Geometrical Parameters Optimisation for Hydrogen Burners in Steady State Conditions

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ABSTRACT

This work represents a typical CFD application to hydrogen combustion in atmospheric pressure burners of different geometrical configuration with respect to gas injection.

Particularly the influence of burner geometry and gas velocity have been studied in order to characterize the best condition for efficient and low pollutant mixing and combustion in steady state conditions.

The fundamental aspect of this research is to verify and to validate the possibility of real uses of the hydrogen in place of the CH_4 as combustible inside to industrial burners.

First aim of this work is a critic analysis of the capability for a stoichiometric air-gas fuel mixture, meaning like combustible methane before and hydrogen then, to reach the burning condition, with respect to low and high flammability limits, for a given pressure and temperature of reactants, varying their inlet velocities and burner configuration.

Second goal is the analysis of the capability or mixture to keep steady the fluid dynamic condition of flame stability.

An industrial CFD code has been used to model or solve the mixing process of reactants in two different burner configurations; particularly the influence of these burner geometry and gas velocity have been studied in order to find the better combustion condition for a given inlet condition setting.

Numerical results are reported in diagrams giving some very interesting information about mixing between air and gas fuel, also with respect to the theory and the literature of combustion process.

The burner used is related to a diffusive flame, that guarantees a greater stability of combustion. Since these simulations have been carried out on small scale, we use the information obtained as a comparison tool for the plant on a larger scale.

INTRODUCTION

Using hydrogen as combustible introduces some very interesting advantages, but the real possibility to use it for scopes both energetic and industrial lead to a series of problematic involving each other.

In fact, on the contrary of the well-known science in the combustion field, especially due to the characteristics of the gas itself and its peculiar chemistry of combustion, its thermal exploitation in terms of conventional combustion chambers is not an easy application.

In the context of the development of technologies for the gasification catalytic both of biomasses, finalized to the gas production with high hydrogen concentration by means of processes with fluidised bed reactors, and in process oriented to directly gain hydrogen from hydrocarbons with medium-long carbonic chain, we investigated about the opportunity of the

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use of this fuel species in combustion chambers which actually work with conventional fuel like diesel oil or methane.

GEOMETRICAL ANALYSIS

We mostly analysed the chance to burn mixtures of gas fuel (methane, propane and butane) and hydrogen in different concentration, up to 100% of hydrogen concentration, in burners which already worked with gaseous fuels (mainly methane), with particular attention to geometrical parameters of the burner.

Chemical kinetics for hydrogen oxidation is quite less complicated with respect to a generic hydrocarbon one. Radicals of the chain can be evaluated by these reactions:

$$\begin{aligned} &H + O_2 \rightarrow O + OH \qquad [1] \\ &O + H_2 \rightarrow H + OH \\ &H_2 + OH \rightarrow H_2O + H \\ &O + H_2O \rightarrow OH + OH \ . \end{aligned}$$

HO_2 radical is generated mostly by:

$$H + O_2 + M \rightarrow HO_2 + M$$

where “M” represents any available third species , and is consummated by reaction with other radicals.

Self reaction of HO_2 generates H_2O_2 (hydrogen peroxide):

$$HO_2 + HO_2 \rightarrow H_2O_2 + O_2$$

which is consummated by reaction with other radicals or by heat. In some situation hydrogen presence has some influence on combustion rate. At high combustion temperature, over 1000K, the first reaction of the set [1] is the most important of the chain branching of this exothermic phenomenon; each kinetic perturbation that increases H production makes the total combustion rate to accelerate by enlarging of the chain branching leaving from the [1].

On the contrary, any process that decreases the number of H , has the effect of lowering the combustion rate. At the temperature of common industrial flames, burning mixtures of hydrogen and hydrocarbons, it can be noticed that reaction rate between hydrogen and hydrocarbons are higher than [1]one, so these reaction will compete with [1], decreasing H chain branching rate. In conclusion, though hydrocarbon supply further fuel, their influence makes the global combustion rate to decrease.

Another aspect related to the use of fuel mixtures is that different feed pressure have to be taken into account in order to have the right fuel velocity and rate at the burner. This has been evaluated considering mixtures of methane, propane and butane with increasing quantity of hydrogen: it is possible to calculate the pressure drop Δp (referred to atmospheric pressure), varying H_2 concentration.

$$\Delta p = \rho \cdot \frac{w^2}{2} \qquad [2]$$

where

w = fuel outlet velocity at the burner ;

ρ = mixture density.

Mixture density can be evaluated by components concentration:

$$\rho = \frac{\lfloor \rho_{\text{hydrocarbon}} \times (\%)_{hydrocarbon} \rfloor + \lfloor \rho_{hydrogen} \times (\%)_{hydrogen} \rfloor}{100} \qquad [3]$$

Two different outlet condition have been simulated, with fuel velocity of 5 and 20 m/s.

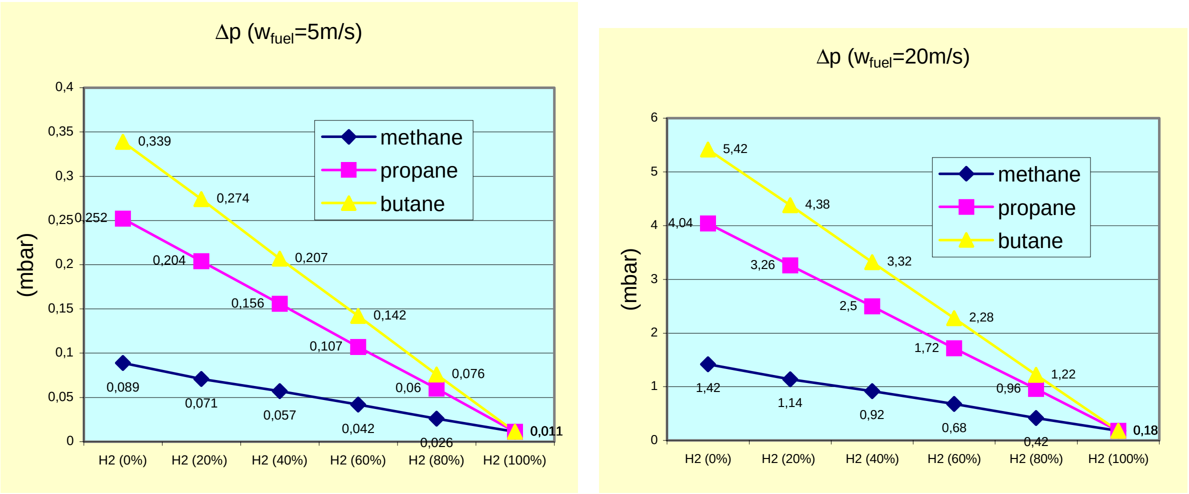


Fig. 1-2: Pressure drop for different fuel outlet velocities

It can be first noticed that the presence of hydrogen makes Δp to decrease, due to the very low hydrogen density at atmospheric condition. In case of methane, for example Δp for 100% hydrogen is less than 15% of Δp for 100% methane. This is a problem to solve when considering the chance to change fuel from methane to hydrogen, in the same burner.

Always considering the comparison between hydrogen and hydrocarbon gaseous fuels the different air/fuel ratio has to be considered both in volume and in mass terms; as shown in fig. 3 and 4 mass air/fuel ratio increases with hydrogen concentration but decreases if considered in volumetric terms, even if for methane the difference is less evident than for propane and butane.

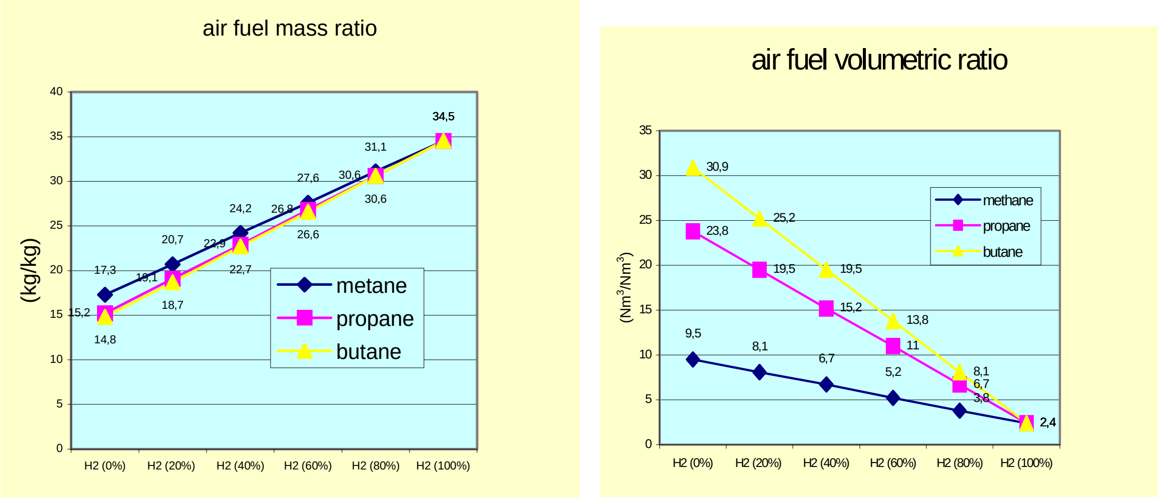
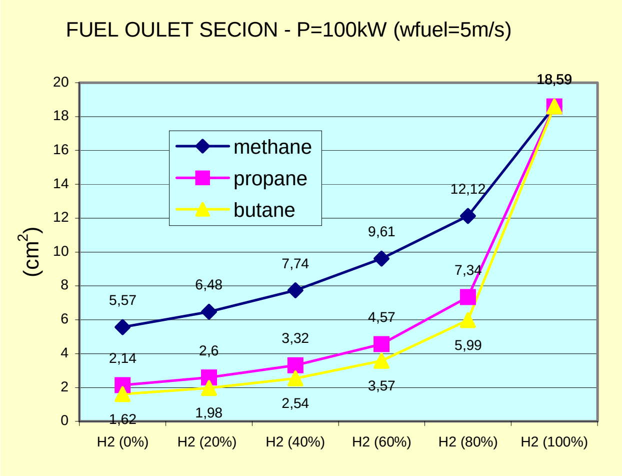


Fig. 3-4: air- fuel ratios (mass and volume)

The analy Corresponding author e-mail address: giulange@unina.it sis of the chance to change fuel (from methane to hydrogen mixtures) on the same burner leads to evaluate the outlet section of air and fuel ducts in non premixed flames burners.

First of all the diagram of fuel section varying hydrogen concentration in fuel mixture has been evaluated, keeping the same thermal power of the burner, as shown in fig. 5; in fig. 6

instead the air section has been reported. It can be noticed that their behaviours are opposite: fuel outlet section increases while air one decreases.



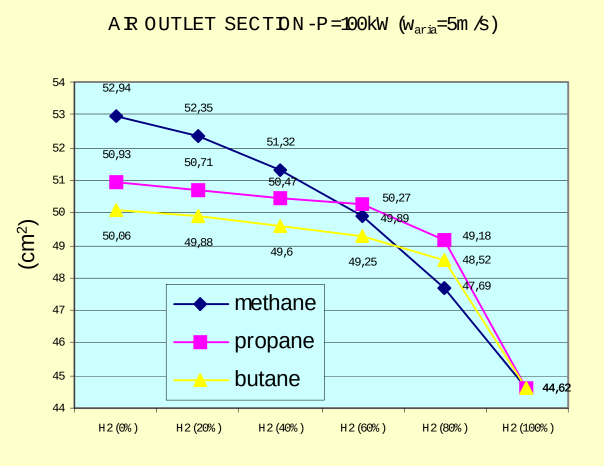


Fig.5: fuel outlet section

Fig.6: air outlet section

Analysis results can be combined in order to obtain the diagram of total burner section. As shown in fig. 7 the different trends of fuel and air outlet section have a compensation, so it'is possible to keep the same burner with its external global section, only changing the fuel duct with the double effect to change both air and fuel outlet section.

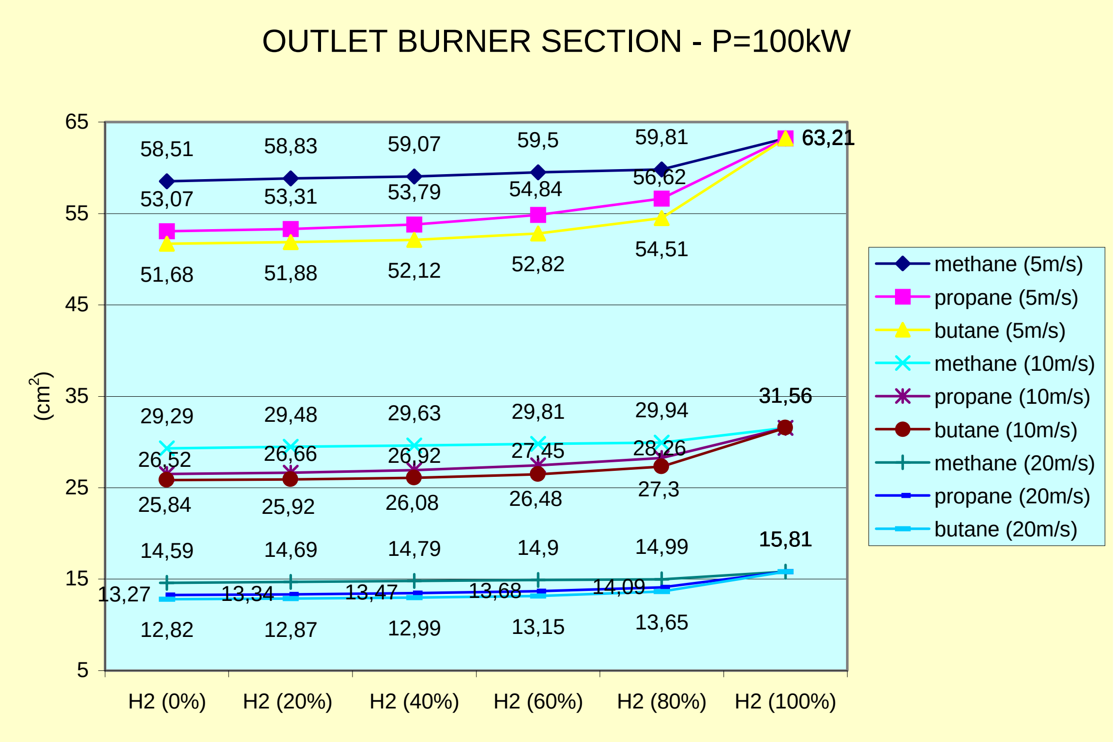


Fig.7: total burner outlet section

CFD ANALYSIS

After geometrical analysis of the chance to burn different fuel, with or without hydrogen, on the same burner, a CFD analysis has been performed in order to highlight the chemical and fluid dynamic difference between methane and hydrogen, inside the flame.

A comparison between these fuels has been pointed out on the same burner, at the same thermal power output: it's reported below in four diagrams of turbulent viscosity and fuel mass fraction for methane and hydrogen.

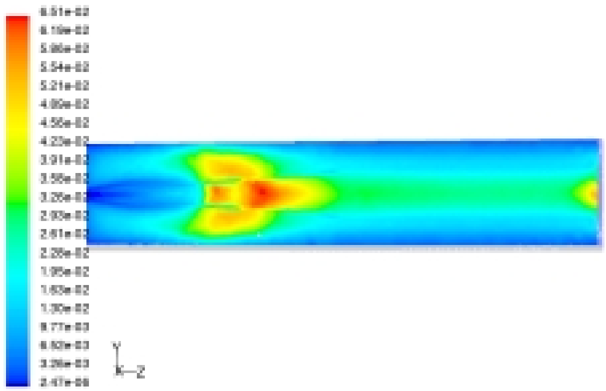


Fig.8: hydrogen turbulent viscosity

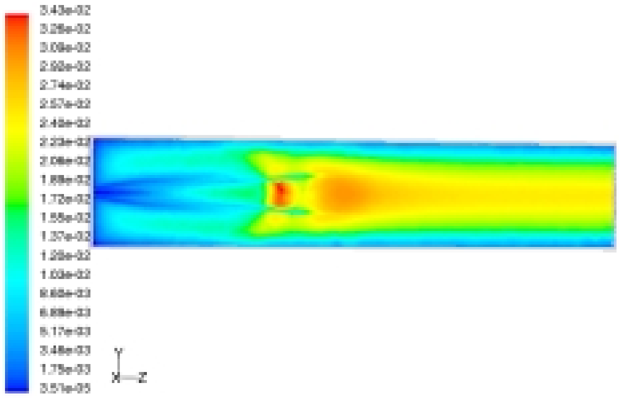


Fig.9: methane turbulent viscosity

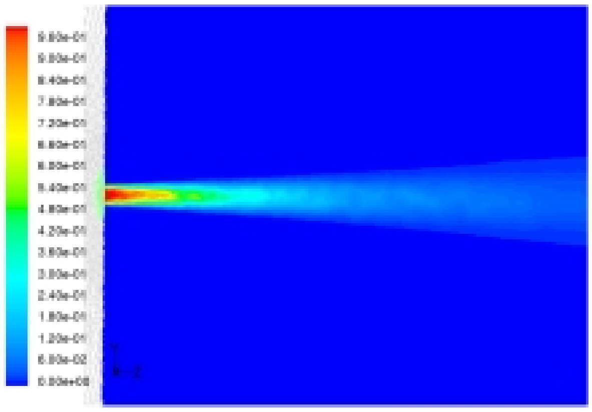


Fig.10: hydrogen mass fraction

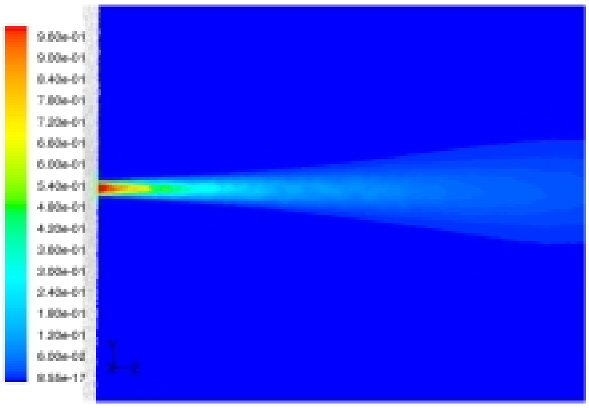


Fig.11: methane mass fraction

The Corresponding author e-mail address: giulange@unina.it se are only the first results of the analysis to be continued. It can be notice as the hydrogen flame is larger than methane one due to better mixing of fuel in air.

CONCLUSIONS

The analysis till now performed, to be continued instead, has highlighted that it is possible to have multi fuel burners, that is a very interesting chance in order to burn not only hydrogen mixtures, but also syngas and others low heat value gaseous fuels.

This would be an important goal to be reached for the economy of combustion systems, and the benefit of rational use of primary resources.

A multi fuel burner should have also a good flexibility index and so a good ratio between maximum and minimum fuel rate, as reported in the analysis.

A big benefit of this type of burner would be the chance to switch from one fuel to another in order to guarantee the continuity of supply, as requested in hospital buildings for example.

There is also an economic benefit because it is possible to choose the most chip fuel at the moment on the market.

Finally there is a technical benefit coming from the simultaneous use of different fuel, as in case of liquid and gaseous fuel, where gaseous one can contribute to atomize the liquid one, and liquid could increase thermal radiation from the flame.

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