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The effect of the central swirled jet nature on confined coaxial jet characteristics.

Sirine Chouaieb[#1], Wassim Kriaa[#2], Hatem Mhiri[#3], Philippe Bournot[*4]

[#1]UTTPI, National Engineering School of Monastir, Monastir (TUNISIE)

[1]chouaieb.sirine@yahoo.fr
[2]kriaawass@yahoo.fr
[3]Hatem.mhiri@enim.rnu.tn

[*]Institut de Mécanique de Marseille, 60 rue Juliot Curie Technopôle de Château-Gombert 13453 MARSEILLE Cedex 13 (FRANCE)
[4]philippe.bournot@yahoo.fr

***Abstract*— We propose to study numerically the effect of a swirl generator on the behavior of a turbulent confined coaxial jet. 3D simulations were carried out using the commercial code FLUENT. RANS calculations were conducted to investigate the effect of the central jet nature.**

Results were discussed for reactive and non reactive conditions. Hydrogen and methane were tested to evaluate reactive mixture quality. The annular swirler placed at the outlet of the coaxial configuration central pipe enhances mixing for non reacting conditions. However, for ractive conditions, a flashback problem can occur due to flattened concentration radial profiles. Numerical findings show that hydrogen tends to mix more rapidly and constitutes the most adapted test case for both non reacting and reacting conditions. Nevertheless, a geometry modification must be accorded to the adopted swirler for reactive mixture.

***Keywords*— Coaxial configuration, Mixing process, Central gas nature, Hydrogen, Swirler geometry.**

I. INTRODUCTION

Swirling flows can be encountered in numerous engineering engines such as mixers, cyclone separators, rotary kilns, burners…etc.

The helical aspect and the generation of a central recirculation zone (CRZ) make swirling flows useful in mixing improvement [1]-[4], flame control [5] and pollutants reduction [6], [7].

T. Parra et al. [8] have varied swirl angle and underlined the importance of the CRZ in mixing process enhancement for high swirled flow (S>0.6).

R. Thundil Karuppa et al. [9] have simulated an isothermal flow developed downstream an annular swirler. The effects of vane number (4, 8 and 12) and swirler geometry (with and without solid central zone) on mixing quality were investigated numerically. Results showed that the 8 vanes swirler was characterized by the more efficient mixture.

It should be noted that the effect of a swirl generator installed in the central pipe of a coaxial configuration was not well documented.

In this work, an annular swirler was added to the central pipe of a coaxial configuration to evaluate its effect on the flow behavior. An annular swirler is characterized by a solid central zone [10]. The importance of annular swirlers can be underlined by the numerous studies carried out [8]-[12].

The main purpose of this paper is to discuss numerically the effect of an annular swirl generator in the central tube of a confined coaxial configuration. Two fuels (hydrogen and methane) were tested to evaluate the effect of the central jet nature in the presence of the swirl generator for both non reactive and reactive mixtures. We demonstrate also that a modification of the swirler geometry is necessary in reacting case.

II. PRESENTATION OF THE CONFIGURATION

This work is based on the experimental geometry of M. Amielh et al. [13] (Fig.1a). The adopted coaxial configuration consists on a central jet of helium of diameter D_j equal to 26 mm emerging into a co-flowing air (D_a=285 mm).
An annular swirler with four injectors is added at the outlet of the central pipe (Fig.1b).

The annular swirler is characterized by the geometric swirl number S equal to 0.7 calculated according to the following expression [10]:

$$S = \frac{2(1-a^3)}{3(1-a^2)}\tan\alpha \qquad (1)$$

$a = \frac{R_{sd}}{R_s}$; R_{sd} and R_s represent respectively the swirler solid central zone radius and the swirler radius (R_{sd}= 3.5mm, R_s= 13mm and a=0.27).

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α : Swirl angle (α=45°).

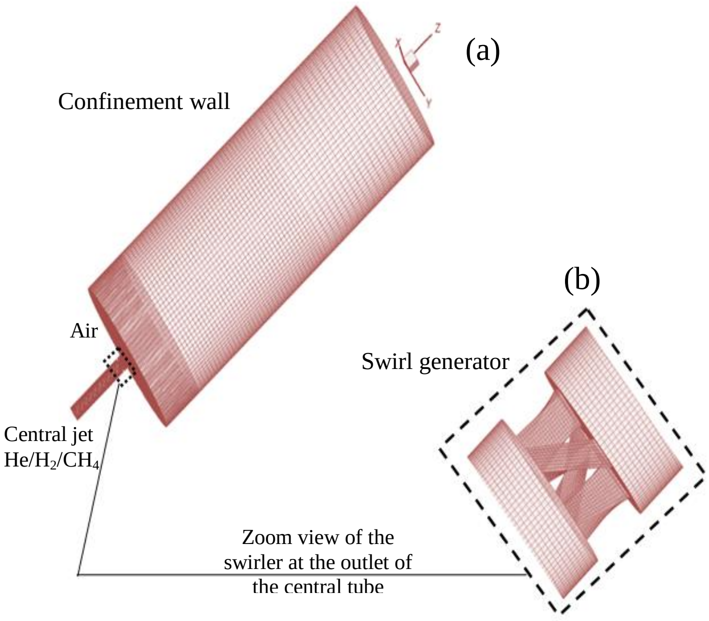


Fig. 1 Geometry and mesh distribution of the coaxial configuration (a) and the swirler (b)

III. GEOMETRY CONSTRUCTION AND GRID MESH

The cylindrical confinement and the swirler meshes are depicted in Fig. 1. In the whole domain, hexahedral multizone, structured mesh is used. The adopted grid mesh contains about 2000000 cells.

It is noticed that several meshes varying from 700000 to 3500000 have been tested to guarantee numerical results independency from grid density.

IV.NUMERICAL APPROACH

The equations governing the flow of interest are the Navier–Stokes equations. The flow is considered to be multi-component, turbulent and stationary on average. The ideal gas assumption is used for species calculation. Thermo-physical properties are calculated using the kinetic theory of gases.

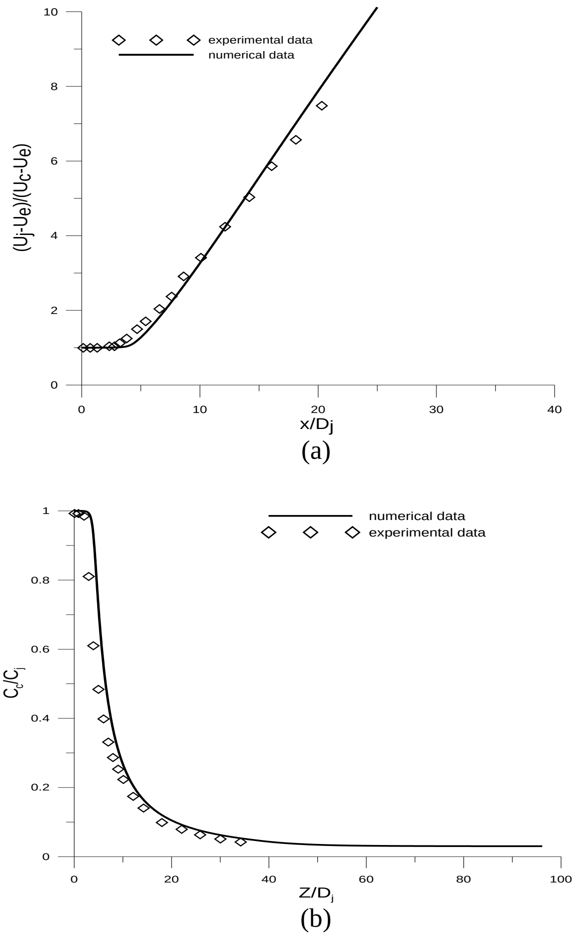
The k-ε Realizable model is used as a turbulence closure model.

V.RESULTS AND DISCUSSIONS

A. *Numerical validation*

Present results were compared to the experimental data of M. Amielh et al. [13] and T. Djeridane et al. [14] respectively for dynamic and concentration fields.

Fig.2 illustrates predicted and measured normalized centerline axial velocity profiles. Comparison between numerical and experimental data of M. Amielh et al. [13] shows good agreement.



(a)

(b)

Fig. 2 Dimensionless axial mean mass fraction profiles: comparison of numerical and experimental evolutions

In the present study, the experimental configuration of M. Amielh et al. [13] was equipped by an annular swirl generator in the central pipe (Fig. 1). The main objective is to analyze mixing and dynamic structure of the considered variable density flow under the swirler insertion for different gases.

B. *Central jet nature effect in the presence of a swirl generator*

In this section, we propose to evaluate the effect of the considered swirler (Fig. 1b) on the flow behavior for different gases issued from the central pipe. Three gases were considered corresponding to density ratios *w* equal to 0.14 for helium/air, 0.067 for hydrogen/air and 0.59 for methane/air.

Two fuels (hydrogen and methane) are applied to discuss reacting case. It is noticed that the central jet density effect is studied for the same momentum flux value (M_j=0.1N) and by keeping a constant co-flowing air velocity (1.2 m/s). This choice has already been adopted by several authors studying

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density effect for variable density flows [13-15]. Indeed, for a similar momentum flux value at the outlet nozzle, different gases can be characterized with similar initial forces.

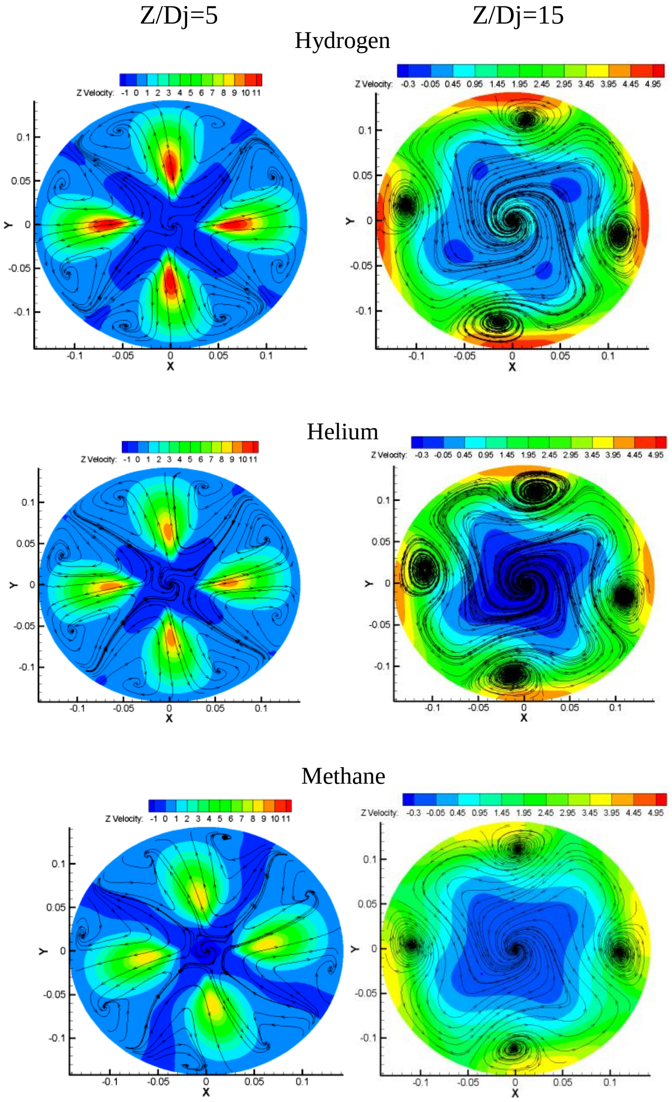

Fig. 3 Streamlines and axial velocity contours of hydrogen, helium and methane for $Z/D_j=5$ and $Z/D_j=15$

Fig. 3 displays axial velocity contours and streamlines in the confinement at the cross-sections $Z/D_j=5$ and $Z/D_j=15$ for different gases (hydrogen, helium and methane). Overall, the dynamic structure is the same for the three gases. Nevertheless, it is seen that vortices are even more intense for the lighter gas. Indeed, hydrogen velocity contour is marked by larger velocity values.

Fig. 4 shows mean mass fraction contours distribution of hydrogen, helium and methane for $Z/D_j=5$. We notice that hydrogen tends to mix more rapidly than heavier gases do. Indeed, for the same section, it is seen that methane mass fraction is the greatest compared to helium and hydrogen. This means that better mixture can be ensured for a central pipe ejecting hydrogen.

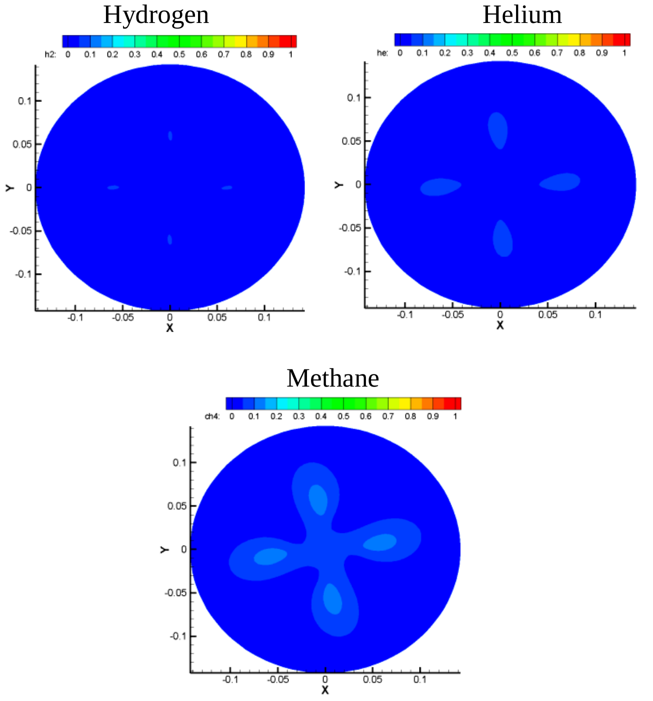

Fig. 4 Contours of hydrogen and methane mean mass fraction in the confinement for $Z/D_j=5$

Axial profiles of the centerline mean mass fraction for the three tested gases are plotted in Fig. 5.

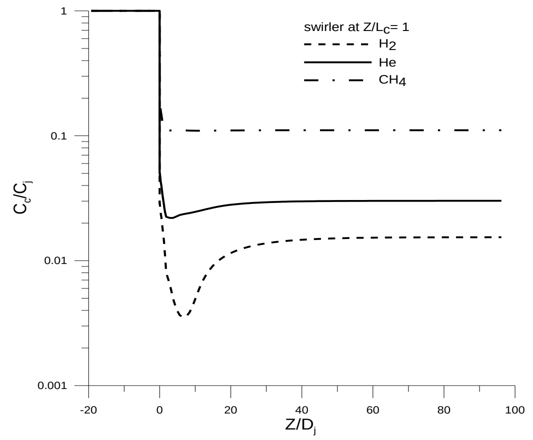

Fig. 5 Centerline evolutions of the mean mass fractions of different gases: Hydrogen, Helium and methane

From Fig. 5, it can be seen that the central jet mass fraction decreases immediately in the confinement inlet ($Z/D_j=0$). The central mass fraction reaches a constant value varying with the central jet nature. It is seen that this value is lower for the lighter gas which corresponds to better mixing process at the centerline.

Fig. 6 depicts radial evolution of dimensionless mean mass fraction of the three tested gases.

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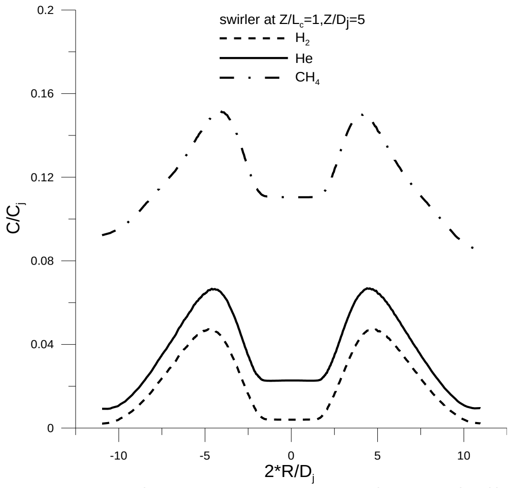

Fig. 6 Radial evolutions of the central jet mean mass fraction of different gases: Hydrogen, Helium and methane (Z/D_j=5)

It is shown that radial profiles shape is not affected by the central gas nature. It can also be noticed that lighter gases are characterized by lower radial mass fraction. This is in conformity with Fig. 3 and previous works of T. Djeridane et al. [14] and P. Wang et al. [15] studying variable density flows.

For non reactive conditions, it is found that the annular swirler associated to the central pipe ejecting hydrogen constitutes the best test case. However, reactive mixture should be analyzed more carefully. Actually, for combustion application, the flattened radial profiles can cause flame flashback. Indeed, in several combustion engines, the central tube holds fuel. In our case, the flattened problem of radial profiles corresponds to a fuel mass fraction near the confinement wall while it is better for flame stability to have a fuel concentrated in the central zone (downstream the central nozzle).

It is seen that hydrogen is characterized by the lowest radial mass fraction spreading near the confinement wall. Nevertheless, the flashback problem could not be avoided. In order to solve this problem, we propose to modify the swirl generator central zone from solid (annular swirler) to fluid (non annular swirler). In fact, we assume that the flattened radial profiles could be caused by the annular aspect of the adopted swirl generator.

Fig. 7 represents the radial mass fraction profiles of hydrogen for the initial swirler (annular) and the modified one (non annular). It is noticed that the swirler geometry modification succeeds in avoiding the flattened radial profiles and consequently the flashback problem.

As a conclusion, we can say that for reactive mixture, the best test case corresponds to a central jet ejecting hydrogen and equipped with a non annular swirler.

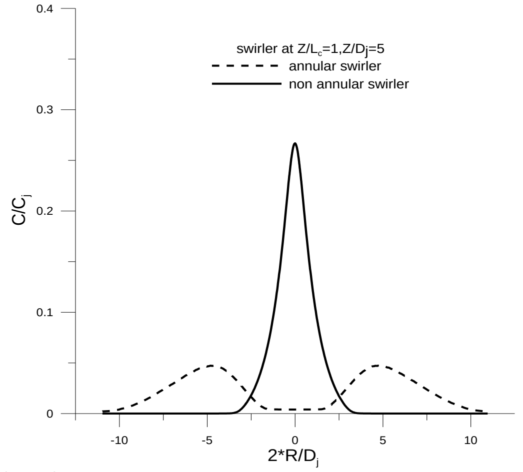

Fig. 7 Effect of the swirler geometry (annular/non annular) on the radial mean mass fraction of hydrogen

VI. CONCLUSIONS

In the present paper, numerical simulations were conducted to investigate the effect of an annular swirl generator disposed within the central tube of a variable density coaxial configuration. The effect of the central jet nature in the presence of the swirler was discussed.

Comparison to experimental data showed a satisfactory agreement for both velocity and mass fraction measurements. The confined coaxial configuration was simulated under the swirl generator presence in the central pipe (S=0.7).We have shown that the dynamic structure is globally similar for the three tested gases (hydrogen, helium and methane). However, vortices intensities were higher for hydrogen. Therefore, the dynamic flow structure is promoting light gases mixing. Hydrogen was judged as the best test case ensuring the more efficient mixing process for non reacting conditions.

The analysis of the reactive case showed that a flame flashback is possible because of the flattened resulting radial profiles. It has been demonstrated that a geometry modification of the adopted swirler could guarantee good reactive mixture. Numerical findings showed that a non annular swirler added to the central tube of hydrogen constitutes the best test case if reactive condition is required.

REFERENCES

[1] K. Merkle, H. Haessler, H. Buchner and N. Zarzalis. Effect of co- and counter-swirl on the isothermal flow and mixture-field of an airblast atomizer nozzle. *International Journal of Heat and Fluid Flow* 2003; 24: 529–537.

[2] A. Olivani, G. Solero , F. Cozzi, A. Coghe. Near field flow structure of isothermal swirling flows and reacting non-premixed swirling flames, *Experimental Thermal and Fluid Science* 2007; 31: 427–436.

[3] F. Rong, H. Shun, C. Yen. Aerodynamic characteristics and thermal structure of nonpremixed reacting swirling wakes at low Reynolds numbers. *Combustion and flame* 2008; 155: 539-556.

[4] Y. Zheng, M. Zhu, D. M. Martinez, X. Jiang. Large-eddy simulation of mixing and combustion in a premixed swirling combustor with synthesis gases, *Computers & Fluids* 2013; 88: 702–714.

[5] X. Zhu, R. Li, D. Li, P. Zhang, R. Qian. Experimental study and RANS calculation on velocity and temperature of a kerosene-fueled swirl laboratory combustor with and without centerbody air injection. International Journal of *Heat and Mass Transfer* 2015; 89: 964–976.

[6] A. Frassoldati, S. Frigerio, E. Colombo, F. Inzoli, T. Faravelli. Determination of NOx emissions from strong swirling confined flames with an integrated CFD-based procedure. *Chemical Engineering Science* 2005; 60: 2851 – 2869.

[7] A. Khalil and K.A. Gupta. Swirling distributed combustion for clean energy conversion in gas turbine applications. *Applied Energy* 2011; 88: 3685–3693.

[8] T. Parra, R. Perez, M.A. Rodriguez , F. Castro, R.Z Szasz, A. Gutkowski. Numerical Simulation of Swirling Flows–Heat Transfer Enhancement. Journal of Fluid Flow, *Heat and Mass Transfer* 2015; Volume 2, ISSN: 2368-6111 DOI: 10.11159.

[9] R. Thundil Karuppa , V. Ganesan. Study on the effect of various parameters on flow development behind vane swirlers. *International Journal of Thermal Sciences* 2008; 47: 1204–1225.

[10] B. Taupin. Etude de la combustion turbulente à faible richesse haute température et haute pression. Thèse présentée à l'institut national des sciences appliquées de Rouen 2003.

[11] P.V Koen, E .Van Den Bulck , Confined annular swirling jet *combustion. Combust. Sci. and Tech*. 2003; 175: 545-578.

[12] M. Falese, Y.M. Gicquel, Th. Poinsot . LES of bifurcation and hysteresis in confined annular swirling flows. *Computers & Fluids* 2014; 89: 167-178.

[13] M. Amielh, T. Djeridane, F. Anselmet, L. Fulachier. Velocity near-field of variable density turbulent jets. *Int. J. Heat Mass Transfer* 1996; Vol. 39: 2149-2164.

[14] T. Djeridane, M. Amielh, F. Anselmet, L. Fulachier. Velocity turbulence properties in the nearfield region of axisymmetric variable density jets. *Phys. Fluids* 1996; 1614, DOI: 10.1063/1.868935.

[15] P. Wang, J. Frohlich, V. Michelassi, W. Rodi. Large-eddy simulation of variable-density turbulent axisymmetric jets. International Journal of Heat and Fluid Flow 2008; 29: 654–664.