ME – PhD Thesis Colloquium

Experimental Investigation of Syngas Combustion in a Novel Two-stage combustor

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ABSTRACT

In recent years, syngas has gained research interest as the focus shifts from fossil to renewable fuels. Syngas generated from biomass such as wood, agricultural residue and paper is a promising fuel to achieve net-zero carbon emission. It is mainly composed of CO, H_2 and diluents such as CO_2 and N_2. The combustion characteristics of biomass-derived syngas significantly differ from the well-studied fuels in terms of calorific value, stoichiometric fuel-to-air ratio, ignition delay, and flammability limits. In the present study, a novel combustor configuration consisting of a combination of catalytic and swirl combustion is explored to achieve near-zero NOx emissions without impacting combustion stability. The first stage is a fuel-rich catalytic stage, whereas the second stage utilizes swirl. A preheated and premixed syngas-air mixture is supplied to the first stage, where syngas is consumed partially. The remaining unburnt fuel is combusted using excess air in the second stage. In this stage, the flame is stabilized by two co-centric swirling streams where the inner stream is the unburnt gases coming from the first stage, and the outer stream is the oxidizer. By changing the swirling direction of the streams, co and counter-swirl flames are obtained.

The first part of the study investigates the catalytic combustion of syngas in the first stage at rich equivalence ratios. The transient temperature measurements show three distinct regions of catalytic combustion: kinetically controlled, light-off, and steady-state regions. It is found that the start-up time depends on the conductivity of the monolith placed inside the first stage. The NO_x emission is found to be very low (< 1 ppm) at the exit. The second part of the study explores the lean unconfined co/counter swirl-stabilized flames in the second stage. Both co/counter swirl flames are observed to be highly stable over a large range of flow rates, maintaining a constant overall equivalence ratio. In the next part, confined flames are studied. The emission, temperature, flame shape and combustion noise are investigated at three overall equivalence ratios ($\Phi_{overall}$). The CO emission reduces drastically in the presence of confinement, and the emission is ~10 ppm for an overall equivalence ratio of 0.55. The NO_x emission is below 2 ppm for all cases. Planar laser-induced fluorescence (PLIF) measurements of the OH species shows the radicals are well distributed over the combustor for co/counter-swirl flames. Particle image velocimetry (PIV) measurements indicate that the flame shape is related to the shape of the inner recirculation zone. The sound pressure level (SPL) for the co/counter-swirl flames is ~110 dB. The frequency domain data contains a dominating peak at all values of $\Phi_{overall}$. The high-speed OH* chemiluminescence imaging at 5 kHz) confirms excitation of the axial mode of the combustor. Apart from axial mode, the chemiluminescence signal shows the presence of a precessing vortex core (PVC) in the flow. In the next part, the effect of O_2 concentration in the oxidizer stream is studied. The OH* chemiluminescence intensity reduces and the flame height increases when O_2 concentration decreases. The sound pressure level (SPL) also shows a decreasing trend with O_2. The global luminosity calculated from high-speed chemiluminescence indicates that the peaks corresponding to axial mode and PVC are suppressed at low O_2 concentrations. In terms of emissions however, the CO emission increases with a reduction in O_2. Additionally, the feasibility of achieving distributed combustion is assessed from the various data obtained on emissions, chemiluminescence intensity, SPL, and combustion stability. It is found that the co-swirl configuration is best suited for achieving distributed combustion. Finally, in the last part of the study, the effect of momentum ratio, density ratio and heat-release rate on the flow field is studied in detail. Overall, it is established that the syngas-fired, two-stage rich-catalytic lean-swirl stabilized combustor developed in this study is an ultra-low emission burner suitable for industrial process heat/power applications. Additionally, the current study has led to an improved understanding of fuel-rich catalytic combustion and the structure, dynamics, and flow field of co/counter-swirl turbulent, partially-premixed flames.

ABOUT THE SPEAKER

Atanu Dolai is a PhD student in Department of Mechanical Engineering, IISc, Bangalore. He completed his BE from Jadavpur University, Kolkata in 2015. He then joined IISc Bangalore where he completed his MTech degree in 2017. Subsequently, he joined IISc as a PhD student in 2017. His research interests include energy from renewable fuels and low temperature combustion with a focus on catalytic and distributed/flameless combustion.