Methane/Air laminar diffusion flames in magnetic gradients

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1 Introduction

Combustion systems involve coupled phenomena such as gas injection, mixing, entrainment, gas recirculation and heat transfer from the chemical reaction. Different means have been carried out for controlling combustion depending on the phenomenon which is desirable to be controlled.

We propose to investigate the control potentialities offered by the application of a magnetic field. Two essential mechanisms govern the interaction between a magnetic field and combustion: the electromagnetic one which arises on charged particles in motion in a magnetic field and the interaction with the magnetic properties of the substances. In the case of a laminar diffusion flame, the Lorentz force developing on ionic species is negligible due to the low velocity and low ions concentrations, see for example [1].

Based on the magnetic properties of the combustion gases the magnetic force per unit volume Fi acting on species i in a magnetic gradient is expressed by:

$$F_i = (1/2\mu_0)\ \rho Yi\ \chi i\ \nabla(B^2)$$

The magnetic force is proportional to the mass density and magnetic susceptibility of chemical species i, ρYi and χi and the gradient of the square of magnetic induction $\nabla(B^2)$. Taking into account only the paramagnetic susceptibility of oxygen, we consider two mechanisms able to set in a combustion system: the attraction by the magnetic force toward the high induction field and the thermomagnetic convection phenomena. Thermomagnetic convection is described in F. Khaldi et al. [2], it is driven in a volume diffentially heated by a magnetic force acting on a paramagnetic medium which magnetic susceptibility decreases with temperature.

The influence of a magnetic field on combustion has been extensively referenced. N. Wakayama [3] investigated methane diffusion flames within magnetic field gradients. It was observed that a decreasing magnetic field along the flame caused its shape more elongated and slender while an increasing magnetic field produced shorter and thicker flames. These effects are attributed to the oxygen strong paramagnetic property and the diamagnetic property of the combustion products. The influence of magnetic gradients on partially premixed and diffusion flames in air are presented in [4]. Decreasing magnetic field is found to increase combustion rate for diffusion flames while the magnetic fields had little effect on the premixed flame. It is concluded that the dominant magnetic action is on the oxygen flow into increasing magnetic fields strength. Yamada et al. [5] investigated numerically the action of magnetic field on OH radical distribution in a H_2/O_2 diffusion flame. The magnetic gradient is found to change the OH density distribution in the flame. The effect is related to the magnetic force on oxygen and is due to the mass density and the magnetic susceptibility of O_2 which is much larger in the peripheral region of the flame. In [6], Yamada et al. confirmed their numerical predictions by experiments: a radial migration of the OH towards the central axis of the flame is driven by the magnetic field. Numerical simulations made by solving the equations of gas dynamics and magnetism shows that the magnetic effect is essentially due to the magnetic force acting on O_2 and not directly on OH itself.

In [7], Baker et al. present the experimental behavior of a laminar diffusion flame set in an upward decreasing magnetic field. Under certain conditions, the magnetic force is found to decrease the flame height, prevent the flame from attaching to the magnet assembly, increase the intensity of the flame and the flow rate below which

the flame extinguish. A dimensionless analysis shows a correlation between, the experimental results and a dimensionless analysis including buoyancy and magnetic convection.
From coaxial jets of methane and air, combustion occurs upstream of the injection zone: the flame said lifted is piloted by a triple flame front which position is on the stoechiometric line. Experiments on the influence of a magnetic field on the stability of a lifted diffusion flame are reported in [8]. It is shown that an upward decreasing field from a permanent magnet generates a downward magnetic force on the injected air reducing the lift height. In the present paper, we consider the same flame configuration but set in the bore of a electromagnet. In addition to the attraction effects, the heat release from the flame drives thermomagnetic convection in air.

2 Experiments

The experimental device is schematically represented figure 1. A coaxial burner with a central methane jet and two annular air jets is chosen to generate a lifted laminar diffusion flame. Here, we present results with only one annular air jet (U_{air2}=0m/s). The inner diameters of tubes in the burner exit section are: D_{CH4}=5mm and D_{air1}=10mm. The burner, set on a vertical stage, is able to be positioned at three vertical positions for his exit section: 1, z= -185mm; 2 z= 0mm; 3, z= +85mm. Experiments are carried out in ambient air at atmospheric pressure.
An electromagnet generates a horizontal magnetic field of 1.3T magnetic induction at its centre and two areas of strong magnetic gradient are observed whose maxima are located at 135mm vertical distance from the magnet centre (fixed at 0). Distributions of the magnetic induction and squared gradient are given figure 2.

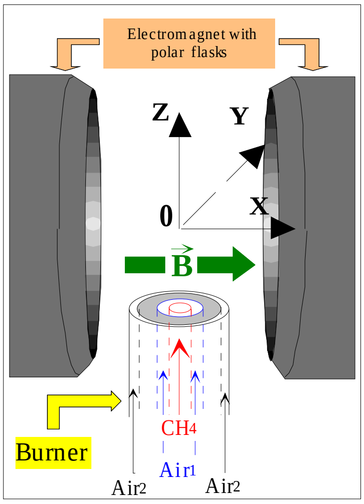

Figure 1: Experimental set-up

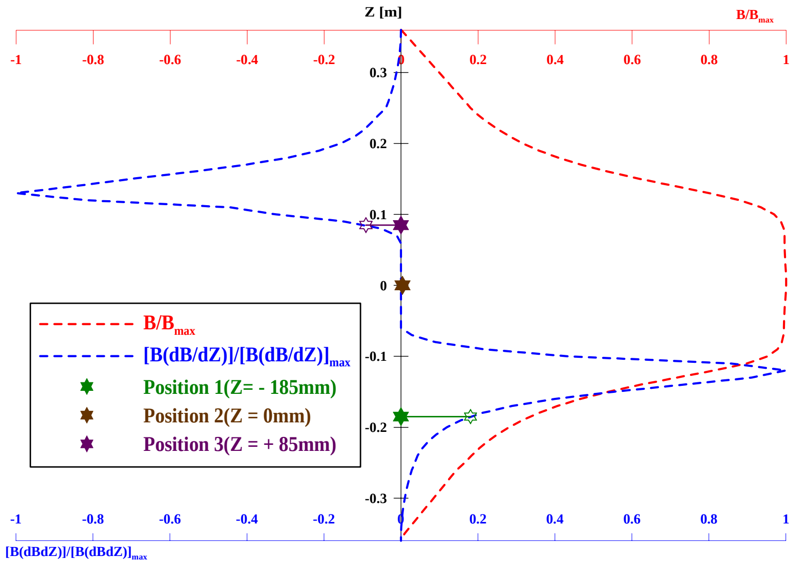

Figure 2: Magnetic field and gradient on 0Z vertical axis (X=Y= 0)

3 Results and discussion

The methane flow rate is kept constant and for increasing values of the air flow rate, side views of the flame are recorded by a numerical camera. The mean flame position and length are measured by image analysis (based on an average of 1000 images for each value). Flame configurations for a fixed value of methane flow rate and increasing air flow rates are shown in figure 3 when magnetic field is applied. The flame behaviour changes from a nozzle attached flame fig. 3a, to a near lift off in fig. 3b, and lifted flame in fig.3c-d. At increasing air flow rate the flame is bluer and thinner. Variations of the flame lift-off height without and with magnetic field are reported for the z-positions 1 and 3 of the burner on figure 4a and 4b respectively. As the air flow rate increases the lift height is zero at first, then increases linearly with the air exit velocity and then presents a plateau corresponding to a destabilized lifted flame. When the magnetic field is applied, the lift is decreased for the burner set in position 1 in the positive magnetic gradient and the lift is increased for the position 3 in the negative gradient.

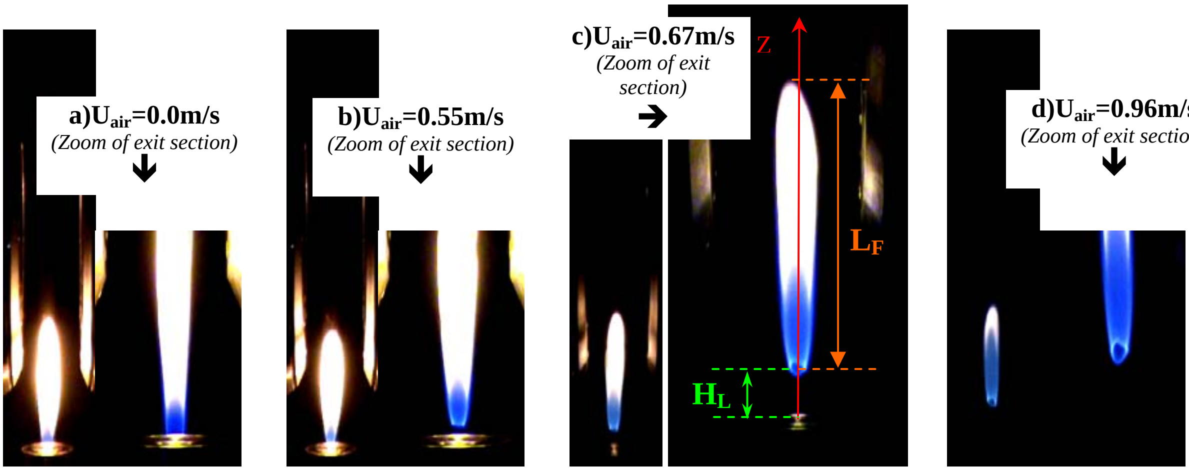

Figure 3: Flame configurations with burner at Z=-185mm, with magnetic field. Methane exit velocity .79m/s. Air exit velocity a) 0; b) 0.55; c) 0.67; d) 0.96 m/s

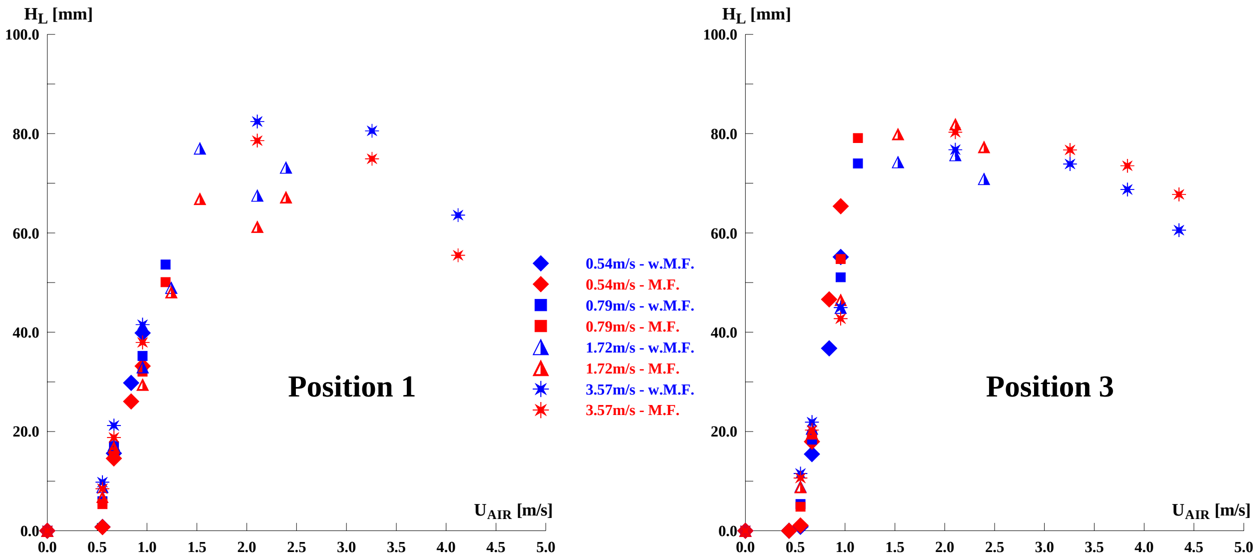

Figure 4: Lift height variation versus the air co-flow velocity without and with the magnetic field at the two z-positions: 1, Z=-185mm; 3, Z=+85mm *(Legend: blue=without magnetic field, red = with magnetic field)*

The direct action of the magnetic force consists to attract oxygen hence air inside the bore, maxima of magnetic force being at 135mm apart from the magnet centre. In the bottom part of the bore the air is attracted upwards whereas in the top part of the bore the magnetic gradient is reversed: air is attracted in the bore by a downward force. Considering the thermomagnetic convection due to temperature variation of the oxygen magnetic susceptibility and heat release at the flame front, when the force is upward, magnetic convection drives hot air downwards It is opposed to the buoyancy convection driven by gravity. In the top part of the bore, hot air is magnetically driven upwards adding to the gravity driven convection.
At burner position 1, the lift height reduction is related to a reduced convection; the inverse phenomenon is observed at the burner position 3 where the convection is enhanced by the magnetic effect.

The measurements of flame length are reported with and without magnetic field figure 5 for the two burner positions 1 and 3. The application of a magnetic field is shown to increase slightly the flame length whatever the burner exit section position, the methane and the air flow rate.

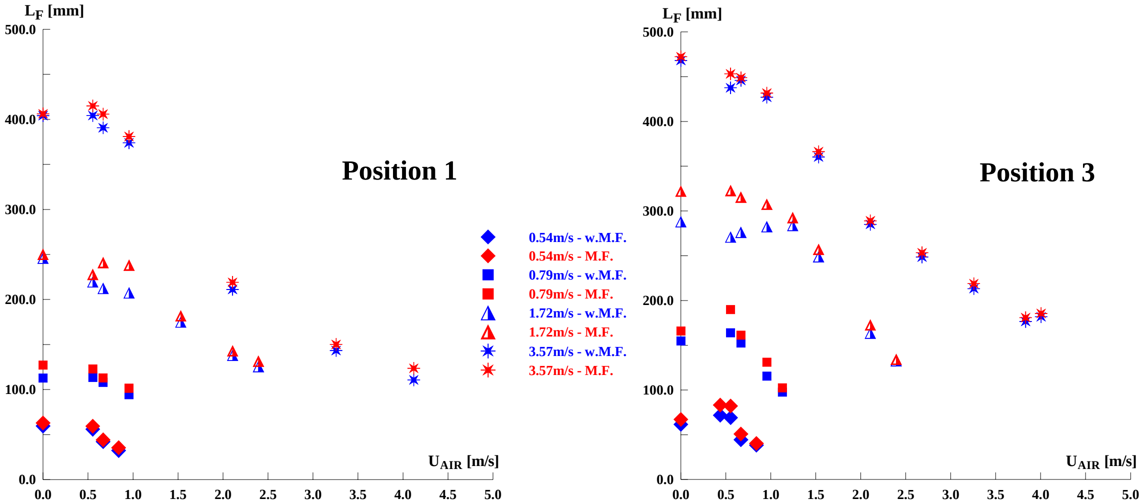

Figure 5: Flame length variation versus the air co-flow velocity without and with the magnetic field at the two z-positions: 1, Z=-185mm; 3, Z=+85mm *(Legend: blue=without magnetic field, red = with magnetic field)*

5 Conclusion

Characteristics of the influence of magnetic field gradients on CH_4/air lifted flames from a coaxial burner were investigated. The influence of the magnetic gradients on the air flow through attraction of air in the bore and convection of air along the flame is able to produce sufficient action to modify the stability of lifted laminar diffusion flames.

References

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Acknowledgements

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