A numerical study of the magnetic influence on coaxial jets flow

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1 Introduction

Mixing two streams of fuel and oxidizer to create a diffusion flame is obtained in many practical instances by the use of coaxial burners. Although a large use in industrial applications, this process leads to unstable diffusion flames: depending on the gas exit velocities they are either anchored, lifted and may be blown out. Complex interaction mechanisms between the flame and the jet flow have been shown of major importance in the flame stability. That is why flows from coaxial jets have been extensively studied, however most of the references are dealing with turbulent flows, see for instance [1-3]

Coaxial jets behaviour associates the dynamic of a simple round jet with the one of an annular jet. They are characterized by two shear layers: the internal one between the central jet and the annular jet and the external layer between the annular jet and the ambient air generally at rest. Those layers are of primary importance in the mixing process. The boundary layers developing along the duct wall separating the two streams produce a wake region behind the wall which interacts also within the near flow field. In case of coaxial jets with density difference, the important parameters are the geometry and the ratios of initial velocity and density. Following Rehab et al [1] our analysis of coaxial jets will be based on the momentum flux ratio $M=\rho_2 U^2{}_2/ \rho_1 U^2{}_1$ and on the ratio of the outer to the inner nozzles diameter $\beta=D_2/D_1$.

In order to control the flame, we study the potentialities offered by the action of a magnetic force on the jets flow field. Based on the magnetic properties of the constituent 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 $\nabla(B^2)$. In [4], the effect of a magnetic gradient in the near field zone on the behaviour of a diffusion flame is investigated experimentally. It is shown that the application of a magnetic gradient reduces the lift height of a laminar methane/air diffusion flame issuing from a coaxial burner. We present here a numerical simulation of the steady state laminar flow from a methane /air coaxial injector with and without magnetic force acting on the air annular jet corresponding to the experimental study presented in [4].

2 Numerical modeling

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We consider an axisymmetric burner as described figure 1 with two concentric tubes; methane is issuing from the inner tube and air from the external one into ambient air at rest. The simulation is isotherm at 300K. Conditions concerning the geometry and the flow rates are given in table 1.Since the outer velocity in the annular jet is larger than the inner one, the outer jet dominates the near field flow.

	Diameter mm	Exit flow rate $m^3.s^{-1}$	Mean exit velocity $m\ s^{-1}$	Density $kg\ m^{-3}$
Inner jet Methane	D_1= 4	4.32 x 10^{-6}	U_1=0.344	ρ_1=0.6517
Outer jet Air	D_2= 10	5.13 x 10^{-5}	U_2=1.02	ρ_2= 1.172

Table 1 : Injection conditions

A general purpose CFD code was chosen for the present investigation. The theoretical model is based on the conservation equations of mass, momentum, and species for a multi-component system, with consideration of gravitational body force. Simulations take into account the magnetic force acting on oxygen, hence on air. The magnetic field corresponds to the permanent magnet used in the experiments described in [4] set in front of the burner exit. The distribution of the vertical magnetic gradient is schematically represented figure 1; it presents a negative maximum of $-30T^2/m$ at 6mm above the burner rim. Consequently, at the exit of the burner, air is submitted to a downward magnetic force. The physical presence of the magnet is not taken into account. In table 2 the parameters of the simulation are collected: Reynolds numbers of both jets evidence a laminar regime. The Froude number Fr >1 shows the domination of inertia in the near field flow a few diameters length from the burner as detailed by Chen et al. [5].

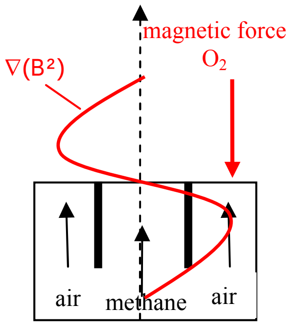

Figure 1 Schematic of the burner

Diameter ratio	$\beta=D_2/D_1$	2,5
Velocity ratio	$r_u=U_2/U_1$	2.35
Density ratio	$r_d=\rho_2/\rho_1$	1.8
Momentum flux ratio	$M=\rho_2U^2_2/\rho_1U^2_1$	9.95
Central Reynolds number	Re_c	78
Annular Reynolds number	Re_a	509
Froude number	Fr	3.78

Table 2 : Jets adimensional characteristics

The 2D-axisymmetric domain includes the flow inside the burner from an imposed flow rate at the entrance and atmospheric pressure is applied on the free domain boundaries. Results are obtained by solving the Navier-Stokes equations. The magnetic force on oxygen is introduced in the momentum equation as a source term. The governing equations are solved using a control volume based finite difference method with a non staggered grid of about 16k cells.

3 Results and discussion

Streamlines for the cases without and with the magnetic force are reported figure 3. The magnetic effect is deduced by comparing the two results. The magnetic force does not affect significantly the pure jet flows. It is in the ambient fluid that the magnetic influence is the most remarkable. Instead of being entrained by the annular air jet upward, the ambient air in the shear layer is dragged downwards by the magnetic force just in front of the maximum magnetic gradient value. The reduced velocity in the air-air shear layer is then entrained upstream.

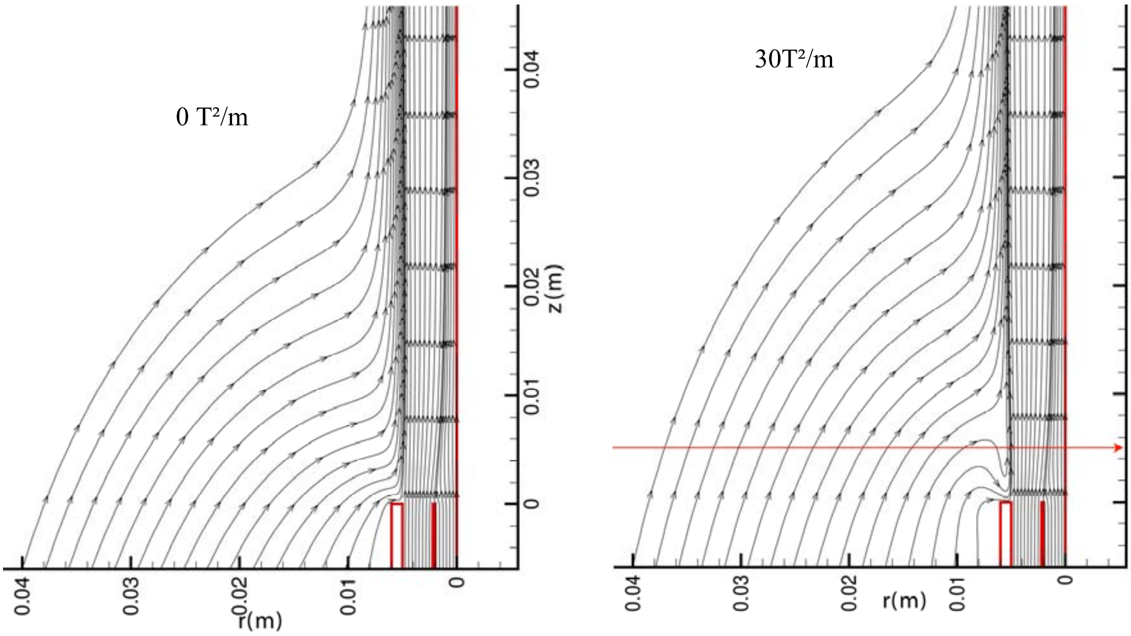

Figure 3: Streamlines of the jet flows without (left) and with the magnetic force (right).
(*Red arrow corresponds to the vertical location of the maximum negative magnetic gradient*)

Axial velocity on the z-axis is shown figure 4. Figure 5 shows the axial velocity distribution in the calculated domain. We observe a decrease of the velocity in the near burner zone. This decrease is attributed to the wake effect due to the boundary layers which develop along the inner burner wall. As the annular air jet is stronger than the methane one, the spreading of the air jet dominates, so, a wake area appears in the near exit section of the methane jet. When the magnetic force is applied, it is observed a drastic reduction of the velocity along the vertical axis above the wake region.

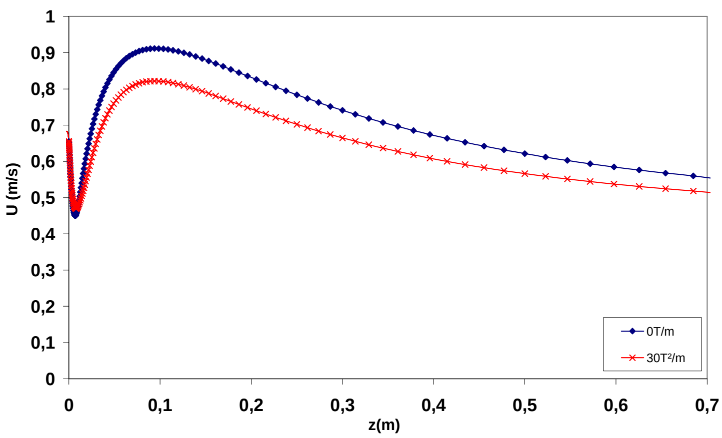

Figure 4: Velocity vertical component on z-axis.
(Legend: blue=without magnetic force, red = with magnetic force)

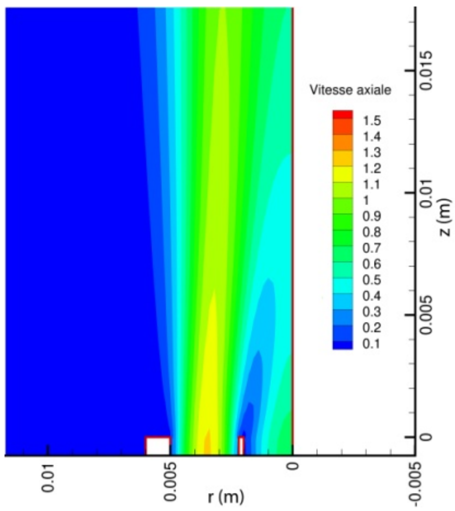

Figure 5: Vertical velocity distribution without magnetic force

Considering a methane/air flame burning upstream of the coaxial jets, Figure 6 presents the evolution of the stoechiometric radius. The stoechiometric radius is defined as the distance between the vertical axis and the point where the mean mass fraction is strictly equal to the stoechiometry. In the near field zone (z<10mm), the radius is decreased due to the burner wall wake. In the wake region the methane cannot diffuse outward. It is observed that the curve is displaced toward larger radius when the magnetic force is applied. As the magnetic force acts downwards reducing the outer velocity of the air jet, the radial diffusion of methane is enhanced.

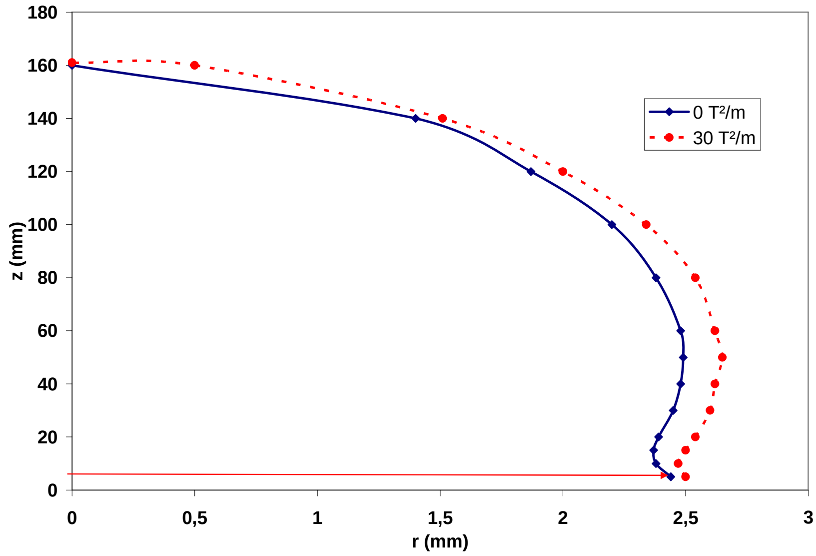

Figure 5: (r,z) evolution of the stoechiometric radius for the methane air laminar flame. . (*Red arrow corresponds to the vertical location of the maximum negative magnetic gradient*)

When the magnetic force is applied to the coaxial jets of methane and air, the numerical simulation shows that it induces a drastic reduction of the air outer velocity. The mixing layer between ambient air and air jet is strongly perturbed. As a consequence it appears that the radial diffusion of methane is promoted.

Considering the lifted flame burning methane in air upstream of the flow field, the application of a negative magnetic gradient just at the rim of the burner on the jets flow would modify the local premixing, decreasing the z-position of the stoechiometric line. The mixture fraction on which depends the lift phenomenon is perturbed by the modification induced in the flow field. This could explain the observed reduction of the lift height of the flame.

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