Optimization of a premixed low-swirl burner for industrial applications

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ABSTRACT

This study was motivated by recent tests results showing that a 5cm i.d. low-swirl burner (LSB) stabilizes ultra-lean premixed turbulent flames up to 600kW. A parametric study has been performed to determine the optimum ultra-lean LSB configuration, i.e. one that will achieve low NO\textsubscript{x} and flame stability, for thermal input between 15kW to 150kW. Using Laser Doppler Velocimetry (LDV), non-reacting centerline velocity and rms fluctuation profiles were measured, and were found to show self-similar behavior. This self-similarity may explain why the flame remains stationary relative to the burner exit despite a change in bulk flow velocity from 5 to 90m/s. The recess distance of the swirler affects the shape of the mean and rms velocity profiles. Lean blow-off limits were also determined for various recess distances, and an optimum exit length was found that provides stable operation for ultra-lean flames.

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INTRODUCTION

Background & Motivation

Previous studies of the low swirl burner (LSB) concept have been conducted in the laboratory, using air jets to create low swirl in a premixed flow (Chan, et. al. 1992, Bedat and Cheng, 1995). The original air jet configuration was deemed too complicated for industrial acceptance, so a fixed-vane swirler centerbody was subsequently developed (Yegian, 1998). The vane design supports a low-swirl flame similar to the jet swirler, while providing a simpler method for generating low-swirl flow. The swirler section is comprised of an annular vane section along the inside wall of the burner and a central bypass with a perforated screen (see Figure 1). This vane LSB design serves as the basis for the current study.

The LSB has been successfully demonstrated in both laboratory-scale and industrial-scale test facilities. The LSB can access a remarkably wide range of stable operating conditions (15kW to 1MW). Coupled with the relatively low emissions observed over this wide range, this makes the LSB attractive for burner applications requiring <10 ppm NOx.

Typical premixed burners can access only a relatively limited range of velocities at low equivalence ratios. Higher velocities introduce instabilities that require expensive and/or complicated measures to prevent flame blowoff. In contrast, industrial tests have demonstrated stable LSB operation at high velocity/ultra-lean conditions that are typically inaccessible to conventional burners.

This paper describes a detailed study of the flow field produced by a 5cm diameter LSB with a fixed-vane centerbody. A parametric study was performed, selecting aspects of the LSB geometry that could be easily varied for laboratory testing.
Objective

The current study characterizes the flow field generated by the vane swirler design. Determining the flow field under different LSB configurations will allow a better understanding of which parameters best optimize burner performance. LDV measurements and lean blowoff testing at fixed velocities will provide a means for validating future CFD modeling and ultimately allow development of improved LSB’s without expensive prototyping.

Information about the flow field sensitivity to various factors was determined by altering the centerbody recess distance (3.5cm to 14cm), bulk flow rate (10L/s to 50L/s), and screen placement (upstream or downstream of centerbody). Ultimately, this information will be used to develop a correlation between important characteristics of reacting and non-reacting flows. Using this correlation, properties of reacting flows, such as flame stabilization point, could be inferred by studying the non-reacting flow for the same geometry.

RESULTS

LDV and lean blowoff tests were performed over various LSB configurations. For most trials, LDV measurements were made on non-reacting flows instead of reacting flows, as a wider range of non-reacting flow conditions can be accessed under laboratory operation.

Non-reacting velocity profiles were obtained using LDV. 2-D velocity maps were obtained for a range of bulk flow rates (10L/s to 30L/s), as a starting point for visualizing the flow field. These 2-D profiles show a divergence field at the burner exit that increases in intensity with increasing velocity. The profiles also show a recirculation zone appearing in the non-reacting flow for velocities above 5m/s (see Figures 2a and 2b). This is consistent with previous LSB studies using air-jet swirlers, which also showed no recirculation for flows slower than 5m/s. The 2-D profile shows that the zero-velocity crossing along the centerline is the point on the recirculation zone closest to the burner.
Preliminary tests demonstrated that the recirculation zone produced under non-reacting conditions does not appear when a flame is present. The LSB creates a divergent flow field, with a linearly decreasing velocity gradient stabilizing the flame at the point where the premixed reactant velocity balances the flame propagation speed. The flow expansion due to flame heat release appears to prevent the formation of the recirculation.

Centerline velocity profiles were obtained for a range of flow rates (5L/s to 50L/s) and centerbody recess distances (3.5cm to 14cm). The local centerline velocities were normalized using the average bulk velocity, as determined from the flow rate. The average bulk velocity was determined by measuring the flow rate upstream of the burner, and dividing by the cross-sectional area at the burner exit. When plotted together, the normalized velocity profiles for a given recess distance were shown to be self-similar above 10L/s (see Figure 3). For different recess distances at a fixed velocity, the profiles overlap for the middle recess distances between 6cm and 12cm (see Figure 4).

The centerline velocity is mostly linear between the burner exit and zero-velocity crossing point. The non-reacting normalized rms velocity also exhibits self-similarity behavior above 5m/s. The normalized rms velocity is centered about 10%, and peaks at the zero-velocity crossing (see Figure 5).

In order to test the stability limits of the LSB, the lean blowoff was found for a range of velocities (5m/s to 25m/s) and recess distances (3.5cm to 14cm). Blowoff tests were performed by maintaining a constant bulk flow rate and lowering the equivalence ratio until the flame disappeared.

In its initial configuration, the centerbody screen was placed on the downstream side of the vane swirler section. Under the downstream screen placement, the blowoff equivalence ratio increased with velocity, but was lower for a given velocity above 5m/s when using longer recess distances (see Figure 6a). Unfortunately, larger recess distances are undesirable in industrial applications, where compactness is preferred.

Blowoff tests were also performed with the centerbody screen in the upstream position. This screen position reduced blowoff variation over both
recess distance and velocity, extending the ultra-lean operation to higher velocities and lower recess distances (see Figure 6b).

CONCLUSIONS

This parametric study shows that LSB performance can be optimized by changing the geometry of LSB components. Stability improvements were observed due to various parameter changes, indicating that

The swirler recess distance affects flowfield development. The stability range was extended to include short recess distances and higher velocities by changing screen position. Future work will address the flow field effect of changing the screen blockage ratio, and map out the reacting flow field for the same parameters used above. This information will serve to develop the correlation between non-reacting and reacting flow conditions.

The non-reacting normalized velocity profiles show self-similar behavior. If the self-similarity continues for velocities above 25m/s, then the flow field could be predicted for any velocity using this LSB configuration. Such extended self-similarity, combined with a correlation between reacting and non-reacting flow profiles, would allow LSB flame prediction for velocities and configurations not yet tested. All of this information could serve to validate CFD modeling of the LSB, and hence facilitate further development of the LSB while reducing expensive prototyping.

REFERENCES

