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Flashback Avoidance in Swirling Flow Burners

Impedimento de reflujo de llama en quemadores de flujo giratorio

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Abstract

Lean premixed combustion using swirling flows is widely used in gas turbines and combustion. Although flashback is not generally a problem with natural gas combustion, there are some reports of flashback damage with existing gas turbines, whilst hydrogen enriched fuel blends cause concerns in this area. Thus, this paper describes a practical approach to study and avoid flashback in a pilot scale 100 kW tangential swirl burner. The flashback phenomenon is studied experimentally via the derivation of flashback limits for a variety of different geometrical conditions. A high speed camera is used to visualize the process and distinguish new patterns of avoidance. The use of a central fuel injector is shown to give substantial benefits in terms of flashback resistance. Conclusions are drawn as to mitigation technologies.

Keywords:

- flashback
- swirling flows
- high speed photography

Resumen

El uso de flujos giratorios en condiciones pobres premezcladas se utiliza ampliamente en turbinas de gas y en combustión en general. A pesar de que el reflujo de llama no suele ser un problema durante la combustión de gas natural, existen muchos reportes sobre el daño que el reflujo puede producir en turbinas de gas actuales, especialmente cuando se utilizan mezclas de combustible con hidrógeno enriquecido. Por ende, este artículo describe una aproximación práctica al estudio y eliminación del reflujo de llama en un quemador de flujo giratorio tangencial de 100kW. El fenómeno de reflujo de llama se estudia experimentalmente mediante la derivación de los límites de reflujo para una gran variedad de geometrías diferentes. Se utilizó una cámara de fotografía rápida para visualizar el proceso y distinguir algunos parámetros para evitar el fenómeno. El uso de un inyector de combustible central produjo beneficios substanciales en términos de resistencia al reflujo de llama. Se presentan conclusiones sobre cómo mitigar el fenómeno.

Descriptores:

- *reflujo de llama*
- *flujos giratorios*
- *fotografía de rápida velocidad*

Introduction

The crucial feature of swirl burners is the formation of a central recirculation zone (CRZ) which extends blow off limits by recycling heat and active chemical species to the root of the flame in the burner exit. However, unless its size and shape are properly controlled, problems can arise. The CRZ can, for instance, readily extend back into the burner, even surrounding the fuel injector and facilitating early flashback (Subramanya and Choudhuri, 2007; Thornton *et al*., 2007; Lieuwen *et al*., 2008).

Flashback can occur when the gas velocity becomes lower than the flame speed, allowing the flame to propagate upstream, potentially causing damaging effects. The phenomenon can be caused by (i) boundary layer flame propagation, (ii) turbulent flame propagation in the core flow, (iii) combustion instabilities and (iv) upstream flame propagation of coherent vortical structures (Lieuwen *et al*., 2008, Lefebvre, 1999). For the latter, flow speed not necessarily can be lower than the flame velocity everywhere, though flashback is still observed. This refers to a highly complex phenomenon. This paper focuses on the two main causes of flashback:

- Flashback occurring through the low-velocity flow in the boundary layer along the walls of the burner close to the exit and governed by the critical boundary velocity gradient,
- Flashback occurring due to coherent structures.

The mechanisms may involve the use of homogeneous and/or heterogeneous reactions. Lieuwen *et al*. (2008) reviewed flashback in the context of syngas fired combustors and noted that minimization of flashback requires that the flow field should not have strong local velocity deficits and the axial flow velocity must be substantially above the local turbulent flame speed, S_t. High turbulence levels, one of the very useful features of swirling flow because of their mixing potential, detrimentally affect flashback limits due to their effects on S_t, especially for hydrogen enriched syngases.

Lean combustion tends to reduce flame velocity, but other factors associated with engine cycles, such as high temperatures, pressure, turbulence levels and pre-ignition reactions in the gases due to appreciable residence times at high temperature cause increased flame speeds, encouraging flashback.

With swirl burners, the swirl number, S (Syred and Beer, 1974) defined by the normalized ratio of axial flux of axial momentum and axial flux of angular momentum, is crucial as higher values ($S > 1.2$) tend to exacerbate the formation of excessively large CRZs which extend back into the burner. Moreover, higher swirl numbers tend to increase turbulence and consequently, the turbulent flame speed (Valera *et al*., 2011; Huang and Yang, 2004; 2005) and propensity to flashback in low velocity regions. Combustion located downstream of the tangential inlets alters significantly the axial flux of axial momentum Syred and Beer, 1974) hence local swirl number is also affected. This effect depends strongly on the equivalence ratio, rate of heat release, location of flame front and mode of fuel injection. Such changes in swirl number due to combustion can subsequently alter the resistance to flashback. Off-design condition operations that impact on the swirl number and flame stability can produce oscillations associated with unsteady flashback (Dhanuka *et al*., 2009).

These factors can explain the anomalous behavior of many swirl burners under various conditions, including flashback. Premixed combustion can especially change a highly swirling flow from a situation with a large stable CRZ to one where the CRZ is eliminated, the effect being a maximum at an equivalence ratio, ϕ, ~1 where heat release is at its highest point. Varying the equivalence ratio can substantially affect the occurrence, strength and size of any CRZ formed. Therefore, the evidence suggests that flashback is very dependent on several parameters, making very difficult to generalize any pattern that directly influence this phenomenon.

Flame flashback from the combustion chamber into the mixing zone can limit the reliability of swirl stabilized lean premixed combustion in gas turbines. A phenomenon labelled combustion induced vortex breakdown (CIVB) has been identified as an initial flashback mechanism in some swirl burners (Kröner *et al*., 2003; Kiesewetter *et al*., 2007; Kröner *et al*., 2007). It occurs with values of S between 0.5 and 0.9 when vortex breakdown is about to, or has just occurred (Gupta *et al*., 1984), without the presence of a central fuel injector. The phenomenon occurs as a sudden transition driven by the interaction of chemical reactions and vortex dynamics. First, a CRZ forms downstream of the burner exit that holds the flame. Then, the chemical reactions in the vortex core lead to the propagation of the CRZ into the burner. A closed recirculation bubble forms and the drop of density leads to the extinction of the downstream CRZ (Kröner *et al*., 2007). Lieuwen *et al*. (2008) also indicated that the CIVB phenomenon is primarily determined by density gradients and other combustion aerodynamic phenomena. Syred and Beer (1974) and Gupta *et al*. (1984) showed that these effects can be caused by swirl number re-