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Stability characteristics and flame structure of low swirl burner

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Abstract

Low swirl burner provides stable lifted flames for fundamental studies of flame structure and turbulence/chemistry interaction in well defined boundary conditions. In the present study the stability characteristics of the burner have been investigated with four tangential jets at the same stoichiometry as the main jet. Two different burner nozzles with 40 mm and 53.5 mm diameters have been used for the stability measurements. In addition, a combined two-dimensional Rayleigh/LIPF-OH technique has been applied for simultaneous measurements of temperature and OH-radical for reaction zone and flame front investigation. Three flames have been selected near extinction for detailed measurements.

The data show that the relation between of the main jet velocity, U, and the velocity of the four tangential jets, u, is linear. For the present data set with the nozzles investigated the linear trend can lead to an almost constant ratio of UD/u as 5.08 mm with D as the nozzle diameter of the burner. The flame structure varies from corrugated to highly wrinkle according to the turbulence level.
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1. Introduction

Low swirl burner design was introduced by Cheng [1]. The burner provides stable free open lifted flames above the burner nozzle. In this burner a turbulent premixed jet flows through a tube and subjected to small tangential streams of air, at about two diameters upstream the nozzle exit, that produce low swirl. This generates divergent flow, reduces the local mean velocity and, then, stabilizes the flames. Bedat and Cheng [2] have used a turbulence generator that is developed by Videto and Santavicca [3] to produce intense isotropic turbulence [1]. The advantage of the low swirl burner is that the flames are not subjected to shear or recirculation. In addition the flames are accessible for laser measurements. The low swirl burner produces flames that cover a wide range in the corrugated flamelet and the thin reaction zones regimes. This makes the burner a good candidate for fundamental research and the data can also be used for model verification. Recently this burner has been considered for further fundamental research during the turbulent non-premixed flames meeting prior to the 30th Symposium on combustion.

The stability mechanism and characteristics of the low swirl burner are presented in Cheng [1]. They concluded that the stabilization mechanism is quite similar to stagnation flow stabilized flames. Thus the flame configuration can be treated [1] as a close approximation of the normal one-dimensional planar flame and stretched premixed turbulent flames of Bray-Moss-Libby model [4]. Cheng and coworker [2] found that the flame zone is free from the effect of swirl, which affects the rim of the flame only. Velocity and scalar characteristics of the low swirl flames are reported in [1]. The burner has been used to measure the turbulent burning velocity [5]. Using air tangential jets should dilute the main jet and this affects the stability and may also affects the flames structure.

Accordingly, in this work the stabilization characteristics and flame structure have been investigated using tangential jets of the same stoichiometry as the main jet. In

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Nomenclature

D	nozzle diameter	U	velocity of main jet
LIPF	laser induced predissociation fluorescence	Z	height above the burner
LS	low swirl		
X	radial coordinate	*Subscript*	
Re	Reynolds number	j	jet
rms	root mean square		
T	temperature	*Symbol*	
u	velocity of tangential jets	ϕ	equivalence ratio

addition, two nozzles at different diameters have been investigated. Three flames have been selected for detailed flame structure study using advanced laser based techniques. The flames are selected near the extinction limit. A combined Rayleigh and laser induced predissociation fluorescence of OH radical has been used for simultaneous imaging of temperature and OH. More data are reported in our recent work [6] to present the flow field characteristics using PIV technique.

2. Burner and selected flames

The idea of the low swirl (LS) burner is based on the reduction of the local jet velocity at the boundary using a swirl component of four tangential jets [1]. This leads to a stable flame due to the balance between the jet velocity upward and the flame speed downward. As introduced above, the burner has been designed by Cheng [1] and tested by Bedat and Cheng [2]. The burner schematic diagram is shown in Fig. 1. The fuel and air are mixed before entering the burner. The mixture enters a large settling chamber and passes through a porous plate to arrest the flame in case of flame flash back. The mixture then passes through a circular slit of 0.8 mm width. The circular flow then passes through a cone at an angle of 38° that creates

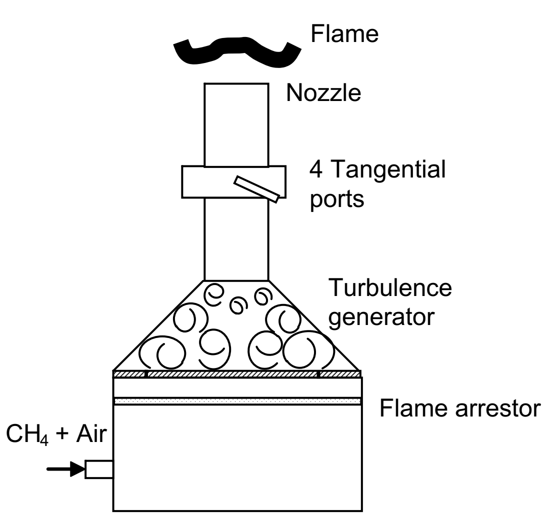

Fig. 1. A schematic diagram of the low swirl (LS) burner.

Table 1
List of the selected flames

Flame	Jet Velocity U_j (m/sec)	Jet equivalence ratio ϕ_j	Reynolds number Re
F1	3	0.7	1.03 E04
F2	5	0.7	1.71 E04
F3	8	0.7	2.74 E04

high turbulence level due to the breakdown of the jet into several sizes of eddies. This idea of the turbulence generator was developed by Videto and Santavicca [3] in one-dimensional slit. High level of turbulence up to 25% can be achieved [1]. The jet passes through the nozzle where four tangential ports of 3 mm diameter are used to inject four jets at an angle of 20°. This provides stable lifted flames at a distance between 15 and 30 mm above the nozzle. In the previous work [1,5] air was injected through these ports. This dilutes the main jet boundary where stabilization takes place and thus affects the overall stoichiometry of the jet. Accordingly, in this work we used the same mixture to be injected through the ports in order to minimize the dilution effect of the jet boundary and thus leaner flames can be investigated.

In the present work the stability characteristic of the burner has been tested based on the main jet and tangential jets velocities. Two different nozzles have been used with diameters of 40 and 53.5 mm. Then three flames have been selected for flame structure study based on the stability curves presented in the next section. The flames are selected near the extinction limit. The data of the three flames are listed in Table 1 below for the large nozzle. The tangential jets equivalence ratio is the same as the main jet, as explained above. The Reynolds number is shown in each flame. The flames are expected to be with the thin reaction zones regime of Peters [7].

3. Stability characteristics

Two nozzles of 40 mm and 53.5 mm diameters have been selected for the present study as explained above. Three parameters have been selected to study the flame stability. These are the main jet velocity, U, the tangential jet velocity, u, and the jet equivalence ratio, ϕ. Fig. 2 illus-

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