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NUMERICAL INVESTIGATION OF CONTRIBUTION OF THREE FLOW CONDITIONERS IN THE DEVELOPMENT AND ESTABLISHMENT OF TURBULENT FLOWS

Boualem LARIBI
Industrial Fluids Laboratory,
Measurements and Applications
University of Khemis Miliana, Algeria
E-mail : boualemlaribi@yahoo.com

Pierre WAUTERS
Mechanical department
Louvain Catholic University
Belgium
pierre.wauters@uclouvain.be

Abdelkader YOUCEFI
Mechanical department
University of sciences and
technology of Oran. Algeria
Youcefi_a@yahoo.fr

ABSTRACT

This numerical study is a comparative study of the development and establishment of turbulent flows through three flow conditioners namely Laws perforated plate, the Etoile and the tube bundle. They are installed in a circular pipe with a disturbance generated by a 90° double bend out of plane which causes a very strong swirl of the fluid. The analysis is done with the code Fluent in which the Navier-Stokes equations describe a three-dimensional incompressible flow with the Reynolds stress model (RSM) as a closure system. This article focuses on the effectiveness of the three packers to produce the condition of fully developed velocity profile. The results are compared to references profiles cited in the literature and experimental results. The flow is simulated with air at Reynolds number of 10^5 in 100mm pipe diameter. The velocity profiles are compared with the profile obtained by the universal law of power $1/7^{th}$.

INTRODUCTION

Most industrial flowmeters are calibrated under conditions of fully developed pipe flow. This condition is very difficult to achieve in reality, given the presence of components of the system of pipes that are essential to its operation. Thus, the presence of singularities such that valve, elbow ... etc, are clearly a source of error in flow measurement [1]. To avoid such errors [2] technology flow straightener or flow conditioners [3,4] have grown steadily in recent years. Their main role in accelerating the formation of fully developed pipe flow, ie, obtaining a fully developed velocity profile [5,6] on a length of pipe as small as possible. In industrial practice, for reasons of space that do not have long distances in straight lines, and to minimize turbulence distortion of the flow is usually placed between the meter and disturbance a flow conditioner [1,5]. This element's mission is to accelerate the development of flow and to ensure the fully developed pipe flow over a shorter distance (between 20 and 30 pipe diameter). The aim of this paper is to perform numerical simulations of the development and establishment of flow with the presence of flow conditioners. The disturbance of the flow is ensured by a 90° double bend out of plane [6]. Many researchers see this as a standard perturbation which not only produces a very disturbed velocity profile, but also a disturbed turbulence intensity profile [7,8]. The numerical analysis is based on solving Navier-Stokes equations with constraints Reynolds model RSM [9] as a closure system. An analysis of the results obtained by the code Fluent v6.3 [10] has begun to analyze some flow parameters and their establishment.

NOMENCLATURE

D inner pipe diameter
k turbulent kinetic energy
Rey Reynolds number
t time
y radial coordinate
z axial coordinate
u mean velocity
U_{max} maximal velocity
ε dissipation rate of k
ω specific dissipation rate

EXPERIMENTAL SIMULATION

Conduit

Our facility includes a pipe diameter D equals 100mm, and length 10D followed by a 90° double bend out of plane followed in turn leads to a length of 40D [11].

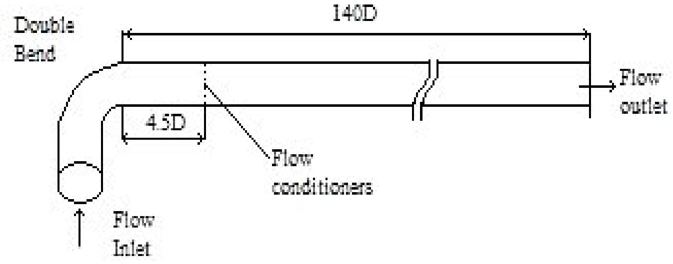

Figure 1. Conduit

The flow in the duct is ensured by air with a Reynolds number 10^5. The air leads from the entrance on the length 10D then it crosses the double bend to join again the pipe lengthwise 40D as shown in figure 1. The conditioners are placed in the axial station, 4.5D downstream of double bend.

Flow conditioners

The conditioners used in our study are the perforated plate Laws [12], the tube bundle [1], and the Etoile [1]. It is noted that the two last are described by the norm ISO5167. The description of the three conditioners is as follows:

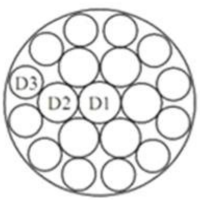

Figure 2. Perforated plate

The perforated plate has 19 holes: one has a central hole diameter D1 = 0.225D surrounded by 6 concentric holes diameter D2 = 0.213D and they are surrounded by 12 holes of diameter D3 = 0.177D. It has a thickness of 0.123D. Figure 2.

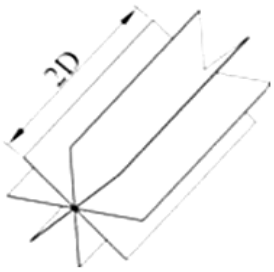

Figure 3. Etoile Straightener

The Etoile straightener is composed of four plates of thickness 0.01D arranged as in figure 3. Its length is 2D.

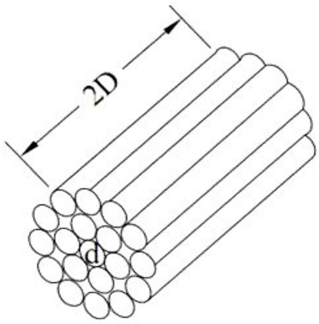

Figure 4. Tube bundle

The tube bundle consists of 19 tubes of same diameter d arranged as in figure 4. Its length is 2D.

TURBULENT MODELE IN FLUENT

Basic equations

The fluid is considered as incompressible, three dimensional and stationary. The average equations of continuity and momentum are given as follows:

The average continuity equation in tensor notation

$$\frac{\partial U_i}{\partial X_i} = 0 \qquad (1)$$

The averaged momentum equation in tensor notation

$$\frac{\partial}{\partial X_j}\left(\rho U_i U_j\right) = -\frac{\partial P}{\partial X_i} + \frac{\partial}{\partial X_j}\left(\mu\left(\frac{\partial U_i}{\partial X_j} + \frac{\partial U_j}{\partial X_i}\right) - \rho\,\overline{u_i u_j}\right) \qquad (2)$$

The terms $\left(-\overline{u_i u_j}\right)$ of correlation turbulent or Reynolds stresses represent the transport of momentum fluctuating must be modeled.

The Reynolds stress model (RSM) [10]

Let ϕ a general dependent variant (velocity ...etc). The conservation equations can be put in the following generalized form called transport equation of the property ϕ:

$$\frac{\partial(\rho\phi)}{\partial t} + div\left(\rho\phi\vec{U}\right) = div\left(\Gamma.grad\ \phi\right) + S \qquad (3)$$

In this model, each term of the six turbulent correlations is resolved by the transport equation 3. We obtain six equations with six unknown variables to solve. A discritisation of equation 3 by the method of finite volumes provide a system of algebraic equations to solve. The solution will be obtained for all unknown flow parameters. A succinct description is presented in the bibliography Fluent code [10].

Reference data examined

In this section, the parameter considered is the velocity profile. The stations considered are 0.8D, 5D, 9D and 40D downstream of the double bend. The velocity profiles of U/Umax are compared to the profile obtained by the universal power law with ±5% tolerance as recommended by ISO 5167 [1]. It is done by the following equation [13,14]:

$$\frac{U_i}{U_{\max}} = \left(1 \pm 2\frac{y_i}{D}\right)^{1/7} \qquad (3)$$

RESULTS AND DISCUSSION

Etoile velocity profiles

Figure 5 shows the development of velocity profile U/Umax for four axial stations, 0.8D, 5D, 9D and 40D downstream of the double bend.

At station 0.8D, velocity profile is disturbed and that is outside the range of the theoretical profile set by ISO 5167. It shows a maximum values of radial values of y/D between

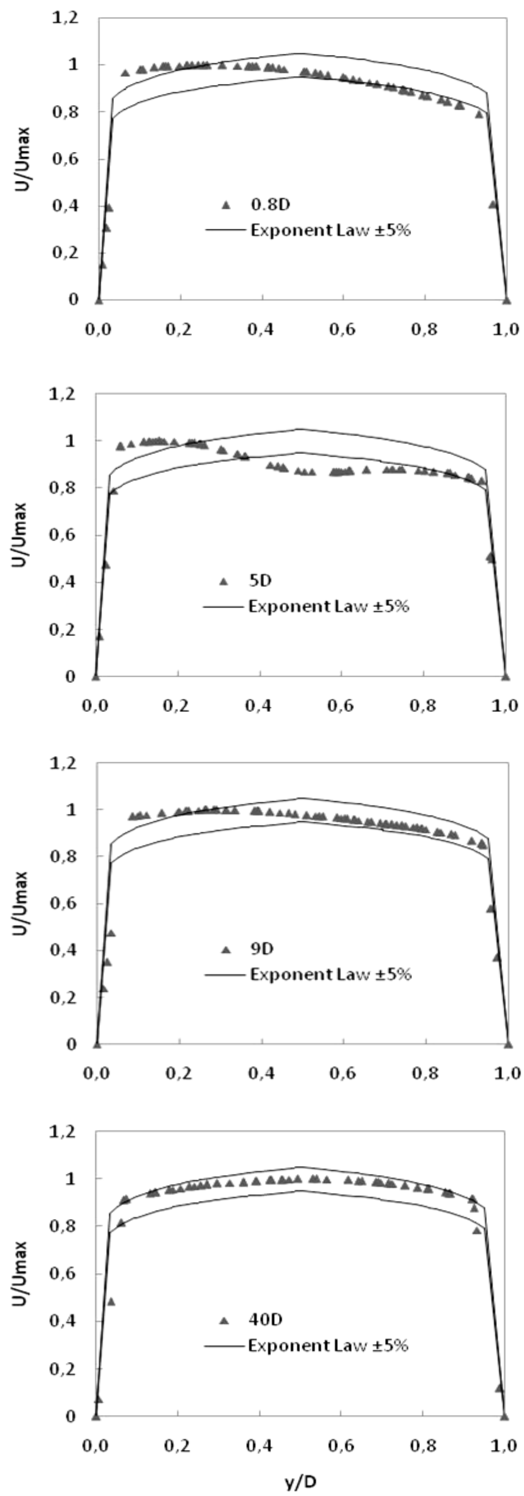

Figure 5. Etoile velocity profiles

0 and 0.4, and minimum values for the values of y/D > 0.4. These results are in good agreement with experimental results obtained by LARIBI. A station 5D downstream of the double bend, 0.5D downstream the Etoile, the flow seems to be hindered in the center of the pipe. This is mainly due to the design of Etoile in its central part where the plates are welded. These results are also in good agreement with experimental results obtained by Laws and al [5].

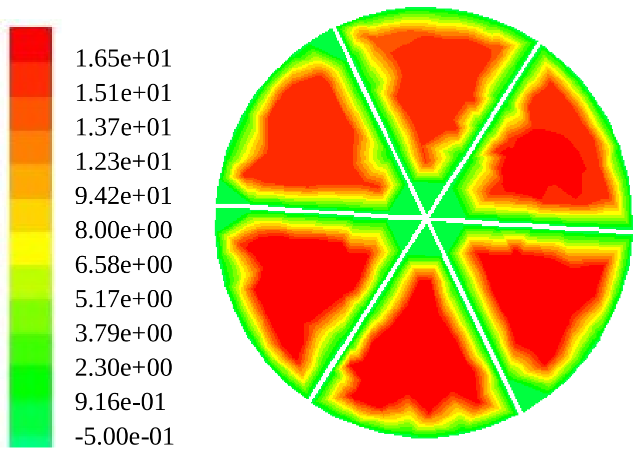

Figure 6. Etoile contour velocity

At the station 9D, the velocity profile begins to adjust to the profile given by the power law ±5% to be fully enveloped by the station 40D latter. In fact examination of intermediate stations which are not presented in the text showed that the profile begins to adjust the theoretical profile from the station 22D. Figure 6 shows the contour velocity at station 5D and we can see the deficit of the flow in center line of the pipe in the intersection of the plates and approach walls.

Tube bundle velocity profile

Figure 7 shows the development of velocity profile U/Umax for the same axial stations as the Etoile before.

A station 0.8D, the velocity profile was the same finding as the Etoile regarding disturbed profile. It shows a maximum values of radial values of y/D between 0 and 0.4, and minimum values for the values of y/D > 0.4. At station z/D=5 the profile appears sinuous with several maxima and minima. This is due to the design of tube bundle with concentric tubes arrangement.

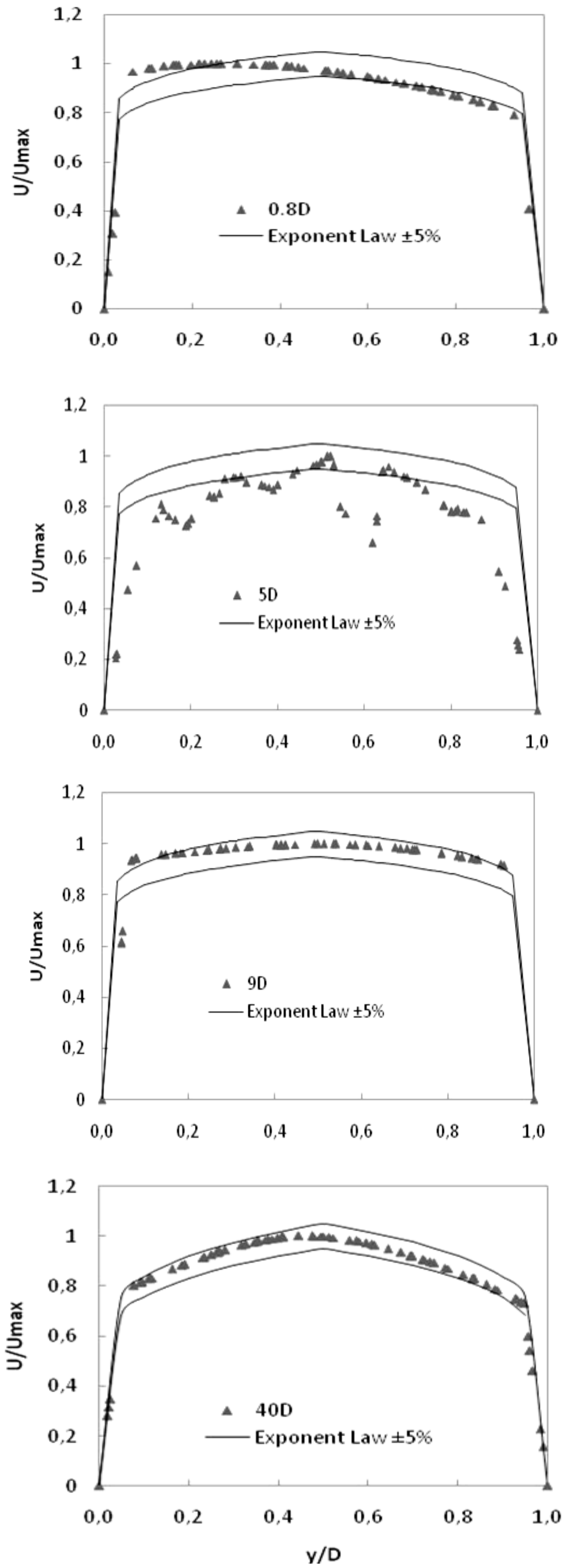

Figure 7. Tube bundle velocity profiles

At the station 9D, the velocity profile begins to adjust to the profile given by the power law ±5%. The velocity profiles same to reach the fully developed velocity profile at the station 40D. In fact, examination of intermediate stations which are not presented in the text showed that the profile begins to adjust the theoretical profile from station 22D like the Etoile velocity profile. Figure 8 shows the contour of the velocity at station 5D and it is clear that the jets flow through the holes, 0.5D downstream the tube bundle, present maximum velocity.

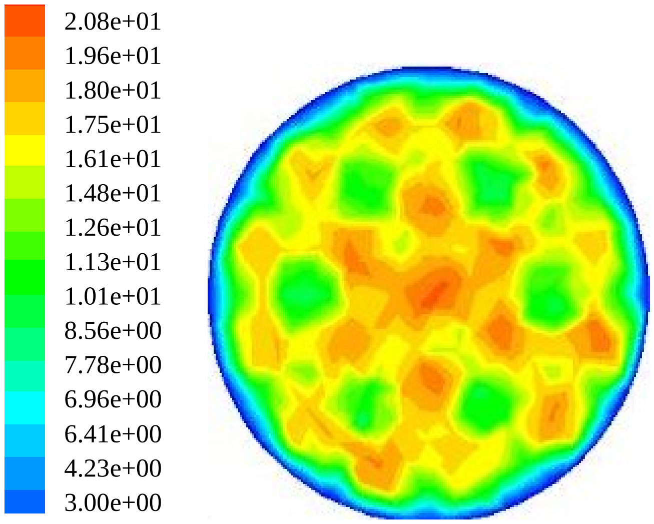

Figure 8. Tube Bundle contour velocity

Perforated plate velocity profiles

Figure 9 shows the development profiles of U/Umax for the same axial stations as before. At station 0.8D, it was the same finding as the Etoile and the tube bundle regarding the velocity profile distribution. At station 5D downstream of the double bend, just outside of the perforated plate, flow seems winding with several maxima and minima that represent jets and braking zones of flow. This is mainly due to the design of the perforated plate with the distribution of the holes. A 9D station downstream of the double bend, the velocity profile seems to fit the profile given by the power law ±5% and completely enveloped by it. A good stability of the velocity profile is stored until the station 40D. Figure 10 shows the contour of the station velocities for 5D and we can see the jets that arise out of the plate very safe with maximum velocity.

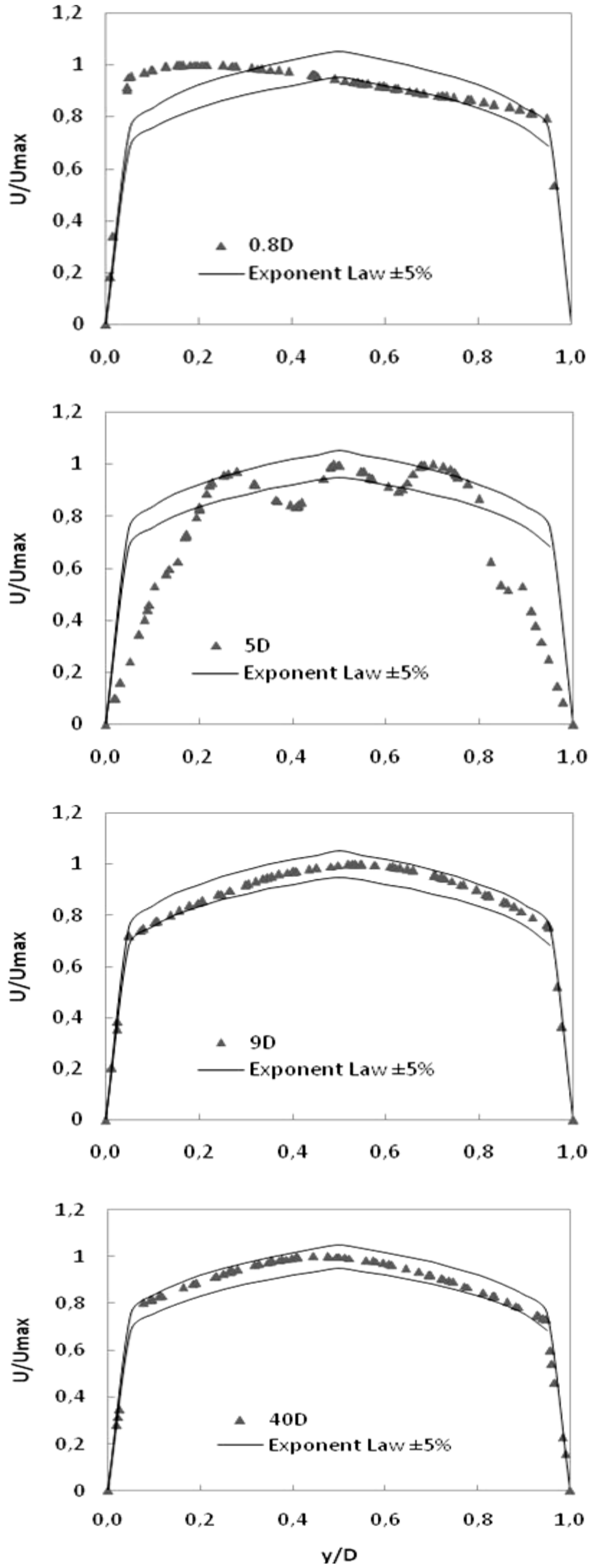

Figure 9. Perforated plate velocity profiles

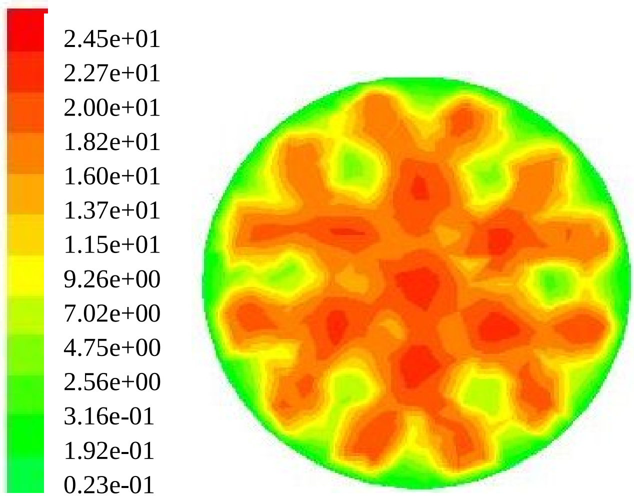

Figure 10. Perforated plate contour velocity

CONCLUSION

In this numerical study we can see the efficiency of flow conditioners in the development and establishment of turbulent flows in conduits. It seems that the perforated plate present the best performances for a fully developed velocity profile over a length as small as possible in our case at 9D downstream of the double bend. This result is in good agreement with those obtained by Laws and al [12]. Many researchers have found that this profile can be disturbed if turbulent intensity profile is not fully developed [7]. It remarkable to see the efficiency of the Fluent v6.3 code in the simulation of flow through the flow conditioners. This will lead to future work to examine the other flow parameters such as turbulence intensity and the swirl of the fluid. We could then proceed to the analysis of discharge coefficient for accurate flow measurement.

ACKNOWLEDGEMENTS

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