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Swirl generator effect on a confined coaxial jet characteristics

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ABSTRACT

The effect of a swirl generator placed in the central pipe of a cylindrical confinement on mixing process enhancement is numerically investigated. 3D simulations were carried out using the commercial code FLUENT. RANS calculations were conducted to investigate the effect of the swirler position, the central gas nature and the swirler geometry on the swirled flow behavior.

Results show that for an annular swirl generator, the swirler location in the central pipe affects considerably the dynamic structure and the mixing process in the confined volume. Moreover, it has been shown that the optimal swirler position depends on the intended application: For non reacting case, the central pipe outlet is judged as the best test case to guarantee good mixing process. On the contrary, for reacting case, the annular swirler should be placed far from the main pipe outlet to ensure better mixture and avoid flash-back problem caused by flattened radial concentration profiles. By modifying the central jet type (Helium, hydrogen and methane), it has been proven that hydrogen tends to mix more rapidly. However, the flattened radial concentration profiles problem persists for the different gases. Meanwhile, this problem can be solved by modifying the geometry of the swirler placed at the central pipe outlet.

Introduction

Mixing process control is the main purpose of industrials as well as researchers in several engineering applications such as mixers, cyclone separators, rotary kilns, burners … etc. Particularly, numerous technologies can be applied for coaxial burners to ensure better mixture such as hydrogen enrichment [1], central microjet addition [1,2] or swirl generator insertion [3–10]. In this work, the latter technique is evaluated to promote mixing quality in a confined coaxial jet configuration. Several researchers have been interested in swirling flows. An experimental study has been carried out by Rashad et al. [4] to evaluate the effect of geometric parameters on swirl atomizers' spray characteristics. Experimental results have discussed the optimal atomizers parameters. Another experimental work has been conducted by Mizutani et al. [5] in which the inlet swirling flow effect on a triple elbow system flow field was examined. In their work, the flow separations zones responsible in inducing pressure fluctuations were identified by following velocity fields. Takano et al. [6] have explored experimentally a swirling flow influence on mass and momentum transfer for a pipe with elbow and orifice. The optimal mass transfer coefficient was determined and it has

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Nomenclature

Fr	Froude number $\left(Fr_j = \frac{\rho_j U_j^2}{g\lvert\rho_j - \rho_e\rvert D_j} \right)$
R, X, Y	Radial position, m
Re	Reynolds number $\left(Re_j = \frac{\rho_j\, U_j\, D_j}{\mu_j} \right)$
Pr	Prandtl number ($Pr = \frac{C_p\, \mu}{\lambda}$)
S	Geometric swirl number $\left(S = \frac{2(1-a^3)}{3(1-a^2)} \tan\alpha \right)$
Sc	Schmidt number ($Sc = \frac{\mu}{\rho \cdot D_k}$)
U	Velocity component, $m.s^{-1}$
w	Density ratio $\left(w = \frac{\rho_j}{\rho_a} \right)$
y	Mean mass fraction
Z	Axial position, m

Greek symbols

ρ	Density, $kg.m^{-3}$
μ	Dynamic molecular viscosity, $kg.s^{-1}.m^{-1}$
ν	Kinematic viscosity, $m^2.s^{-1}$
ε	Dissipation rate of the turbulent kinetic energy, $m^2\, s^{-3}$
δ_{ij}	Kronecker Symbol
τ_{ij}	Stress tensor, $kg.s^{-2}.m^{-1}$

Subscript

a	Air
c	Central value
h	Hydraulic
j	Central jet
t	Turbulent

been shown that the swirler addition provides six times larger value compared to the straight pipe without swirl. Mansouri et al. [7] have investigated numerically an enriched premixed propane flame. The k-epsilon model was used as a turbulence closure model. The effects of hydrogen addition, swirl intensity and equivalence ratio on swirl-stabilized burner characteristics have been discussed. De et al. [8] have conducted a numerical study on a swirling laboratory-scale combustor. The effects of swirl number, geometry and premixedness on flame behavior have been discussed. Numerical results show that stability behavior can be reached while operating at low swirl. U. Ahmed et al. [9] have been interested in underlining, experimentally, the swirl number, the nozzle to plate distance and Reynolds number effects on the impingement surface heat transfer for impinging turbulent air jets. Experimental results showed that a transitional swirl number depending on Reynolds number controls heat transfer characteristics. Wannassi et al. [10] have adopted RANS approach to analyze the dynamic behavior of the flow through swirler blades. By varying Reynolds number and blade angles, the authors have identified vortical structures at the inlet of the swirl generator inlet and at the jet exit.

In this study, the effect of an annular swirl generator on a variable density coaxial jet behavior is numerically investigated. Actually, an annular swirler is characterized with non-contiguous injectors and a solid central zone [11]. The importance of annular swirlers can be reflected by the numerous studies presented in the literature. The swirl number S effect on mixture in a coaxial configuration was investigated by Parra et al. [12]. The adopted swirler was installed in the annular pipe ejecting air. By varying the swirl angle (S ranging from 0.14 to 0.95), the authors underlined the importance of the CRZ in mixing process enhancement for high swirled flow ($S > 0.6$). The geometry effect of an annular swirler placed in a cylindrical tube inlet was discussed by Yilmaz et al. [13]. Three different swirler geometries were tested in which the central zone had no deflecting element, or was occupied either by conical or spherical deflector. Experimental results showed that the best heat transfer can be achieved for a swirler with no deflecting element. Karuppa et al. [14] have simulated an isothermal flow developed downstream an annular swirler placed in an air tube discharging into a tunnel. The effects of vane number (4, 8 and 12) and swirler geometry (with and without solid central zone) on mixing quality were numerically investigated. Results showed that the swirler occupied by 8 vanes was characterized by the more efficient mixture since it generated the more appropriate central recirculation zone (CRZ). Nevertheless, no effect was accorded to the geometry in mixing process enhancement.

Annular swirl generators were also used to avoid flame instabilities in combustion equipments such as flame flashback. In this case, a bluff-body was putted on the swirler central zone. Indeed, the bluff-body was used to control the CRZ size and push it far from the injection stream exit [11]. Straub et al. [15] have underlined the effect of the swirler position inside a cylindrical tube on the dynamic structure of a premixed flame. Four different swirler positions varying from 9.3 cm to 15.16 cm upstream the combustion chamber inlet were adopted. Based on the experimental results, the authors concluded that the flame oscillations were more important for the swirler position closer to the combustion chamber inlet.

A more recent study was conducted by Ayhan Sarac et al. [16]. These authors have examined swirler position effect on heat transfer. Experimental results showed that the swirler position played a key role in heat transfer process.

It should be noted that the effects of a swirl generator inserted either in a cylindrical tube or in an annular tube of a coaxial configuration were widely encountered in literature. To the authors' knowledge, the effect of a swirl generator placed in the central tube of a coaxial configuration was not well documented.

The main purpose of this paper is to discuss, numerically, mixing quality under the insertion of an annular swirl generator in the central tube of a confined coaxial configuration. In addition, it is noticed that swirlers are commonly added to air flow. The originality of this paper consists on the fact that the swirl motion is added to the central pipe of a coaxial configuration. Generally, for coaxial combustors, the central tube is holding fuel. To the authors' knowledge, the evaluation of the swirler insertion in the fuel central tube was not discussed for both non reactive and reactive cases. In a first step, we focus on the effect of the annular swirler position on the flow dynamics and mixing enhancement. In a second step, two fuels (hydrogen and methane) were tested to analyze the effect of the central gas nature in the presence of

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