Available online at www.sciencedirect.com
ScienceDirect
Proceedings of the Combustion Institute 000 (2016) 1–10
Proceedings of the Combustion Institute
www.elsevier.com/locate/proci

Study of emission pollutants and dynamics of non-premixed turbulent oxygen enriched flames from a swirl burner

Toufik Boushaki [a,b,*], Nazim Merlo [a], Christian Chauveau [a], Iskender Gökalp [a]

[a] *ICARE CNRS, 1C, Avenue de la Recherche Scientifique, 45071 Orléans, France*
[b] *University of Orléans, IUT, GTE, 45067 Orléans cedex 2, France*

Received 4 December 2015; accepted 7 June 2016
Available online xxx

Abstract

The paper investigates the dynamics of methane – oxygen enriched air turbulent non-premixed swirled flames and their emission characteristics. The burner configuration consists of two concentric tubes with a swirler placed in the annular part supplying the oxidant. Fuel injection is radial through holes in the central tube at the burner exit. This allows enhancing air-fuel mixing and eases flame stabilisation. Fuel is injected into the highest turbulence level regions where the local mixing is enhanced, and generating a shift from a non-premixed flame towards a partially premixed one. The idea of oxygen enrichment of the air is related to the augmentation of CO_2 concentration in the flue gases to improve the CO_2 capture efficiency by membranes. Stereo-Particle Image Velocimetry is used to analyse the velocity flow fields. The measurements are performed for oxygen concentrations ranging from 21% to 30%, with swirl numbers from 0.8 to 1.4 and global equivalence ratio from 0.8 to 1. Results show that combustion noticeably affects the swirling motion and that tangential velocities rapidly decrease along the axial axis. The recirculation mass flow ratio dramatically increases compared to non-reactive cases. Increasing global equivalence ratios increases the recirculation mass flow ratio contrary to oxygen enrichment effects. The exhaust gas compositions are measured using gas analysers. It is observed that NO_x emissions decrease when the global equivalence ratio increases. It suggests that CO_2 in the recirculated burned gases could be responsible for NO_x destruction at relatively high oxygen enrichment rates. Globally, the results show that, by combining enhanced mixing and moderate oxygen enrichment of the air, the developed and characterized new burner configuration has a good potential to be

---

[*] Corresponding author at: ICARE, CNRS, 1 C Avenue de la Recherche Scientifique, 45071 Orléans, France.
E-mail address: toufik.boushaki@cnrs-orleans.fr (T. Boushaki).

http://dx.doi.org/10.1016/j.proci.2016.06.046

Please cite this article as: T. Boushaki et al., Study of emission pollutants and dynamics of non-premixed turbulent oxygen enriched flames from a swirl burner, Proceedings of the Combustion Institute (2016), http://dx.doi.org/10.1016/j.proci.2016.06.046

used to stabilize non-premixed fuel and oxidant streams as partially premixed low emission flames with an increased concentration of CO_2 in the flue gases.

Keywords: Oxygen enrichment; Non-premixed flame; Swirling flame; Pollutant emissions; CO_2 capture

1. Introduction

The use of gaseous fuels for energy generation, such as natural gas but also more and more synthetic gases from various gasification processes, is growing worldwide. Gaseous fuels emit less CO_2 compared to coal or fuel oil and the recent rush to shale gas in the US and the development of large scale coal gasification plants in China, will keep this resource alive for several decades [1]. In most gaseous fuel applications for industrial combustion, the diffusion or non-premixed combustion mode is preferred for obvious safety reasons [2]. This is all the more justified when hydrogen or hydrogenated fuels such as syngas, are used [3]. It is well known that the NO_x generation propensity of non premixed flames is higher compared to premixed flames [4]. This emission problem combined with the safety issue indicates the relevance of developing innovative burner configurations which rapidly convert a non-premixed flame to a premixed or at least-partially premixed one. Such a burner should ideally prevent any explosion risk by avoiding premixing the fuel with the oxidant before ignition and generate a premixed like flame after ignition. This paper discusses the characteristics of such a burner configuration which combines a swirling co-flow of the oxidant with a radial injection of the fuel [5–7].

Another issue today is the CO_2 capture from industrial flames. This constraint will become more stringent in the future and will be applied not only to very large power plants but also to medium scale industrial combustion systems. Post-combustion CO_2 capture is today a costly process when chemical capture solutions are applied [8]. Oxy-fuel combustion is an elegant solution but disadvantaged by the energetic penalty of oxygen generation. Post-combustion capture of CO_2 using physical processes such as membranes appear as a viable solution at least until low cost oxygen production technologies is available [9,10]. Membrane capture systems of CO_2 require, however, CO_2 concentrations not smaller than 20% in flue gases [11]. This can be obtained by partial oxygen enrichment of the reactive mixture [12,13]. One negative aspect of this approach is obviously its NO_x enhancing effect [14,15]. Combining an innovative burner configuration allowing enhanced mixing with a moderate oxygen enrichment to enable CO_2 capture by membranes is the challenge of the present work.

In the following paragraphs the burner configuration is first described and characterized by stereo-PIV under non-reacting and reacting conditions. Instantaneous and averaged OH images are also obtained to help characterize the flame structure. Post flame emission measurements of CO_2, CO and NO_x are performed to discuss the merits of the developed burner configuration and the future research paths for its improvement.

2. Experimental system

2.1. Burner and flame configurations

The burner used in this study consists of two concentric tubes with a swirler placed in the annular part supplying the oxidant flow (air or oxygen-enriched air) as shown in Fig. 1a. Eight guide vanes are designed with various vane angles to induce swirl intensity variations. The central pipe delivers radially the fuel (methane) through eight holes symmetrically distributed on the periphery of the tube, just below the burner exit plane. Note that this configuration of swirl burner delivers a 3D flow configuration and not an axisymmetric one. The fuel injection mode strongly determines the flame type [6]. The outer annular part outer diameter and the related radius are defined by D_b and R_b respectively. Figure 1b and c show the variations of flame shapes with the axial and the transverse (or radial) methane injection modes. With axial methane injection, a long yellow typical turbulent non-premixed flame is obtained for which slight increases of air flow rates eventually lead to flame blow-out. When the radial methane injection is applied, a tulip-shaped blue flame is obtained. Thus, the combustion mode is changed from diffusion-type to partially premixed type swirling flames. In the present work, the radial injection of fuel is used to enhance mixing at the near field of the burner exit. Variations of the flame shape with oxygen content are depicted in Fig. 1d–f.

The degree of swirl for rotating flows is usually characterized by the non-dimensional swirl number S_n which represents the ratio of the axial flux of radial momentum G_x and the axial flux of axial momentum G_z [16]:

$$S_n = \frac{G_x}{G_z R} \qquad (1)$$

Please cite this article as: T. Boushaki et al., Study of emission pollutants and dynamics of non-premixed turbulent oxygen enriched flames from a swirl burner, Proceedings of the Combustion Institute (2016), http://dx.doi.org/10.1016/j.proci.2016.06.046