Product Gas Characteristics of Ammonia/Hydrogen/Air Premixed Laminar Flames Stabilized in Stagnation Flows for Various Equivalence Ratios

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ABSTRACT

Ammonia is expected to contribute to the energy agenda as a carbon-free fuel. To improve the weak flame characteristics of ammonia flames, hydrogen addition is also anticipated. However, hydrogen addition changes the emission characteristics of the ammonia flame. In this study, product gas characteristics for ammonia/hydrogen/air premixed flames for various equivalence ratios were experimentally characterized using a stagnation stabilized flame under atmospheric pressure and room temperature conditions. It was clarified that the maximum NO mole fraction significantly increased due to hydrogen addition. N_2O, which has a significant global warming potential, was observed for very lean conditions.

1. Introduction

Climate change is a global critical issue and is one of the development targets of the sustainable development goals (SDGs). To solve these global concerns, reduction in carbon dioxide is an urgent issue. In Japan, the Green Growth Strategy has been proposed to achieve such a carbon neutrality by 2050 [1].

Ammonia utilization is one of the potential solutions towards carbon neutrality. Towards the application of the molecule in combustors, fundamental ammonia flame characteristics have been studied [2]. The laminar burning velocity of ammonia is slower than that of conventional hydrocarbon flames [3]. Hydrogen addition has been proposed to increase the laminar burning velocity because the binary fuel of ammonia/hydrogen has a faster laminar burning velocity than pure ammonia [4]. However, product gas characteristics of ammonia/hydrogen/air flames have not been clarified yet, especially for laminar flames. Understanding the product gas characteristics is necessary to determine optimal conditions with minimum unwanted emissions that adhere to the regulations. In this study, product gas characteristics of ammonia/hydrogen/air premixed laminar flames stabilized in a stagnation flow were experimentally investigated for various equivalence ratios.

2. Experimental Setup

Figure 1 shows the schematic of the experimental setup used in this study. The detailed descriptions are available elsewhere [5]. A nozzle burner with an outlet diameter of 40 mm was employed. To generate a stagnation flow, a top plate was mounted 20 mm above the nozzle burner. There were sampling holes on the surface of the top plate that transfer the product gas to the FTIR (BOB-2000FT, Best Instruments) gas analyzer. Ammonia and hydrogen were used as fuel, and air was used as oxidizer. The hydrogen fraction in the binary fuel, ξ_{H2}, was set as $\xi_{H2} = [H_2]/([H_2]+[NH_3])$, here [X] is the mole fraction of the species X [4]. In this study, the hydrogen fraction ξ_{H2} was set to 0.3 as suggested by [6]. All experiments were conducted at atmospheric pressure condition, and the mixture inlet temperature was 295±2 K. The mixture inlet velocity varied from 0.24 to 0.45 m/s since the laminar burning velocity changes depending on the equivalence ratio.

When the concentrations of the product gas exceeded the measurable range of the FTIR gas analyzer, a dilution sampling method was employed [7]. The product gas was diluted by a dilution gas upstream of the FTIR gas analyzer. The composition of the dilution gas used in this study was CO_2/N_2 (CO_2 mole fraction = 15.9 %). CO_2 was used as the tracer species because the product gas studied in this work does not contain CO_2 (if the CO_2 from the air is neglected). With the absence of CO_2 in the product gas, the dilution ratio and the actual concentration of species of interests could be derived using the measured concentration of CO_2 by the FTIR gas analyzer. The detailed descriptions of the dilution sampling method are available elsewhere [5, 7].

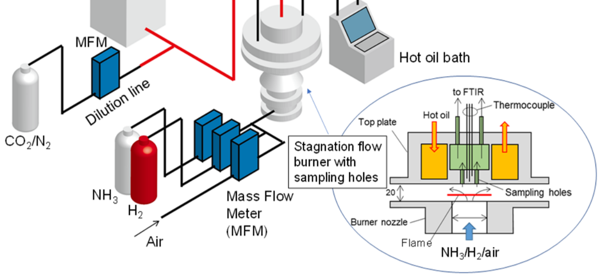

Fig. 1 Experimental setup.

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3. Results and Discussion

Figure 2 shows the product gas characteristics of ammonia/hydrogen/air flames in terms of equivalence ratio, ϕ. The maximum NO mole fraction was around 8700 ppm at ϕ ~ 0.85, and was larger than that of ammonia/air flames, whose maximum NO concentration was around 3500 ppm within the examined conditions in the previous work [5]. The NO mole fraction decreases with an increase in the equivalence ratio from ϕ ~ 0.85, and unburnt NH_3 starts to increase at rich condition. In this condition, the optimal equivalence ratio for the minimum emissions of NO and unburnt ammonia was ϕ ~ 1.20. The optimal equivalence ratio was larger than that of ammonia/air flames [5]. In addition, hydrogen was also generated from the rich flames that reached as ~8 %. The trade-off relationship between NO and unburnt ammonia at slight-rich condition can be applied to the rich-lean two-stage combustion concept [2]. The optimal equivalence ratio is the target equivalence ratio at the primary combustion region for the two-stage combustion to allow simultaneous NOx and unburnt ammonia reduction in a gas turbine combustor.

NO concentration reduces with leaner mixture below ϕ ~ 0.85. However, at the same condition, NO_2 production becomes significant. The major NOx molecule examined in this study was NO. It was also noted that the production of N_2O which has a large global warming potential of around 300 [8] was significant around ϕ ~ 0.60.

4. Concluding Remarks

Product gas characteristics of strain stabilized ammonia/hydrogen/air premixed laminar flames were experimentally investigated under atmospheric pressure and room temperature conditions. Maximum NO concentration was around 8700 ppm at an equivalence ratio of around 0.85. In addition, significant production of N_2O production was observed around the equivalence ratio of 0.60.

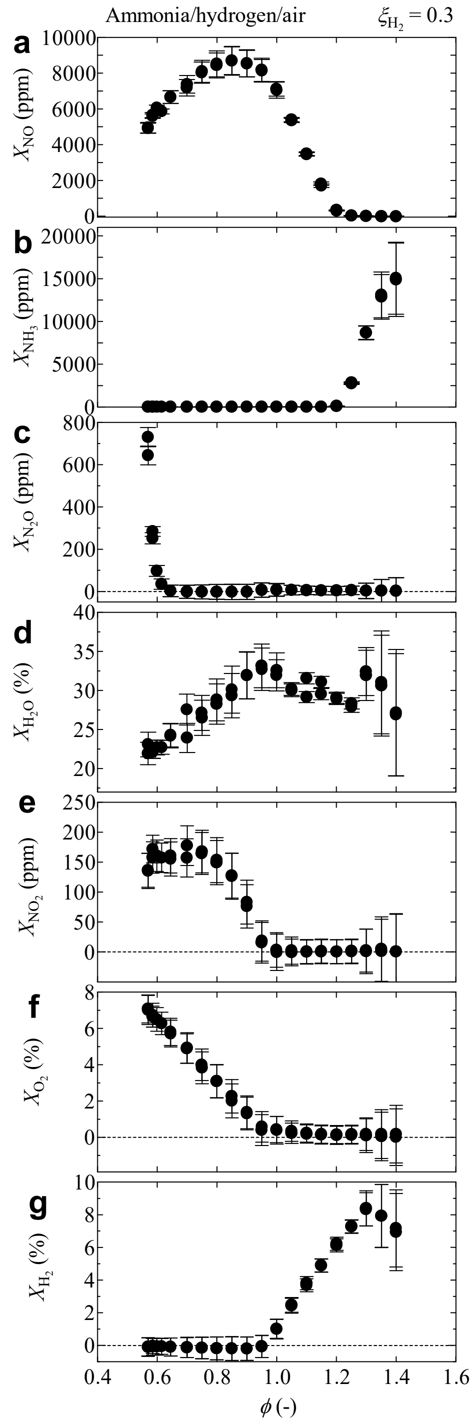

Fig. 2 Product gas characteristics of ammonia/hydrogen/air laminar premixed flames of (a) NO; (b) NH_3; (c) N_2O; (d) H_2O; (e) NO_2; (f) O_2; (g) H_2.

Acknowledgment

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