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Effects of hydrogen addition and Carbone dioxide dilution on the velocity field in non reacting and reacting flows

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ABSTRACT

The evolution of anti-pollution standards and the optimization of combustion efficiency push the development of new fuels with high energy efficiency. It is necessary to develop new alternative fuel to improve the efficiency of conventional systems, reduce emissions (NO_x, SO_x, soot particles) and recover for its materials. A new fuel called bio-hythane, a mixture of natural gas up to 20% hydrogen and up to 50% Carbone dioxide, from the recovery of the waste from households and agriculture, via suitable digesters provides a source of renewable energy and usable, is a very interesting solution to improve emission standards and optimization of the combustion chambers.

This experimental study is led in a non-reacting configuration and in combustion in order to focus on the effects of hydrogen addition and CO_2 dilution in the fuel on the velocity profiles, the turbulence intensity and the turbulent kinetic energy. From PIV measurements the results show that from the velocity and fluctuations profiles the high diffusivity and the low density of hydrogen allow bio-hythane jet to spread more efficiency in the combustion. The combustion decreases the entrainment of the ambient fluid and raises the viscosity of the flow, leading to an increase of the longitudinal velocity along the bio-hythane jet and a reduction of the turbulence in comparison with non-reacting configuration.

The Carbone dioxide addition reduces the fall of the turbulence because the temperature of the flame is less important. Effects of hydrogen and CO_2 are also highlighted by analysis of turbulent kinetic energy along the bio-hythane.
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Introduction

Regulations on protection of the environment lead to develop new technologies of combustion. A new alternative fuel, mixture of natural gas (NG), hydrogen up to 20% in volume and carbon dioxide up to 50% in volume, called bio-hythane, has been created from the recovery of the waste from households and agriculture, via suitable digesters. It provides a source of renewable energy and usable, generates a better thermal efficiency and a reduction of pollutant emissions and is expected to play an important role in future energy production. Due to the properties of hydrogen, specially low density, high molecular diffusivity, wide flammability limits, high flame speed, and low ignition energy (Choudhuri and Gollahalli [1,2]) hydrogen in the fuel permits combustion systems to operate with lean fuel mixtures.

Choudhuri and Gollahalli [2] carried out an experimental investigation on turbulent NG–H_2 jet diffusion flame and showed a reduction in the soot concentration and emission index of CO (EICO), but an increase in NO and NOx emissions with the addition of hydrogen to the fuel.

El Ghafour et al. [3] studied experimentally the effect of hydrogen addition on combustion characteristics of NG–H_2 hybrid fuel turbulent diffusion flame at a fixed Reynolds number (4000). They observed that the addition of hydrogen improves the flame stability, reduces the flame length for relatively high hydrogen concentrations and increases the NO and CO concentration.

The influence of hydrogen addition to natural gas on the flow dynamics was investigated experimentally in non-reacting flow and in combustion by Yon and Sautet [4]. Their results show that the combustion decreases the entrainment of the ambient fluid, increases the temperature in the fuel jet and consequently the viscosity of the flow, leading to an increase of the longitudinal velocity along the hythane jet and a decrease of the turbulence in comparison with non-reacting configuration. These effects are more and more important with hydrogen addition due to the decrease of the flame lift-off height and the increase of the heat release rate. Takagi et al. [5] carried out an experimental investigation on turbulent jet flows with and without flame, and they found that the presence of flame decreases the entrainment of ambient fluid, which accelerates the flow.

The chemical effect of CO_2 replacement of N_2 in air on the burning velocity of CH_4 and H_2 flames was studied numerically by Liu et al. [6]. The relative importance of the chemical effect of CO_2 on the burning velocity increases as more CO_2 is added to replace N_2 in air.

Previous studies have proved that the soot formation in diffusion flames were decreases by CO_2 addition to the coflow air, resulting from the short residence time in the inception region [7–11].

It was shown that CO_2 dilution thermally and chemically limits the formation of soot precursors due to the decrease of H radicals consumed in the reaction $CO_2 + H \rightarrow CO + OH$.

The effects of different additives to air on the lift-off of a laminar CH_4/air diffusion flame have been explored experimentally by Guo et al. [12]. They observed that the addition of CO_2 causes flame lift-off due to the dilution, thermal and chemical effects. The dilution effect being the most significant one, followed by the thermal effect. The three effects tend to reduce combustion intensity and cause flame to be lifted. The radiation and transport property effects are negligible.

The effect of CO_2 addition to the air on the transition from an attached flame to a lifted flame issued from a coaxial non-premixed methane-air jet is studied experimentally by Min et al. [13]. Results shows that the CO_2 is the best destabilize among the diluents, because the three effects (dilution > thermal > chemistry) induce loss of flame stability (CO_2 has a strongest ability to break flame stability, than N_2).

Dally et al. [14] investigated experimentally and numerically that CO_2 addition in a non-premixed methane/air flame lowered flame temperature by decreasing reactant concentration inside the reaction zone.

The present study is conducted in non-reacting and reacting flow from a cylindrical burner to investigate the effect of the hydrogen addition and CO_2 dilution on the flow aerodynamics.

The mole fraction of hydrogen (% H_2) in NG–H_2 mixture varies from 0% to 20% and the mole fraction of carbon dioxide volume varies from 0% to 50%. The experimental setup consists of a 15 kW burner powered by natural gas added to hydrogen and carbon dioxide. A study of the jet aerodynamic through Particle Image Velocimetry (PIV) in non-reacting flow and in combustion allows characterizing the flow fields. The evolution of the root mean square (RMS) of the two components of velocity is investigated to deduce the effects of CO_2 dilution and the hydrogen addition on the turbulence intensity and the turbulent kinetic energy.

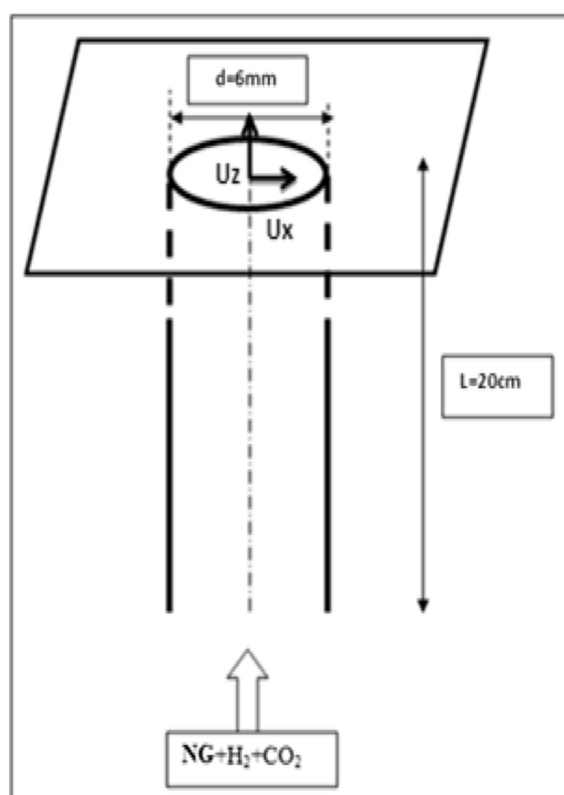

Fig. 1 – . Sketch of the burner.

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