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Enhancement of Combustion Reaction by Radical Injection using Dielectric Barrier Discharges
誘電体バリア放電を用いたラジカル注入による燃焼促進効果

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Through the experiments, we have found that increasing the generation of the important radicals (OH, CH, C_2) in the hydro carbon combustion is strongly enhanced and the combustion speed is increased by ~ 20 % when DBD is applied to oxygen gas. The enhancement of the combustion reaction comes from the ozone production by oxygen DBD. On the other hand, DBD of fuel gas(butane, C_4H_{10})does not improve the combustion reaction as much as that in oxygen.

1. Introduction

Nowadays, the interaction of plasmas with combustion flame is getting much attention from the view point of effective combustion. The technology that reactive plasmas are superimposed to the combustion field is called plasma-assisted combustion. The plasma-assisted combustion technique has various advantages, such as promotion of the ignition and the combustion reaction. Other expected effect is suppression the emission of harmful gases by the electrical discharges. Because non-equilibrium plasmas have a lot of activated species which promote combustion reactions, significant synergy effects are expected. In this report, we investigated the influence of radical injection to hydrocarbon combustion experimentally from the viewpoint of the enhancement of activated species relating to the ignition and improvement of the combustion speed.

2. Experimental Setup and Condition

The experimental setup is shown in Fig. 1. We used coaxial cylindrical reactor to discharge supply gases of butane (C_4H_{10}) and oxygen (O_2). Material of inside electrode is stainless steel and outside is copper line. Dielectric material between the electrodes is quartz. C_4H_{10} and O_2 are added to dielectric barrier discharges separately. Premixed combustion is one of the combustion methods that the fuel and oxidizer are premixed. Optical emission from the combustion flame is measured by spectrometer and UV-CCD camera with interference filter. The combustion radicals are also measured by mass spectrometer working at the atmospheric pressure. C_4H_{10} and O_2 gas rate are 0.1 slpm and 0.65 slpm, respectively. A high voltage power supply for barrier discharges generates V_{p-p} of 15 kV at a frequency of 15 kHz. The time averaged discharge power is about ~ $P \leqq 40$ W in the experiment. Combustion power of premixed flame is about 200 W, so discharge power is much less than the combustion power.

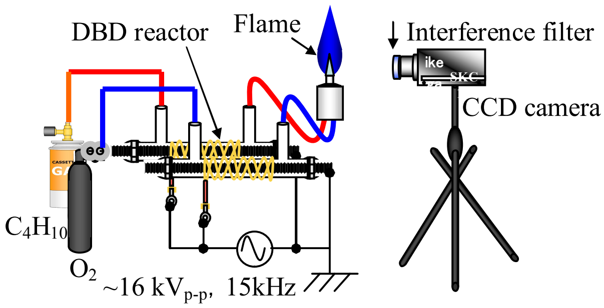
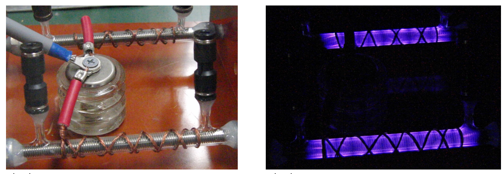


Fig. 1 Experimental setup

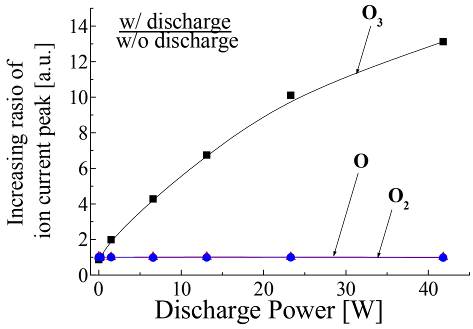


(a) w/o discharge (b) w/ discharge

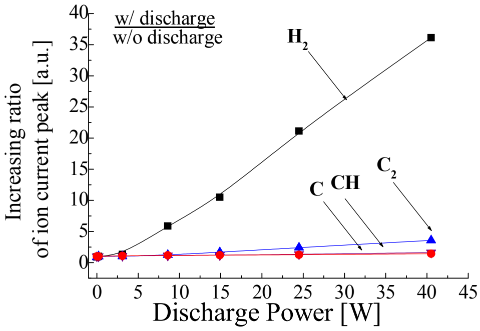
Fig. 2 Plasma emission that applying discharge to C_4H_{10} and O_2 separately

3. Results and Discussion

Fig. 3 shows the enhancement of the hydro -carbon combustion reaction measured by mass spectrometer. When DBD is applied to oxygen, ozone is mainly generated. In the case of butane DBD decomposed particles, such as H_2, C_2, CH from butane gas are generated. The increase of hydrogen molecule is most significant. The emission intensity distributions of OH($\lambda = 308.48$ nm) from the flame measured by UV-CCD camera are shown in Figs. 4(a)~(c) in the different DBD conditions. The intensity distribution shown in Figs. 4(a)~(c) is obtained from the Abel inversion of the measured profiles. The combustion zone with a triangle shape is clearly seen. The increase



(a) O_2 DBD



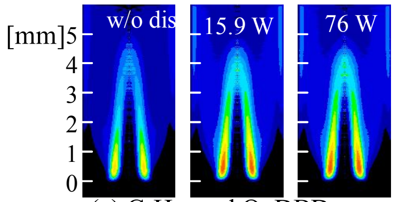
(b) C_4H_{10} DBD

Fig. 3 Increasing ratio of ion current by results of mass analysis

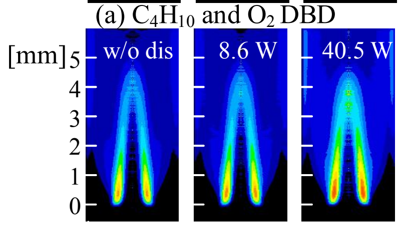
of the OH emission is larger in O_2 DBD case. In addition to the increase of OH radical emission, the contraction of the flame is also significant. Since OH radical is a key particle in the hydro -carbon combustion the enhancement of butane combustion is related to the ozone production by O_2 DBD.

We calculated the combustion speed. Without radical injection, combustion speed is about 2.5 m/s. Combustion speed is enhanced by 20 % in O_2 DBD case. On the other hand, they are about 15 % and 14 % in the cases of C_4H_{10} DBD, and O_2 and C_4H_{10} individual DBD.

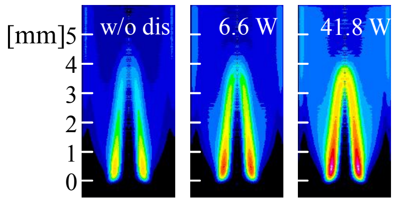
In this experiment, O_2 DBD is most effective for combustion reaction. This is because that O_3 with high oxidizability reacts with C_4H_{10} to produce O and OH radicals. These radicals make the combustion reaction active. In the case of C_4H_{10} and O_2 individual DBD, O_3 reacted with H_2 to produce H_2O. It is possible to cool the temperature in combustion field, and reaction speed reduces that of O_2 DBD. C_4H_{10} DBD produces the resolved particles such as H_2, CH and C_2 and assisted the combustion reaction. When direct electrostatic discharge applied with the combustion flame, combustion speed increases by 40 % than that of without discharges. This is because that direct discharge is efficient for carrying radicals to the combustion flame before radical deactivated.



(a) C_4H_{10} and O_2 DBD



(b) C_4H_{10} DBD



(c) O_2 DBD

Fig. 4 OH radical emission intensity distribution

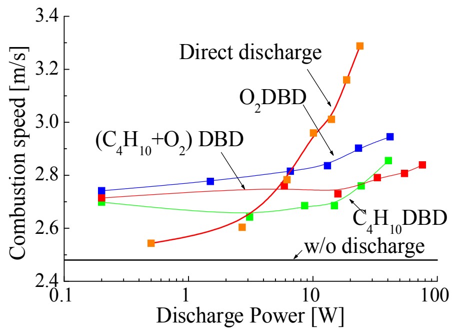


Fig. 5 Dependence of combustion speed to discharge power

5. Conclusion

In summary, our investigations allow one to conclude the following.

1) By radical injection using DBD, radical (OH, CH, C_2) emission intensity and combustion speed is increases. These results demonstrate that radical injection promoted combustion reaction.
2) In the case of O_2 DBD, combustion reaction becomes effective. According to these results, O and OH radical are important to develop combustion.

References

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