in the burner combustion efficiency, small size can be such, for industrial application range is wide, an important field of research. In this study, coaxial DBD-PA is applied to control the flame shape and flame stability.

2 Experimental Details

Figure 1a shows a cross section of the coaxial DBD-PA set up at the round nozzle exit, the main jet, and the overall view of the induced flow due to DBD-PA. It consists of an exposed electrode, an insulated electrode, and a dielectric layer. The dimensions of the actuator are shown in Fig. 1b. The dielectric was made 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 d = 6 mm, the dielectric layer thickness is 1 mm, and the electrodes are 0.5 mm thick. Figure 2 shows a cross-sectional diagram of the DBD-PA attached to the exit of converging round nozzle, which was also manufactured from a machinable ceramic. Plasma was generated by adding the alternating high voltage from the power supply. DBD-PA is applied to the control of the flame stability on condition equivalence

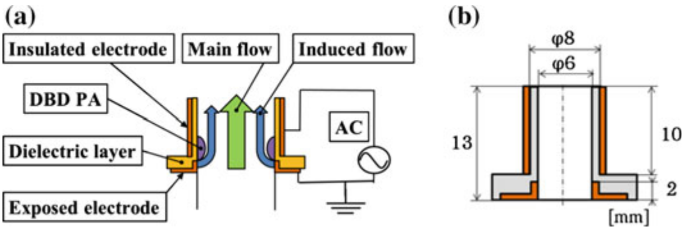
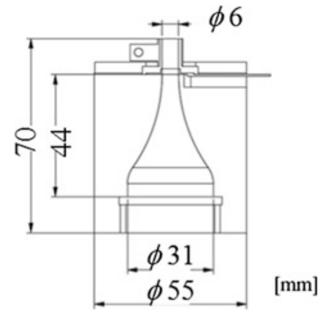


Fig. 1 Coaxial DBD-PA: **a** DBD-PA configuration of electrodes and dielectric layer and induced flow image, **b** DBD-PA dimensions

Fig. 2 Nozzle and coaxial DBD-PA



ratio: $\phi = 0.85$, 1.00. Premixed gas of air and propane was used for fuel. Voltage is applied to the coaxial DBD-PA after ignition, to generate an induced flow by plasma. The applied voltage is 5–8 kV and OFF, and frequency is 8 kHz constant. Flame stability limit is taken with a high speed camera. In the case of pure jets, the laser light seat method was used to visualize the jet shape using of Nd:YAG laser (made of Omicron: in the jet flow LA-D40-CW and $\lambda = 532$ nm) and micro oil particles. It took a picture of the jet flow made visible within the range to $x/d = 6$ with a high speed camera. Distance and y from the nozzle exit show the distance in the direction of the diameter from the nozzle center in x. And the visualization picture was PIV (Particle Image Velocimetry) analyzed.

3 Result and Discussion

Figure 3 shows round air jets visualization. Although weak instability ejection when the plasma off, it can be seen that appear remarkably K-H instability. Once the plasma is applied, vortex ring occurs immediately after the jetting, further leading to diffusion. Figure 4 is a velocity distribution immediately after the ejection. If plasma is OFF, the velocity distribution of the central portion is flat. Here, U_0 is the center velocity of $x/d = 1$ when DBD-PA is not generated. If by applying

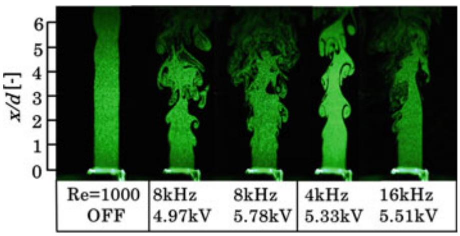
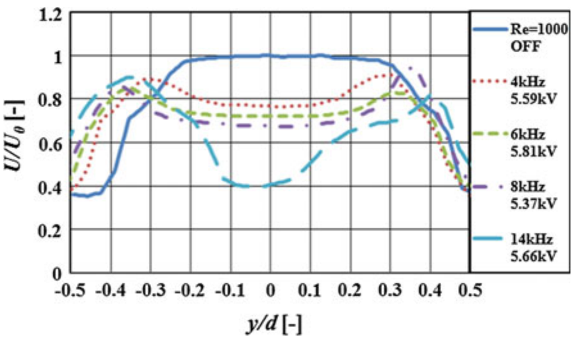


Fig. 3 Round air jet visualization in the case of DBD-PA off and in the case of driving DBD-PA

Fig. 4 Velocity distribution in the cross direction of near the jet exit area ($x/d = 1$)



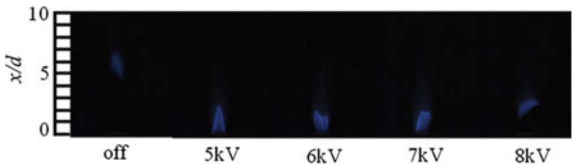


Fig. 5 Images of inner flame shape (Q = 3.31 L/min, ϕ = 0.85, 8 kHz)

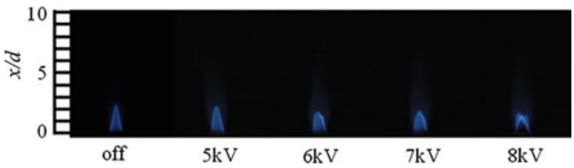


Fig. 6 Images of inner flame shape (Q = 3.31 L/min, f = 1.00, 8 kHz)

plasma, the velocity distribution in the center portion is decelerating. Blowing flow by DBD-PA accelerate the velocity of the boundary layer by the plasma. Since the jet flow rate is constant, the velocity of the center is to slow down.

Figure 5 is a still photograph of laminar flame taken by high-speed camera. Conditions the volume flow rate Q = 3.31 L/min, equivalence ratio is ϕ = 0.85. Equivalence ratio is a value indicating how many times the fuel of the theoretical amount relative to 1 kg of the air supplied: ϕ = (Fuel/Air)/(Fuel/Air: Theoretical air-fuel ratio). For the plasma OFF, so lean condition, the flame blown off without sustained. When the applied voltage is 5 kV, it is stable becomes a cone-shaped flame. If the applied voltage is 6 and 7 kV, although flame shape is deformed, it is stable combustion. Generation of plasma is increased amount of generation of radicals, active species for activating the combustion; flame surface is stable even in dilute state. When the applied voltage is 8 kV, the flame is blown away. When the applied voltage is increased up to 8 kV, blowing force increases. By the velocity of the boundary layer is faster than burning velocity, the flame is blown off.

Figure 6 is a still photograph of laminar flame taken by high-speed camera. Conditions the volume flow rate Q = 3.31 L/min, equivalence ratio is ϕ = 1.00. Even if the plasma OFF, because the equivalent ratio is ϕ =1.00, the flame is not blown off. When the applied voltage is 5 kV, it is stable becomes a cone-shaped flame. If the applied voltage is 6 and 7 kV, although flame shape is deformed, it is stable combustion. If the applied voltage is 8 kV, the further flame shape is deformed, the central portion of the flame dent, and the crown-shaped flame configuration.

As indicated in Fig. 4, around velocity by a blowing force of plasma to accelerate, the central portion is slowing down at the same time. Flame front is stabilized at the balance point of burning velocity and gas velocity. Since the velocity of the center part is decelerated, the shape of the flame recessed central portion is formed.

4 Conclusions

In this study, we experimented at controlling laminar flow flames using a coaxial DBD plasma actuator to produce flames that were superior in terms of shape. Two of the action occurs when the plasma is generated. One is blowing force by the plasma, which increases the velocity of the boundary layer, slowing the velocity of the central portion. The other is the generation of active species by the plasma. Active chemical species is intended to activate the combustion reaction; there is action to stabilize the flame even in lean-burn conditions. Plasma both coexist at the time of occurrence, by both the balance with the applied voltage, and a case where the flame front is stabilized, when blown away.

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