Enhancing Combustion Efficiency and Emission Reduction through MILD Combustion Coupled with Non-Thermal Plasma

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Abstract

This study explores the enhancement of MILD (Moderate or Intense Low-Oxygen Dilution) combustion performance for ammonia/air mixtures using non-thermal plasma (NTP). MILD combustion is known for reducing NO_x emissions through low-temperature, uniform oxidation, and when coupled with plasma, it can further broaden flammability limits and improve fuel conversion. Experiments were conducted using a custom cyclonic burner equipped with plasma actuators. Results show that the application of non-thermal plasma significantly reduces ammonia slip—from 175 ppm to 85 ppm at stoichiometric conditions (Φ=1), with a conversion efficiency above 75%. Additionally, the extinction equivalence ratio (Φ_{ext}) decreased from 0.55 to 0.46 with increasing plasma power, indicating improved lean-burn stability. Despite a slight increase in NO_x emissions, NO was favored over N_2O, reducing long-term environmental impact. These findings confirm the potential of plasma-assisted MILD combustion as a viable pathway for efficient and clean use of ammonia as a carbon-free fuel.

Introduction

The need to reduce emissions from fossil fuels has prompted interest in alternative fuels such as ammonia. MILD combustion offers a viable strategy to limit NO_x through diluted and preheated reactants [1]. However, stabilizing ammonia flames under lean conditions remains a challenge. This study investigates the potential of non-thermal plasma (NTP) to improve ammonia oxidation, reduce NH_3 slip, and extend flammability limits under MILD combustion [2, 3].

Materials and Methods

Experiments were performed using the LUCY burner [4] designed to achieve MILD conditions via strong internal recirculation. The inlets are positioned on two opposite sides to show where the reactants enter. In the middle of the chamber is the stack region, which represents the exit of the combustion chamber. This design promotes symmetry in the measurement locations and helps assess the temperature distribution throughout the chamber. Plasma actuators with needle-to-needle configuration (5 mm gap) were integrated, and the effects of NTP at three power levels (35%, 50%, 65%) were evaluated. Gas analyzers measured NH_3, H_2, NO, and N_2O concentrations, while temperature fields were recorded using thermocouples distributed in the combustion chamber.

Results and Discussion

Non-thermal plasma significantly enhanced ammonia conversion. At Φ=1, NH_3 emissions decreased from 175 ppm to 85 ppm (Plasma 65%), while H_2 levels dropped, indicating improved combustion. NO_x emissions slightly increased but remained low, with NO preferred over N_2O—favorable due to easier downstream treatment, as shown in Figure 1.

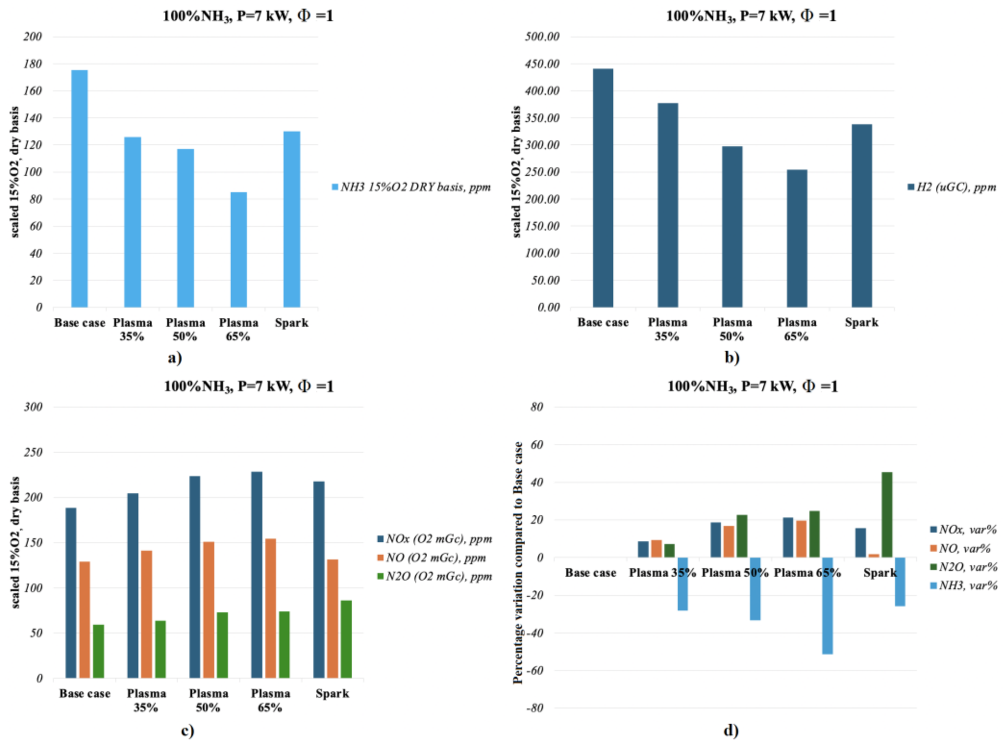

Figure 1. Emissions of NH_3, H_2, and NO_x under stoichiometric conditions (Φ = 1) with increasing plasma power levels.

Under lean conditions (Φ=0.6), NH_3 slip was reduced by 65% with plasma, and the extinction limit Φ_{ext} shifted from 0.55 to 0.46. This confirms the role of plasma in stabilizing low-temperature ammonia combustion without compromising MILD uniformity, as shown in Figure 2.

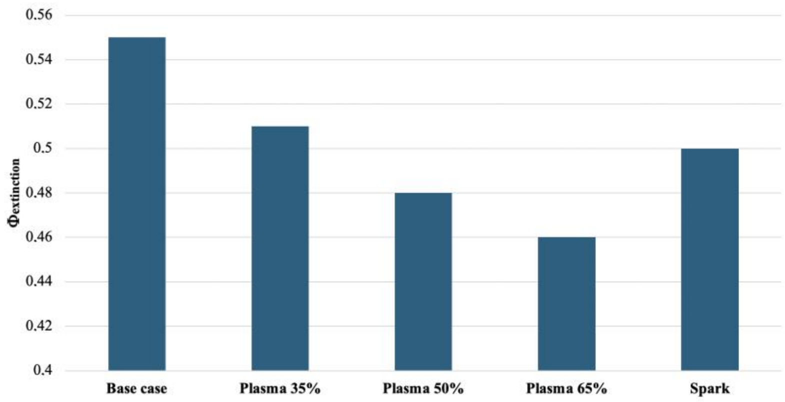

Figure 2. Extinction limits (Φ_{ext}) for ammonia/air mixtures with and without plasma actuation.

Conclusions

Plasma-assisted MILD combustion of ammonia enhances fuel conversion, reduces NH_3 slip, and lowers the extinction limit without significantly raising NO_x. Non-thermal plasma outperforms spark systems due to its broader radical generation and distributed energy input. This technique presents a promising route for ammonia utilization in low-emission energy systems.

References

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