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Effects of Temperature and Humidification in $20_{VOL.\%}$ Cracked Ammonia Swirling Flames

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Topics: Combustion/Thermal Applications

Introduction

Global warming is one of the biggest issues of the 21st century. Different carbon-free fuels are being considered to tackle climate change by reducing our dependence on fossil fuels [1]–[3]. Ammonia has recently gained interest as a zero-carbon fuel and a potent hydrogen carrier to enable carbon-free energy systems [4]–[6]. However, pure ammonia faces some challenges as a fuel in terms of toxicity [7], excessive production of nitrogen oxides [8], low flame speed [9], lower energy density [10] and corrosion [11] but most of these drawbacks can be tackled by the use of doping agents, such as hydrogen and/or methane to improve combustion characteristics [12]–[15]. Previous studies [10], [16], [17] have identified $70/30_{vol.\%}$ NH_3/H_2 blend as a potential alternative of premixed methane flame with the blend exhibiting similar flame speeds at lean conditions and wider stability region. However, previous studies have ignored the nitrogen produced from cracked ammonia as a part of the fuel blend. Obtaining pure H_2 from the cracking process would require molecular sieves, which tend to be highly specialized, expensive components. Therefore, use of the fully cracked molecule (including N_2) needs to be pursued to reduce implementation costs of these technologies. Current study reports flame characteristics of 20% cracked ammonia in an industrial scale swirl burner for the first time at a wide range of equivalence ratios. Effects of different inlet temperatures and humidified conditions have been considered and reported in this study.

Materials and Methods

This work employed a newly designed stratified combustor at Cardiff University with both premixed and stratified operability modes. The premixed tangential swirler with a geometric swirl number of $S_g = 1.05$ was employed. Fuel and air flows in the burner were supplied using dedicated Bronkhorst mass flow controllers (±0.5% within a range of 15-95% mass flow). Experiments were conducted at atmospheric pressure (1.1 bara), two inlet temperatures (295 and 390 K), and with and without humidification at a constant fuel inlet thermal power of 10 kW. A Logitech C270 camera was used to monitor the flame stability at a distance of 5 m.

A pair of LaVision CCD cameras were employed to obtain line-of-sight chemiluminescence traces of various species. The units were triggered simultaneously at a frequency of 10 Hz with constant gain. A range of optical (Edmund) filters were used for each species of interest, namely OH* (309 nm; $A^2\Sigma^+–X^2\Pi$ system) [18], NH* (336 nm; $A^3\Pi–X^2\ \Sigma^-$ system) [18]–[21] and NH_2* (630 nm; single peak of the NH_2 α band) [18], [22]. Exhaust emissions (NO, N_2O, NO_2, NH_3, CO, CO_2, O_2 and H_2O) were measured using a bespoke Emerson CT5100 Quantum Cascade Laser analyser at a frequency of 1 Hz, a repeatability of ±1%, 0.999 linearity, and sampling temperature up to 190°C.

Results and Discussions

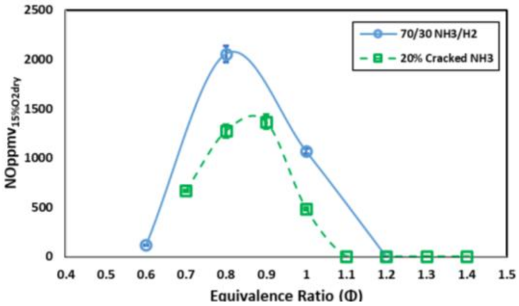

Fig. 1. NO emissions comparison between 70/30$_{VOL.\%}$ NH_3/H_2 and 20$_{VOL.\%}$ cracked ammonia blends.

NO emissions at the exhaust decrease with 20$_{VOL\%}$ cracked ammonia blend, compared to 70/30$_{VOL.\%}$ NH_3/H_2 blend, Fig. 1. This is due to the reduction in the productions of OH and NH radicals which react together to produce HNO, the main source of NO formation in the flame [23], whereas NH_2 production increases at the cracked blend which enables reduction of NO [8]. These changes in radicals' productions are evident in Fig. 2 where the images are normalized to image maximum intensity. The resolution of the radicals' images can be seen as an indicator of their availability in the flame. Interestingly, at the cracked ammonia case, the flames stabilize nearer to the central axis, compared to the 70/30$_{VOL.\%}$ NH_3/H_2 blend. However, NO_2 emissions increases slightly (< 20 ppmv) with the cracked ammonia blend and negligible differences were observed for N_2O and NH_3 emissions.

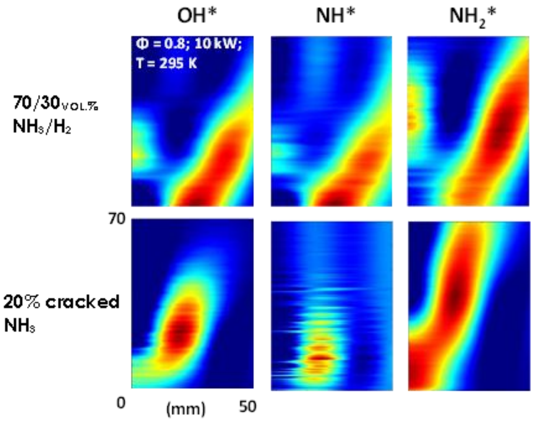

Fig. 2. Changes in radicals' distributions between 70/30$_{VOL.\%}$ NH_3/H_2 and 20$_{VOL.\%}$ -cracked ammonia blends.

With higher inlet temperature of 390 K, stable range of flames widens but suffer from higher NO (Fig. 3) and NO_2 emissions with better N_2O performances. NO and NO_2 emissions increase due to the higher productions of OH and NH radicals, as per Fig. 4 where images are normalized to maximum species intensity. The betterment of N_2O performance at higher inlet temperature can be attributed to higher flame temperature at the lean conditions, thus increasing the production of H radicals which converts N_2O to N_2 [8].

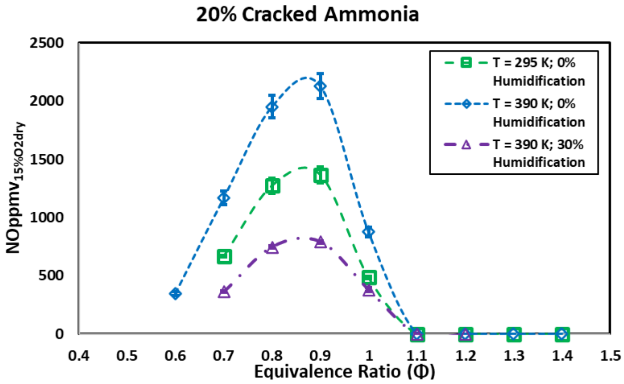

Fig. 3. NO emissions comparison at 20$_{VOL.\%}$ -cracked ammonia blend with different inlet temperatures and humidification.

With 30% humidification, OH and NH radicals' production decreases severely, reducing overall NO and NO_2 productions, but N_2O production increases due to the drop in flame temperatures.

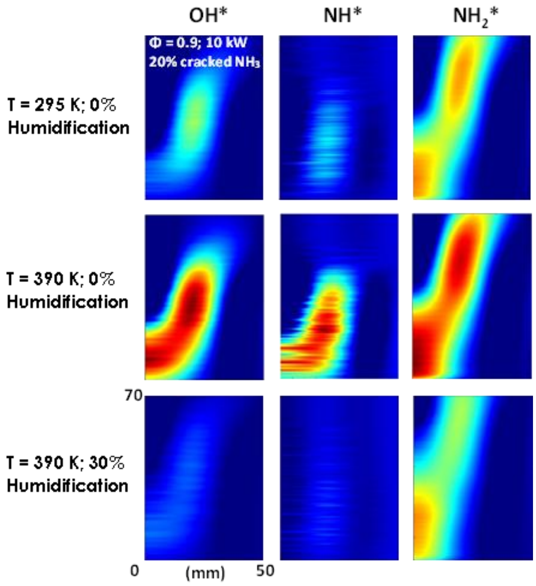

Fig. 4. Changes in radicals' distributions between at 20$_{VOL.\%}$ cracked ammonia blend with different inlet temperatures and humidification.

Conclusions

Flame characteristics and exhaust emissions at 20$_{VOL.\%}$ -cracked ammonia were reported for the first time. Overall exhaust emissions performance improved with the cracked ammonia blend. Increase in inlet temperature enhanced flame stability and better N_2O performance but suffered from higher NO and NO_2 emissions. Introduction of humidification improved NO and NO_2 performance but increased N_2O emissions as the flame temperature dropped. Combinations of these techniques will pave the way for carbon-free energy systems in future.

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