스월연소기에서 저온 플라즈마가 인가된 메탄/공기 예혼합화염의 희박가연한계 확장

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Extension of the lean flammable limit of swirled premixed methane/air flames by non-thermal plasma

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ABSTRACT

The effects of non-thermal plasma on swirled premixed methane/air flames have been experimentally investigated. The non-thermal plasma is applied to the flames through the dielectric barrier discharge (DBD) technique. The results show that the streamer and ozone induced by the non-thermal plasma extend the lean flammable limit by enhancing flame stability. It is also found that the non-thermal plasma is able to considerably reduce CO emission although NO_x emission increases slightly.

Key Words : Dielectric barrier Discharge(DBD), Swirl combustor, flam stability, Streamer, CO and NO_x

Lean premixed gas swirl combustors operating at low temperatures have been successfully adopted to meet current stringent NO_x emission regulations since thermal NO_x can be significantly reduced at low temperatures [1, 2]. Dry-low-NO_x combustion methods can reduce NO_x and CO emissions below 25 and 50 ppm, respectively (corrected to 15% O_2) from natural gas fueled engines [3]. However, there are several issues to be resolved in the development of lean premixed gas combustors: more stringent emission regulations and combustion instability.

Increasingly stringent emission regulations must control the future development of gas combustion systems. Therefore, if environmental issues set legislations below 5 ppm NO_x in the future, we have to find new alternatives to satisfy the worldwide emission standards without expensive equipments for exhaust gas clean up.

The stringent regulations and combustion instability in lean premixed gas combustors have posed unprecedented challenges for combustion researchers to develop new technologies to drastically decrease emissions and enhance combustion at extreme conditions. As one of new technologies, plasma has drawn great attention because it can provide an unprecedented opportunity for emission control and flame stabilization due to its unique capability to produce active species and heat and to modify transport processes.

Furthermore, plasma can be applied to commercial burners with simple modification such that plasma-assisted staged combustion can be achieved. Thus, researchers have been interested in how plasma controls the electrical properties of flames [4-6]. However, plasma enhances flames in a very complex process compared to simple homogeneous plasma without flame. Due to significant difference in plasma properties, different plasmas interact with flames in different ways. It has been found that there are several major flame

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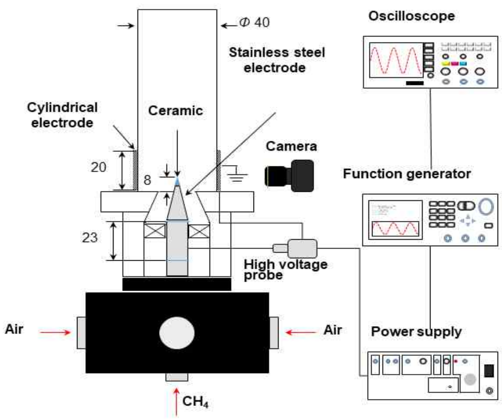

Fig. 1 Schematic diagram of the experimental setup.

enhancement pathways of plasma interaction with flame. Plasma generates heat, ions, electrons, radicals, excited species and ionic wind that can change temperature, chemical kinetics, transport properties and fuel decomposition. Therefore, more than one plasma effect can enhance flames at the same time such that it becomes more difficult to understand its main effect on the flame.

The experimental apparatus consists of a model swirl combustor, a gas supply system, a non-thermal plasma-generating system, and a visualization system, as shown in Fig. 1. The combustor has a swirl nozzle with ten holes through which fuel is supplied in a line and a compressed dry air is also supplied through a contoured mixing chamber with 11 mm-diameter at the exit. The quartz tube has inner and outer diameters of 35.5 and 40 mm, respectively. The non-thermal plasma-generating system is composed of a DBD reactor and a power supply (Trek, 10/10B-HS). The DBD reactor has one sharp tip made of ceramic material installed on the cone-type of fuel nozzle. The cone-type nozzle serves as a central electrode made of stainless steel with 5 mm in diameter, resulting in the intensities of rotational streamers. The other cylindrical electrode made from a woven stainless steel mesh (width: 20 mm; thickness: 1 mm) surrounds the outer quartz tube. The tube acts as a dielectric barrier and the cylindrical electrode is grounded.

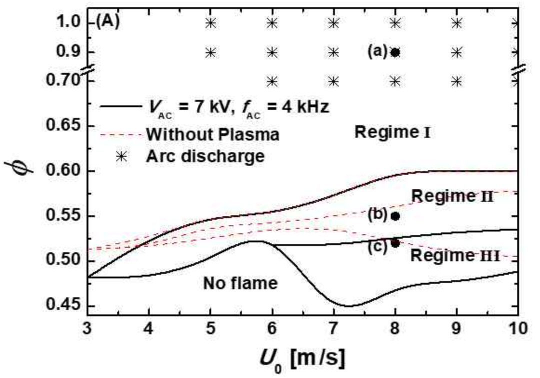

Fig. 2 Stability maps as functions of equivalence ratio and fuel jet velocity; comparing of flame edges with reducing equivalence ratio between base condition and with plasma.

As shown in Fig. 2, the plasma significantly extends the flammable limits in terms of the equivalence ratio for all velocity ranges. Several points are to be noted. First, stable flames can exist over a much wider range of the equivalence ratio and velocity with plasma (the black-solid line) than that without plasma (the red-dotted line). Second, however, the extension of flammable limits is found to be more significant in the high velocity regime (7 - 10 m/s) than that in the low velocity regime (3 - 6 m/s). We found that the extension of the flammable limit in the low velocity regime is primarily attributed to the effect of streamer on the flames while it is due to the ozone effect in the high velocity regime.

Figure 3 shows the emission of CO and NO_x as a function of the equivalence ratio with/without plasma, which were measured by using a DBD technique. The emissions of CO and NO_x show different trends. Although the NO_x emission increases slightly, the amount of CO reduces significantly when plasma with high voltage and frequency (7 kV and 3 kHz) is applied to flames. The CO reduction occurs because ozone induced by plasma enhances complete combustion by increasing preheat zone temperature of flames. In the same way, NO_x is slightly increased due to increased flame temperatures.

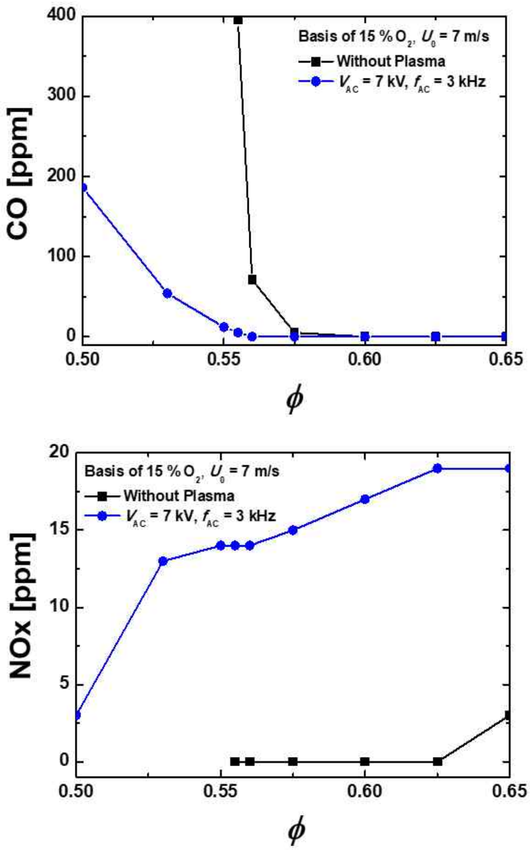

Fig. 3 Emissions of CO (top) and NO_x (bottom) as a function of the equivalence ratio for V_{ac} = 7 kV with f_{ac} = 3 kHz.

Acknowledgement

This research was supported by Korea Gas Corporation (KOGAS), (RD2017-0061).

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