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Combustion with mixed enrichment of oxygen and hydrogen in lean regime

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ABSTRACT

A low global richness of combustion is interesting from an ecological and economic point of view as it helps to limit fuel consumption. In fact, the consequences of the combustion in poor mode are the appearance of local or global flame extinctions, energy loss by radiation and change in flame structure. The flammability limits of the diffusion methane flame can be resolved by the enrichment of the combustion air with oxygen or the use of the pure oxygen as oxidant as well as the addition to hydrogen in natural gas. Moreover, the use of oxygen and hydrogen as previously mentioned allow working in low ranges of richness while maintaining good flame stability. For a constant burner power of 15 kW, the reduction of the richness involves an increase in the oxidizer flow rate injected into the combustion reaction. In this present study, the variation of the richness, the fuel enrichment with hydrogen and the oxidant enrichment with oxygen are shown as major parameters where they have direct influences on the flow dynamic, the flame structure and the pollutant emissions.

The Chemiluminescence of OH* radical and the PIV (Particle image velocimetry) are used in this work to characterize the flame structure, the stability and the dynamics of the flame. The measurement of pollutant emissions effected by a gas analyzer. The enrichment in oxygen and hydrogen provides a stable flame, which is well attached to the burner for the following richness values: 0.7, 0.8, 0.9 and 1. The reduction of the richness promotes the mixture quality of the reactants and leads a reduction in CO_2 and CO concentration. By contrast, the decrease of the richness supports the formation of NOx.

Introduction

The enrichments of oxidant and natural gas with oxygen and hydrogen, respectively, are significant techniques which allow the improvement of several combustion parameters such as the increase in the combustion output, the decrease in the gas consumption and the reduction of the harmful gas emissions. In addition, these enrichments favor the flame

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stability and the flame propagation towards the regions having the highest flow velocities and allow the mixture to be burned in poor combustion conditions while keeping a good global stability. Several studies have been carried out on the diffusion flame combustion. Burke and Schumann [1] were interested by the properties of a diffusion flame, such as the length of dropping, the temperature distribution, the mass fractions of different species and the flame length. Many researchers have reported the effect of velocity ratio (V_{air}/V_{fuel}) on the characteristics of the Normal and Reverse diffusion flame. Mahesh and Mishra [2,3] studied experimentally the characteristics of a turbulent inverse diffusion flame for a liquefied petroleum gas (LPG) in a burner named "backstep" in terms of the flame length, flame structure, temperature distribution and the distribution of the oxygen concentration in the flame. Sze [4] has performed his experimental works concerning the inverse diffusion flame in two burner types, one in circumferential jets and other in coaxial jet functioning with Liquefied Petroleum Gas (LPG). He has quantified for each burner, the flame structure, the distribution of the temperature and NOx emissions. Santos and Costa [5] have realized a series of experiments on non-premixed flame with three types of gaseous fuels, methane, ethylene and propane in terms of lift-off, flame length and emissions NOx. Meunier et al. [6] conducted an experimental and numerical study allowing a better understanding of the effects of physical properties on NOx emissions for a turbulent propane diffusion flame. Montgomery et al. [7] have studied the effect of the air velocity (co-flow) on the lift-off methane-air flame and have showed that the lift-off height increases with air velocity increases.

Many researchers have realized numerical and experimental works on the effect of the hydrogen addition, the dilution with inert and acoustic excitation on the flame stability, the temperature distribution and the NOx emissions. Indeed, Wyzgolik [8] and Oh et al. [9,10] have studied, at the same time, the effect of nitrogen dilution and acoustic excitation on the flame stabilization and NOx emissions. However, the nitrogen dilution reduces the velocity of the combustion reaction, leads to decrease in the flame temperature and consequently a decrease in NOx production. The acoustic excitation has a role to minimize the flame length and reduced the NOx emissions particularly at the resonant frequency. Another work has shown that, the application of a magnetic field reduces the lift-out height of flame and reinforces the flame stability. This application is shown by T. Delmaere [11] in a configuration of a laminar diffusion flame of methane/air in a coaxial burner disposed in ambient air. Mishra and Kumar [12,13] studied the effect of hydrogen addition to the flame length, the soot production, the temperature distribution and NOx emissions for liquefied petroleum gas (LPG) composed by 69% C_3H_8 and 30% C_4H_{10}. El-Ghafour [14] conducted an experimental study of a turbulent diffusion flame of a mixture natural gas and hydrogen to investigate the effect of hydrogen addition on the stability and structure flame, and on the concentrations of different species produced during the combustion process. Yon and Sautet [15] have experimentally studied the influence of hydrogen addition to natural gas, on the turbulent flame properties in a separated jet burner. Also, the effect of hydrogen addition on the stability and structure of diffusion flame, on the flame length, and on the species concentrations emitted by exhaust system, was experimentally studied in many papers [16–19]. They have shown that, the hydrogen addition produced a progressive improvement of flame stability and reducing the flame length. Beltrame et al. [20] have experimentally and numerically studied a diffusion flame of methane with against current, the oxidant used is a mixture between air and oxygen. They have realized a comparison between a methane/air flame and a methane/air enriched with 68% of oxygen flame. This comparison is focused on the temperature and species between the two types of flames, as shown in the following figures (Figs. 1 and 2). It is noted that for a methane/air flame the maximum temperature is about 2200 K and is achieved at the stagnation plane. The maximum mass fraction of H_2O and the total consumption of the reactants (O_2 and CH_4) are localized on the stagnation plane. For methane/air enriched by oxygen flame, we notice a significant increase in the maximum temperature up to 2800 K and an increase of H_2O mass fraction. So, the reactants are completely consumed before the stagnation plane.

The oxygen enrichment has a very important role on the temperature rise within the combustion chamber. An experimental study performed by Wu et al. [21] on the temperature variation as a function of the oxygen content in the oxidizer shows that the variation of the oxygen from 21% to 30% in the oxidant promotes the increase in the furnace temperature. The necessary time for heat up the furnace to 1200 °C is 3700 s for 21% of oxygen and 2000 s for 30% of oxygen. This reduction in time is explained by the decrease of the nitrogen amount in oxidant which limits the thermal losses. These authors show that, the consumption of natural gas is reduced by 26% with enrichment of 30% of oxygen. So, Qiu et al. [22] show that the addition of 28% of oxygen reduces the natural gas consumption between 22% and 28%, according to the type of ceramic furnace. The combustion with oxygen enrichment improves the heating rate and the combustion temperature. Baikal et al. [23] show that the heat flux received by a water-cooled disk increases to 54% for oxygen enrichment from 30% to 100% (the case of oxy-combustion), and the energy efficiency increases with increasing the mass fraction of oxygen in the oxidizer. Bandeira Santos et al. [24] have experimentally investigated the effect of oxygen enrichment on the production of soot. They have showed that the soot reinforced the heat transfer by thermal radiation.

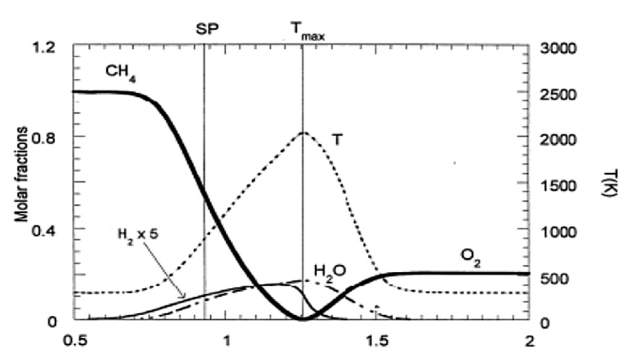

Fig. 1 – Temperature and species variation in methane/air flame.

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