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Numerical study of the interaction of multiple swirling jets mounted with unbalanced positions

A. KHELIL ^a, H. NAJI ^b, M. BRAIKIA ^a and L. LOUKARFI ^a

^a Université de Chlef, B.P. 151, 02000 Chlef, Algérie

^b Université d'Artois, Laboratoire Génie Civil et géo-Environnement (EA 4515), Technoparc Futura, F-62400 Béthune, France

Résumé :

L'objectif de cette étude est d'examiner numériquement l'interaction des jets tourbillonnaires multiples montés avec des positions asymétriques. Cette étude montre que l'arrangement des diffuseurs en positions, affecte la qualité de l'homogénéisation thermique de l'ambiance. La présente étude est réalisée dans des conditions de flux de chaleur uniforme pour chaque diffuseur, l'air étant le fluide de travail et le débit a été ajusté à un nombre de Reynolds $Re_0 = 3.10^4$. Dans ce travail, les simulations ont été effectuées en utilisant le code Fluent avec la méthode des volumes finis, dans lequel le modèle de turbulence $k-\varepsilon$, $k-\varepsilon$ RNG et le modèle de turbulence des contraintes de Reynolds (RSM) ont été utilisées pour les calculs de la turbulence. Les prévisions globales obtenues avec le modèle RSM sont en meilleur accord avec les données expérimentales par rapport à celles obtenues avec le modèle de turbulence $k-\varepsilon$. L'analyse des caractéristiques de l'écoulement montre clairement que l'interaction entre les jets tourbillonnaires induit la redistribution de la température dans la zone de mélange, tout en permettant la diffusion du jet résultant.. Il semble que le jet central joue un rôle important dans l'amélioration de l'homogénéisation thermique. Les résultats de cette étude montrent que le déséquilibre en position entre le jet central et périphérique, affecte la qualité de l'homogénéisation thermique de l'ambiance.

Abstract :

The objective of this study is to examine the interaction of multiple swirling jets mounted with unbalanced positions numerically. This study shows that arrangement in positions, affects the quality of the thermal homogenization of ambiance. The current study is carried out under uniform heat flux condition for each diffuser, the air being the working fluid and flow rate was adjusted at the Reynolds numbers $Re_0=3.10^4$. In this work, the simulations have been carried out using the finite volume CFD solver Fluent, in which the standard $k-\varepsilon$, $k-\varepsilon$ R.N.G and the Reynolds stress turbulence model (RSM) were used for turbulence computations. Overall predictions obtained with the RSM model are in better agreement with the experimental data compared to those of the standard $k-\varepsilon$ model. The analysis of the flow features clearly demonstrate that the interaction between swirling jets induces the redistribution of temperature in the mixing zone, while allowing the spreading of the resulting jet. It appears that the central jet plays an important role in the enhancement of the thermal homogenization. The findings of this study show that an imbalance in position between the central and peripheral jets, affect the quality of the thermal homogenization of the ambiance.

Keywords: Multiple swirling free jets, Thermal homogenization, Swirler vanes angle, CFD, Air diffuser.

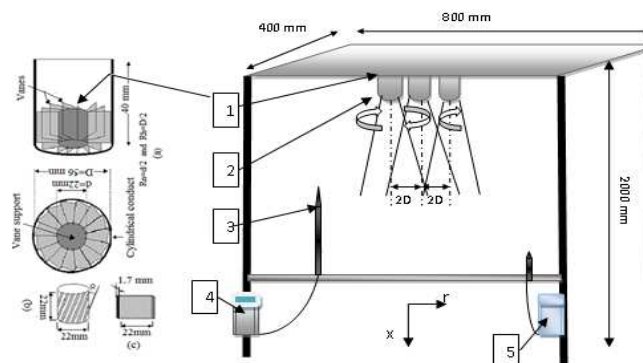
1 Introduction

The understanding of swirl effects, particularly on the entrainment rate of air and on the temperature homogenization is very important for the efficiency of ventilation process. However, to our knowledge, these effects have been scarcely investigated, and consequently the fusion of many swirling jets becomes interesting to study. The multiple swirling free jets studies show that the swirling jets will develop more rapidly than the jets without swirl. Note that the number of jets contributes to decrease velocities. Also, the

distance between blowing orifices involves a decrease of velocities while delaying jets fusion. For high swirl numbers and far from the orifices, velocity profiles of multiple jets have a tendency to increase compared with those of the single jet. The interaction between jets allows the distribution of velocities in the mixing zone in which the normal stresses and maximum shear are located. At near origin of the swirler, the profiles are characterized by irregularities due to the swirler geometry and the blowing conditions. It should be noted that the axial temperature for the multi-jet seems to be an exponential decrease [1,2 and 3]. According to the available literature, there is no advanced research being done on the multiple swirling jets applied to improve the thermal homogenization. Most papers which deal with multiple swirling jets in various geometric, dynamic and thermal conditions are aimed to the improvement of combustion. From the above discussion, the main aim of this study is to examine and perhaps control the influence of various parameters such as the arrangements of the single or multiple swirling jets, on the flow resulting both dynamically and thermally. In addition, we expect that optimization of these parameters would influence the thermal stratification of the atmosphere, and help to optimize the choice of the configuration of interest to industry.

2 Experimental setup and techniques

The experimental facility is depicted in Fig. 1(a and b). It consists of a size chassis 2000x800x400 (mm) which is fixed on a square plate of Plexiglas. On the latter, three devices blowing hot air (hairdryer TEFAL-1500) are fixed and directed downwards, and the lower part of these devices is used to fix different types of diffusers provided with inclined vanes, depending on the studied configuration. Temperatures and velocity of the flow are measured by a hot wire anemometer (type Velocicalc Plus Air velocity Meter), which is a high-precision multifunctional instrument. The data can be viewed on a screen, printed or downloaded to a spreadsheet program allowing us to easily transfer data to a computer for statistical treatment. The accuracy is of order $\pm 0.015 (m/s)$ for velocity and $\pm 0.1 (^\circ C)$ for temperature from thermal sensor. Note that the thermal sensor is supported by rods which are easily guided vertically and horizontally to sweep the maximum space in the axial and radial directions (see Fig. 1).



1-Air blowing Devices, 2- Diffuser with inclined vanes, 3-Thermoanemometer probe,
4- Thermo anemometer, 5-Thermometer

FIG. 1- Experimental facility and test assembly

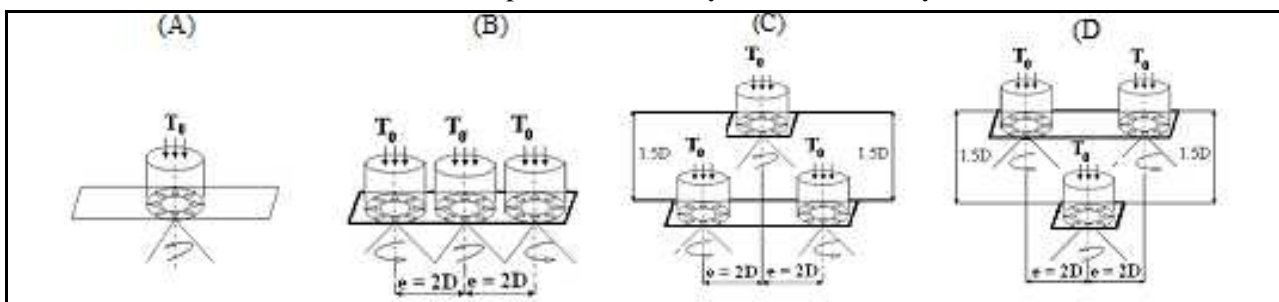


FIG.2: Blowing configurations ($T_0=363K$ and $T_0/2=318K$): (A) Single swirling jet (B, C and D) triple swirling jets.

In this study, the axial and tangential velocities U and W , were measured at the exit of a swirling jet diffuser with a triple probes hot wire anemometer (DISA 55M01). This number is defined as the ratio of the axial flux of tangential momentum to the product of the axial momentum flux and a characteristic radius

[10]. It should be noted that the exact expression of swirl number depends on the injector geometry and flow profiles. For a typical single element injector with a flat vane swirler, the definition of swirl number given by Gupta et al. (1984) can be expressed as

$$S = G_\theta / R G_x = \int_{R_n}^{R_h} U W r^2 dr / \int_{R_n}^{R_h} R_n U^2 r dr \quad (1)$$

Where G_θ is the axial flux of tangential momentum, G_x is the axial momentum flux, and R is a characteristic radius. R_n and R_h are radius of the centre body and the inlet duct, respectively. It is important to note here that if the axial and azimuthally velocities are assumed to be uniform and the vane are very thin, the swirl number can be expressed as:

$$S = \frac{2}{3} \left[\frac{1 - (R_h/R_n)^3}{1 - (R_h/R_n)^2} \right] \tan \alpha \quad (2)$$

where α is the swirler vane angle. Note that in the case of a hubless swirler ($R_h = 0$), the above expression is reduced as:

$$S = 2/3 \tan \alpha \quad (3)$$

One swirl numbers value is considered in this study. These are $S=1.3$ for vane angle $\alpha=60^\circ$. To carry out our experiments, the following operating conditions have been considered: $S = 1.3$, $Q_m = 0.041 \text{ kg/s}$, $Re_0=30.10^3$, $r/D=1$ to 8 and $0 \leq x/D \leq 20$. Here it is useful to note that previous studies were based on similar ranges of Reynolds [4 and 5] to name a few]. It is worth recalling that here our goal is to identify and study the evolution of temperature profiles of axial and radial multi-jet swirling in different configurations. Two configurations consist of three swirling jets in imbalance (B) and in balance (C and D) of position and a single swirling jet configuration (A) have been presented in Fig. 2.

3. Numerical simulation procedure

The $k-\varepsilon$ model is an example of two equation models that use the Boussinesq hypothesis. Here, two different closure models, $k-\varepsilon$ model and the Reynolds Stress Model (RSM), have been used.

3.2 Grid generation

It goes without saying that the strategy of grid generation within the computational region and density of the grid play an important role in the prediction accuracy. The grid was non-uniform, with high density in zones of great interest and low density in zones of less interest, so that minimal computational effort was required whilst gaining sufficient accuracy. The computational grid geometry of the swirl generator and the entire inflow system are presented in Fig. 3. Tetrahedral mesh has been used, and in order to capture wall gradient effects, mesh has been finer toward the vanes. In the radial direction the mesh is fine over the test inlet and then stretched to the exit. Tests with finer grids (up to 1800000 cells) demonstrate that the quality of the prediction is not improved by enhancing the number of cells used [see Table 1]. Computations on different mesh show that the solution of the radial dimensionless temperature in the case of configuration C does not change significantly (errors remain in the order of $\leq 4\%$), which suggests that the solution is independent of the mesh as it can be seen in Fig.4.

Table 1.

Grid 1	Grid 2	Grid 3	Grid 4	Grid 5
973556	1797607	1801362	1801913	1867537

Note that there are a total of 1839831, 2244126, 973556 and 973556 cells for blowing configurations A, B, C and D, respectively.

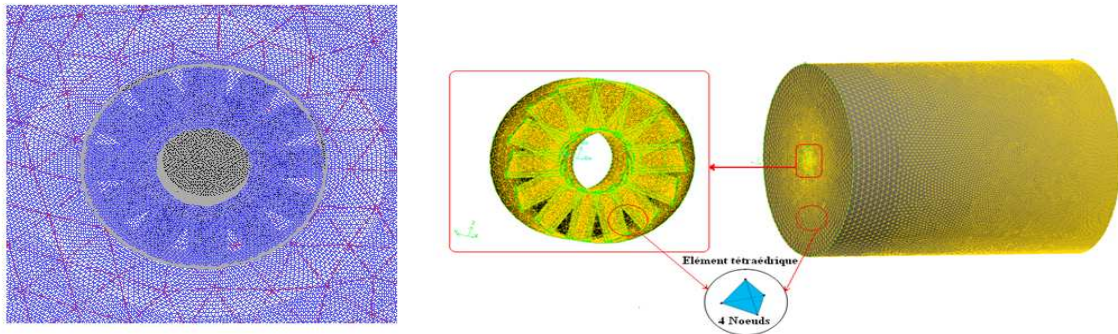
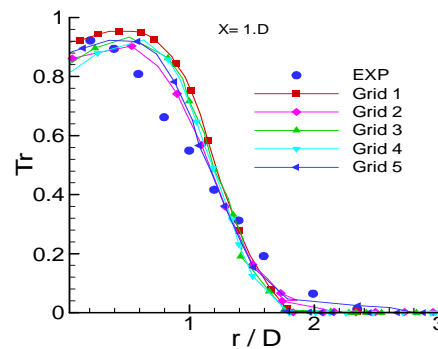


FIG. 3 - Computational grid for the inlet area.

FIG. 4- Sensitivity of dimensionless radial temperature variation to grid density ($k-\varepsilon$ model)

5. Results and discussion

As mentioned before, previous studies showed that for a range of experimental conditions, heat transfer enhancement is strongly depending on blade angle and it seems that the Reynolds number Re has not significant influence, whereas when the initial angle of the velocity α increases, the jet is more spreading in the radial direction [9]. In this study, the dimensionless temperature, r - and x -coordinates were normalized in the form $t_r = [t - t_a] / [t_0 - t_a]$, r/d and x/d respectively, where t is the jet temperature, t_a is the ambient temperature and t_0 is the maximum temperature of the air blowing at origin. Figures 5 and 7 show the contours of temperature determined by the RSM turbulence model. Note that the internal recirculation zone (A), is a mixing zone of the jets and the external fluid. It is represented with a high speed gradient and an increase in the intensity of turbulence, stabilizes the velocity profile at a distance of a jet, the region (B) is an intermediate zone, and in the region (C) the flow is fully established, the temperature has stabilized and the development of the flow streams are homogeneous. Figures 6 and 8 show the streamlines colored by the average temperature determined by the RSM turbulence model, the current lines move radially to expand the distribution of average temperatures along the axes of the triple swirling jet unbalanced position, the maximum temperature is obtained at the central recirculation zone swirling jets. The radial distribution of dimensionless temperature at distance from the inlets $x/D = 1, 3, 5$ and 8 respectively is presented in Fig. 9. The standard $k-\varepsilon$, $RNG k-\varepsilon$ and Reynolds stress models were used to predict the turbulence flow. Along the radial coordinate, the dimensionless temperature profile moves from high values, decreases, and then finally it approaches its asymptotic value which refers to ambient temperature. Some differences from the experimental data were observed in the zone close to the axis for $x > 3D$. For the stations $x/D = 3, 5$ and 8 , both models underestimate the maximum value at the centerline. As can be seen, the temperature predictions obtained by the Reynolds stress model are generally in good agreement with our experimental data. The comparison of the radial distribution of dimensionless temperature (A, C and D) at stations $x/D = 8$ is given in figure 10. As can be seen in this figure, that the configuration D give more spreading and the configuration C leads to a good thermal homogenization with rapid thermal satiability.

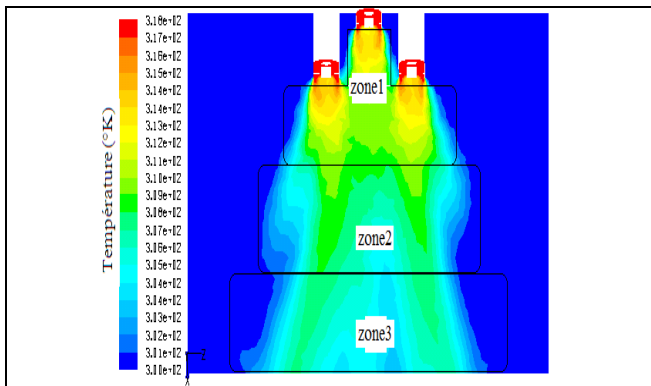


FIG. 5 - Contour of average temperature for configuration (C) determined by the RSM turbulence model.

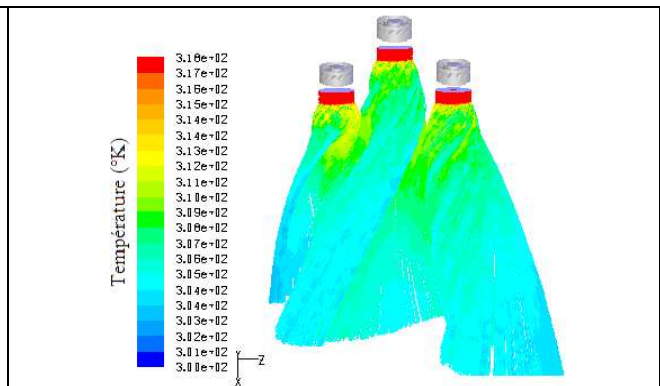


FIG. 6: Pathlines colored by average temperature for configuration (C) determined by the RSM turbulence model.

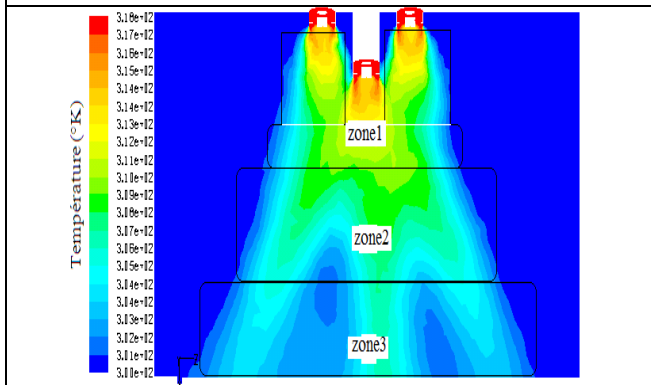


FIG. 7- Contour of average temperature for configuration (D) determined by the RSM turbulence model.

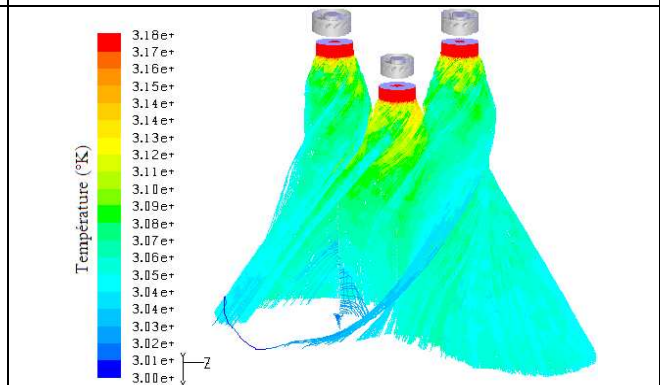


FIG. 8- Pathlines colored by average temperature for configuration (D) determined by the RSM turbulence model.

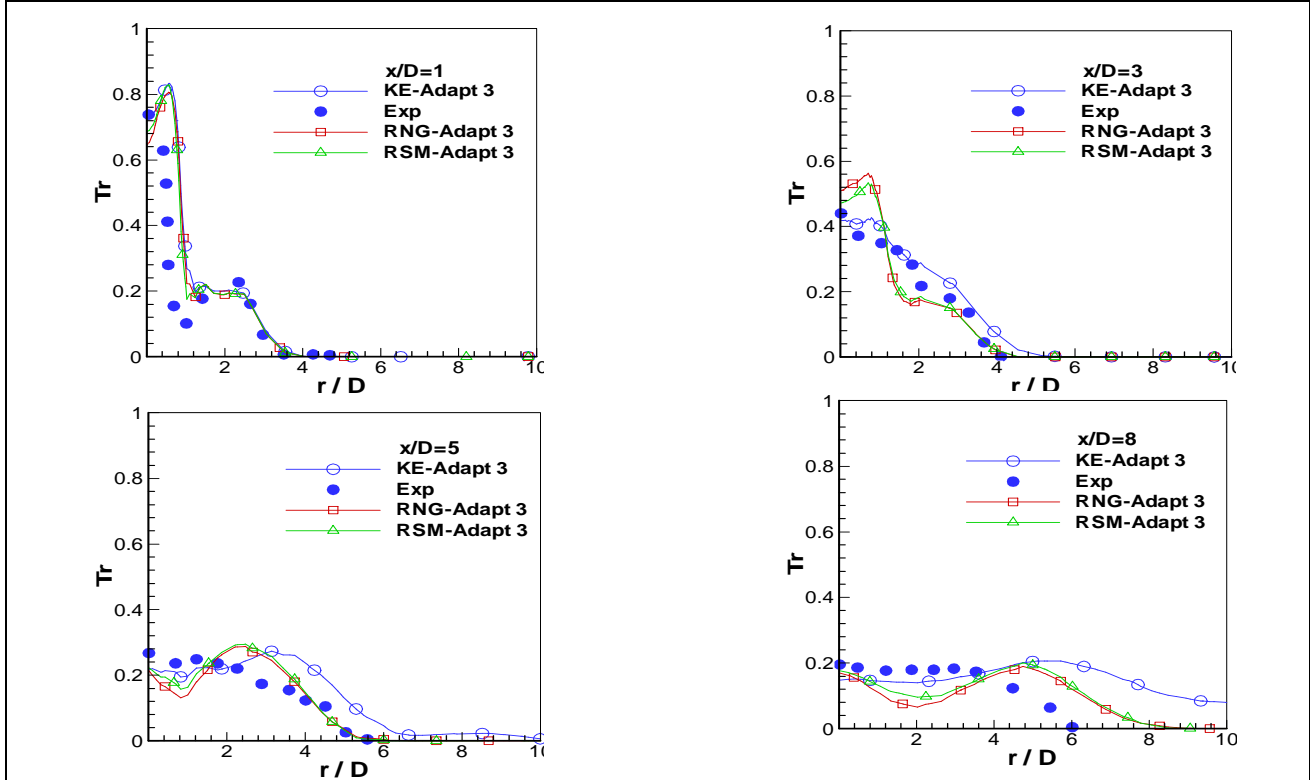


FIG.9- Radial distribution of dimensionless temperature for configuration (D) at stations $x/D = 1, 3, 5, \text{ et } 8$

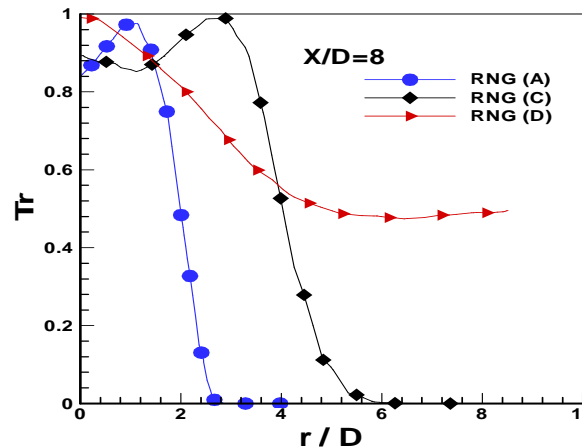


FIG.10- Radial distribution of dimensionless temperature for configuration (A, C and D) at stations $x/D = 8$

6. Conclusion

In this Study, we explored different configurations of blowing multiple swirling jets for use in ventilation applications. We have highlighted more improvement of the thermal homogenization of the treated area using multiple swirling jets with an appropriate choice of the position for blowing air. In this work, a numerical study of different configurations of blowing multiple swirling jets has been fulfilled. The numerical simulation of the flow and temperature fields has been carried out using the standard $k-\epsilon$, $k-\epsilon$ R.N.G and the Reynolds stress (RSM) turbulence models. Based on the investigation conducted for different configurations and parameters, the following conclusions can be made. The analysis of the flow features clearly demonstrates that the interaction between swirling jets induces the redistribution of temperature in the mixing zone, while allowing the spreading of the resulting jet. It appears that the central jet plays an important role in the enhancement of the thermal homogenization. From the thermal homogenization viewpoint, the optimization of parameters such as the diffuser's geometry, the swirler vane angle, the number of blowing jets, and the direction of rotation, balance and imbalance in position between the central and peripheral jets are adequate means to enhance the quality of thermal homogenization.

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