A CFD ANALYSIS OF THE URBAN MORPHOLOGY EFFECT ON AIR POLLUTANTS DISPERSION

ABDELKRIM MERZOUGUI[1], ABDELMALEK HASSEINE[1], DJEMOUI LAIADI[1], SADOUK HOUDA[2], AND JAMEL CHAOUKI[3]

[1] Department of chemical engineering, Mohamed Khider of Biskra University – Algeria
Email address: merzouguikarim@yahoo.com
Email address: Hasseine@yahoo.fr
Email address: ayadhi_jm@yahoo.com
[2] Department of architecture, Mohamed Khider of Biskra University – Algeria.
Email address: saddok.houda@univ-biskra.dz
[3] Department of chemical engineering, Ecole Polytechnique de Montréal, Canada.
Email address: jamal.chaouki@polymtl.ca

Abstract: Air pollution in urban environments can have negative consequences on people's health and comfort of city-dwellers, and on the durability of buildings. Understanding the transfer and deposition of pollutants in the urban environment is therefore essential in the design process of a building. Computational simulations can aid in understanding the pollutant/chemical dispersion in the urban cityscapes. Computational fluid dynamics (CFD) represents the study of fluid mechanics with the use of computer models and simulations. In this paper we study the impact of urban planning on pollution dispersion, the dispersion characteristics, such as the spread of the pollution dispersions, have been determined for different wind speeds and wind directions.

1. Introduction

The unprecedented growths of cities in the 20th century make them major contributors to local, regional and global environmental problems. Sources and dispersion of pollution in the urban atmosphere continues to receive a great deal of research focus in order to address the various adverse impacts it has on climate change, the environment and on human health.

Models with varying complexity have been developed and experimental data on this environment and the wind tunnels were used for validation of these models. Most work has focused on simple geometries, such as street canyon well known (Vardoulakis et al 2003; Berkowicz et al 1997; Britter and Hanna 2003), however, these attempts to study real urban situations gave some important information on the dispersion process, emphasizing the role of the effects on the three-dimensional fabrics, especially at street intersections (Soulhac 2000; Scaperdas 2000). The peak concentrations of pollution can be found in these places because of the presence of high levels of traffic where intersections are more common than in urban canyons regular in real cities. The process flow at intersections and the dispersion of

particles are extremely complex, which makes their treatment much more difficult than that encountered in urban canyons base (Hoydysh Dabberdt et al, 1994; Kastner-Klein et al, 1997; Wichmann-Fiebig et al 1997, Robins al 2002).
More details of the previous literature in this area can be found in the article by Belcher (2005), who examined several approaches to modeling the flow and dispersion in urban areas, discussing in particular the role intersecting streets. Numerical modeling remains relatively feasible, but with more simplifications in the phenomena considered especially in Gaussian and integral models. CFD is the numerical modeling, which approaching best the reality of phenomena since it solves the equations of continuity, momentum, energy and concentration, taking into account the phenomenon of turbulence.

2. Modeling the dispersion of pollutants

This section will discuss the different models Euler / Euler proposed by Fluent (fluent documentation, 2005). Models Euler / Euler proposed by Fluent there are three: Volume Of Fluid (VOF); Mixture Model and Eulerian Model.
For our work, the Fluent documentation models recommends using "Eulerian Model ". We will now detail the equations used and resolved by this model.

2.1. EULERIAN MODEL

When this model is used, Fluent solves an equation for each phase of continuity and an equation of momentum. His equations have been obtained directly from the monophasic equations of continuity and momentum. There are also differences between the set of monophasic and multiphasic equations. The transition from the set of monophasic equations to multiphase set of equations is done by introducing a phase volume fraction, reflecting the presence or absence of a phase. The fundamental averaged equations below are the essential mathematical equations used by the fluent code.

2.2. CONTINUITY EQUATION

The volume fraction of each phase is calculated from a continuity equation:

$$\frac{1}{\rho_{rq}}\left(\frac{\partial}{\partial t}\left(\alpha_q \rho_q\right)+\nabla.\left(\alpha_q \rho_q \vec{v}_q\right)=\sum_{p=1}^{n}\left(\dot{m}_{qp}-\dot{m}_{pq}\right)\right) \quad (1)$$

Where ρ_{rq} is the phase reference density, or the volume average of q^{th} phase in solution domain.

2.3. FLUID MOMENTUM EQUATION

The conservation of momentum for a fluid phase q (air) is

$$\frac{\partial}{\partial t}\left(\alpha_q \rho_q \vec{v}_q\right)+\nabla.\left(\alpha_q \rho_q \vec{v}_q \vec{v}_q\right)=-\alpha_q \nabla p+\nabla.\overline{\overline{\tau}}_q+\alpha_q \rho_q \vec{g}$$
$$+\sum_{p=1}^{n}\left(K_{pq}\left(\vec{v}_p-\vec{v}_q\right)+\dot{m}_{pq}\vec{v}_{pq}-\dot{m}_{qp}\vec{v}_{qp}\right)+\left(\vec{F}_q+\vec{F}_{lift,q}+\vec{F}_{vm,q}\right) \qquad (2)$$

2.4. SOLID MOMENTUM EQUATION

The conservation of momentum for a solid phase is

$$\frac{\partial}{\partial t}\left(\alpha_s \rho_s \vec{v}_s\right)+\nabla.\left(\alpha_s \rho_s \vec{v}_s \vec{v}_s\right)=-\alpha_s \nabla p-\nabla p_s+\nabla.\overline{\overline{\tau}}_s+\alpha_s \rho_s \vec{g}$$
$$+\sum_{l=1}^{N}\left(K_{ls}\left(\vec{v}_l-\vec{v}_s\right)+\dot{m}_{ls}\vec{v}_{ls}-\dot{m}_{sl}\vec{v}_{sl}\right)+\left(\vec{F}_s+\vec{F}_{lift,s}+\vec{F}_{vm,s}\right) \qquad (3)$$

Closing the system of equations requires defining the model of turbulence, Fluent offers three models of multiphase turbulence model based on k-ε. Two other models exist; they are based on the model RSM (Reynolds Stress Model). The k-ε turbulence model options are: Mixture Turbulence Model; Dispersed Turbulence Model and Turbulence Model for each phase. The turbulence model chosen in this work is the model k-ε "Dispersed Turbulence Model", this model solves a transport equation of k-ε for each phase. Solving these equations makes the use of this model somewhat cumbersome, but as complete as possible.

2.5. TRANSPORT EQUATION OF THE KINETIC ENERGY OF TURBULENCE

$$\frac{\partial}{\partial t}\left(\alpha_q \rho_q k_q\right)+\nabla.\left(\alpha_q \rho_q \vec{U}_q k_q\right)=\nabla.\left(\alpha_q\left(\mu_q+\frac{\mu_{t,q}}{\sigma_k}\right)\nabla k_q\right)$$
$$+\left(\alpha_q G_{k,q}-\alpha_q \rho_q \varepsilon_q\right)+\sum_{l=1}^{N}K_{lq}\left(C_{lq}k_l-C_{ql}k_q\right) \qquad (4)$$
$$-\sum_{l=1}^{N}K_{lq}\left(\vec{U}_l-\vec{U}_q\right).\frac{\mu_{t,l}}{\alpha_l \sigma_l}\nabla \alpha_l+\sum_{l=1}^{N}K_{lq}\left(\vec{U}_l-\vec{U}_q\right).\frac{\mu_{t,q}}{\alpha_q \sigma_q}\nabla \alpha_q$$

2.6. TRANSPORT EQUATION OF DISSIPATION RATE OF TURBULENCE

$$\frac{\partial}{\partial t}\left(\alpha_q \rho_q \varepsilon_q\right)+\nabla.\left(\alpha_q \rho_q \vec{U}_q \varepsilon_q\right)=\nabla.\left(\alpha_q \frac{\mu_{t,q}}{\sigma_q}\nabla \varepsilon_q\right)+$$
$$\frac{\varepsilon_q}{k_q}[C_{1\varepsilon}\alpha_q G_{k,q}-C_{2\varepsilon}\alpha_q \rho_q \varepsilon_q+C_{3\varepsilon}\left(\sum_{l=1}^{N}K_{lq}\left(C_{lq}k_l-C_{ql}k_q\right)-\sum_{l=1}^{N}K_{lq}\left(\vec{U}_l-\vec{U}_q\right).\frac{\mu_{t,l}}{\alpha_l \sigma_l}\nabla \alpha\right. \qquad (5)$$
$$\left.+\sum_{l=1}^{N}K_{lq}\left(\vec{U}_l-\vec{U}_q\right).\frac{\mu_{t,q}}{\alpha_q \sigma_q}\nabla \alpha_q\right)]$$

3. Results and Discussion

In order to follow precisely and in detail the variation of velocity fields and consequently the pollution caused by them, particularly in the region close obstacles, we adopted a non-uniform mesh, highly refined near and around the obstacles (Fig. 1). This mesh is very important to visualize and recirculation eddies created by the obstacles. The discredited equations are solved using the Fluent code by a finite volume method. Correct pressure and speed is achieved using the simple algorithm. The convergence is obtained for calculating a sum of normalized residues at 10^{-5} .

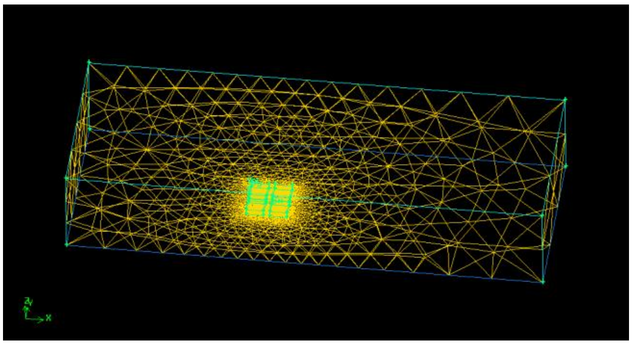

Figure 1: mesh of the study site

The study of the dispersion of pollutants is very complex and requires, first, understanding the flow behavior in the presence of obstacles. Indeed, the extent of the recirculation zone, the nature of the shear layer, like that of the vortices that detach from the obstacle, will interact with and thereby influence the pollutant dispersion. For obstacles with rounded edges or circular shaped roofs, separation of the streamlines is more brutal. The wake is wider and larger recirculation to sharp edges.

3.1. EFFECT OF MORPHOLOGY PLANNING

To illustrate the effect of the morphology urban on the pollutant dispersion, steady state simulations were made with round and square city models with two main streets. For this case, Figures 2 and 3, clearly shows the presence of pollutants for both forms of city square and round, with different distributions of pollution caused by these different forms of city models (Jian Hang et al. 2009). The pollutant is affected by the mean flow around the obstacle, by the recirculation zones and the wakes and the turbulence created by these regions. For more details see the previous work (Hasseine.A et al,2012).

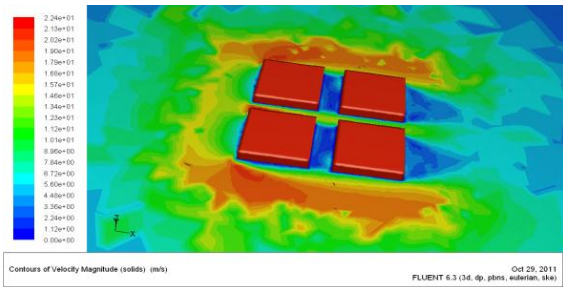

Figure 2: Velocity field of flow for square and shapes (two main streets)

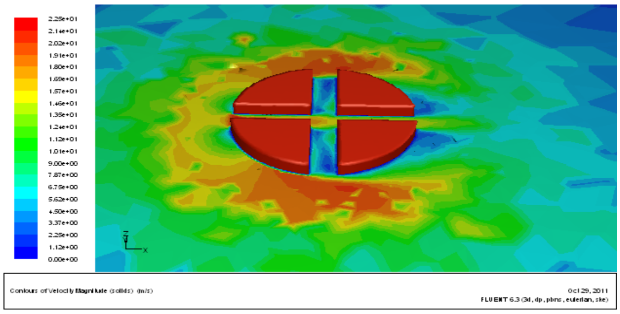

Figure 3: Velocity field of flow for round shapes (two main streets)

3.2. EFFECT OF WIND DIRECTION

Several studies have uncovered meaningful relationships between the urban morphology and wind condition. However, the relationship between the transfer of pollutants in the urban environment, the urban planning and the wind conditions has rarely been investigated.

In this paper, we presented the velocity field of two-phase flow (Air- pollutant) for both square and round shapes(two main streets) for only wind directions of 15° and 30°, for 0° please see the previous work; the other wind directions had similar effect but opposite in direction.

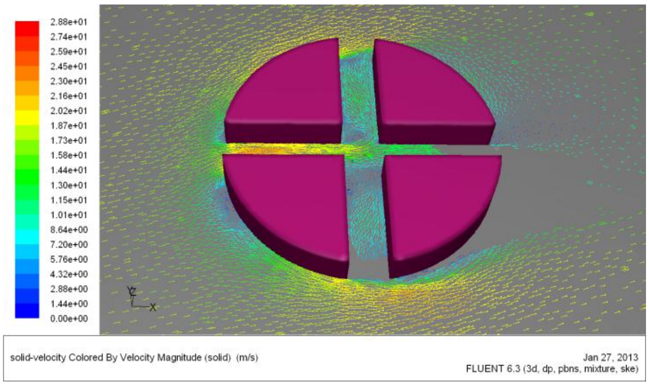

Figure 4: Velocity field of two-phase flow for round shapes (two main streets and ϴ=15°)

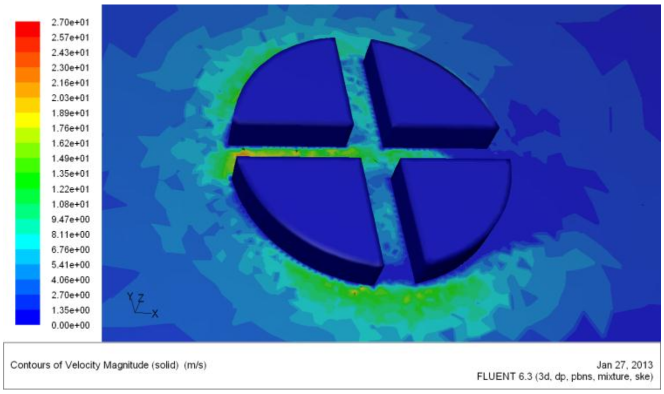

*Figure 5:*contours of Velocity field of two-phase flow for round shapes (2 main streets and ϴ=15°)

Figure 6: Velocity field of two-phase flow for round shapes (two main streets and ϴ=30°)

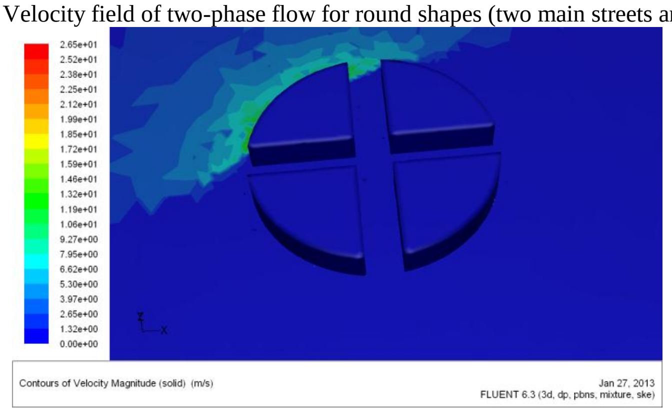

*Figure 7:*contours of Velocity field of two-phase flow for round shapes (2 main streets and ϴ=30°)

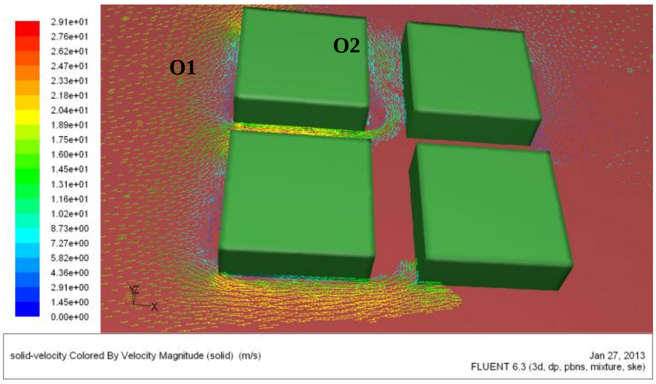

Figure 8: Velocity field of two-phase flow for square and shapes (two main streets, ϴ=15°)

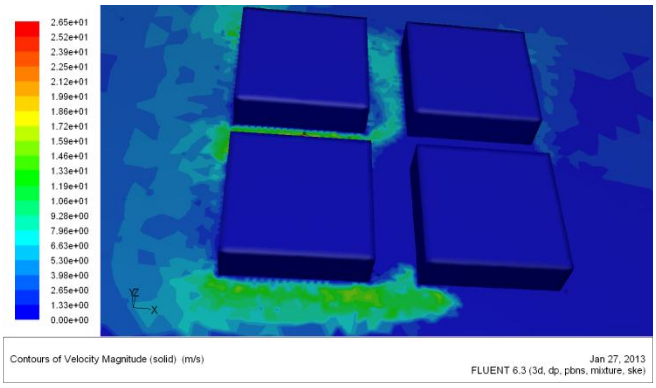

Figure 9: contours of Velocity field of two-phase flow for square shapes(2 main streets, ϴ=15°)

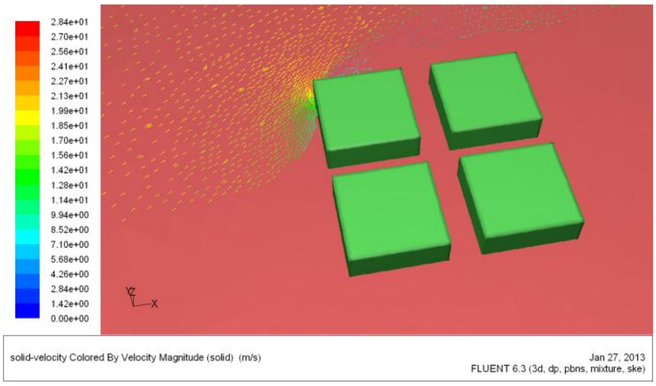

Figure 10: Velocity field of two-phase flow for square and shapes (two main streets, ϴ=30°)

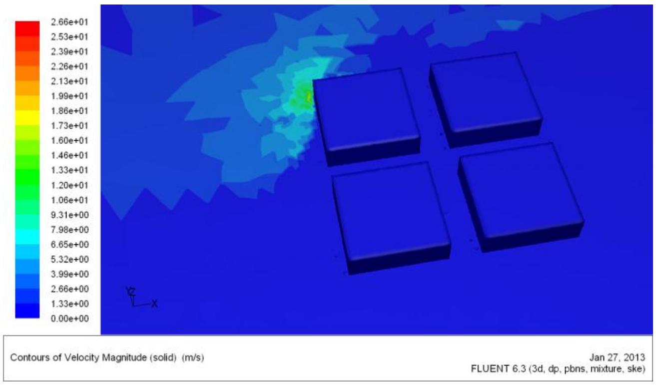

*Figure 11:*contours of Velocity field of two-phase flow for square shapes(2 main streets, ϴ=30°)

Similar to Figures 2 and 3, Figures 8 to11 shows the velocity field and the contours field of two-phase flow (Air-Pollutant) for both square and round shapes for different wind directions. The two-phase flow pattern for a wind angle of 15° (case Round) is similar to that of for a wind angle of 0°.

However, the two-phase flow enters the street through opening O1 and leaves through O2 for a wind angle of 15° (case Square). In both cases, for a wind angle of 30° (case Round and square) the velocity in recirculation region is absence (the effect of pollutant dispersion is not considerable).

4. Conclusions

The shape of the city and wind direction are a significant parameter of the urban form that affects the wind conditions and therefore pollution in some cities idealized models. It was found that the interaction between all forms of city and generates different wind flow around, above and behind the models of city form, and consequently a great influence on the airflow in the cavity the street.

The effect of wind direction on two-phase flow from a two city models (square and round) was studied and showed the effect of pollutant dispassion is not considerable in the both case city models for a wind angle of 30° and a small effect the case square with wind angle of 15°, unlike for the case of round for the same wind angle.

Perspective, the study can be improved by consideration of other factors such as wind speed and the effect of thermal stratification

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