Effectiveness of Perforated Plate in the Development and Establishment of Turbulent Flow for Better Metrological Performances

B. Laribi and M. Mehdi

***Abstract*—This article presents the results of a numerical experimentation on the perforated plate flow conditioner with two disturbances namely a 90° double bend in perpendicular planes and a valve 50% closed. The simulation is done with air as fluid in 100 mm pipe diameter with different Reynolds numbers 10^4, 10^5 and 10^6. The code used was fluent v6.3, where the Navier-Stokes equations are solved by the finite volume method with k-ε like a turbulent model. Validation of numerical predictions for the velocity profiles, turbulence intensity and the gyration angle of the fluid is made according to ISO 5167. The results obtained show the effectiveness of the perforated plate in the development and the establishment of the turbulent flows towards the fully developed pipe flow wish is a necessary condition for flow measurement accuracy. We also note, from the results, that the flow needs more 30D of distance to reach better metrological performances.**

***Index Terms*—Turbulence, CFD, navier-stokes, k-ε, flow meter, flow conditioner.**

I. Introduction

The flowmeters are usually calibrated in fully developed pipe flow [1]. This requires a length of pipe over 100 pipe diameters of the upstream of the flowmeter. In most industrial installations, the long distance can't be met given the presence of elements necessary for the operation and control of the flow such as valves, elbows, expander, reducer etc. The presence of these elements creates serious disturbances in the flow field, which is clearly a source of error in flow measurement [2]. In industrial practice to reduce the length required for the development and establishment of flow, a rectifier device or flow conditioner is placed generally between the flowmeter and the disturber. This element's role is to accelerate the development of the flow and ensure the establishment of a distance generally between 20 and 30 pipe diameters. Different flow conditioners are described and recommended by ISO 5167 [2] and ASME 2530 [3]. The flow conditioner type perforated plate was developed and tested under different flow conditions. The most important flow conditioners works are the Laws conditioner [4], Ghallagher [5] …etc. These flow conditioners are characterized by their porosity graded, ie a graduated arrangement of hole diameters, compared to the diameter of the pipe.

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II. Turbulence Model

Almost simulations throughout the world in turbulence are based on (1) called transport equation. The code CFD Fluent adopts also this equation which is given by [6]

$$\frac{\partial(\rho\varphi)}{\partial t} + div\left(\rho\varphi\vec{U}\right) = div\left(\Gamma_{\varphi}.grad\varphi\right) + S_{\varphi} \quad (1)$$

where ϕ is the general dependent variable which can be the mean velocity U (m/s), the turbulent kinetic energy k (kg.m^2/s^2) ,or the rate of kinetic energy dissipation ε (m^2/s^3).

S_ϕ is the term source of the variable ϕ.

t is the time.

ρ is the density of fluid (kg/m^3).

Γ_ϕ is the coefficient of diffusion of variable ϕ.

The code Fluent presents several models of turbulence, and for the lightening of the text we will not reproduce the equations in this article. The reader can consult literature of code Fluent for more details in [6], [7].

III. Flow Conditioner And Experimental Facility

The geometry and dimensions of flow conditioner studied are shown in (1) [4]. The perforated plate has 19 holes and a central hole of diameter $d1$=0.225D surrounded by six holes of diameter $d2$=0.213D and the latter in their turn are surrounded by 12 holes of diameter $d3$=0.177D. The plate thickness is 0.123D. The perforated plate is placed at a distance of 4.5D downstream of the disturbance. D is the diameter of the pipe. The totale length of the conduit is 44.5D.

Our installation [8], in (2), consists of an inlet pipe length 10D, followed by disturbances a double bend (3), or a valve (4). The perforated plate flow conditioner is 4.5D downstream of the disturbance.

There is 30D downstream of the conditioner. The inner pipe diameter is 100 mm.

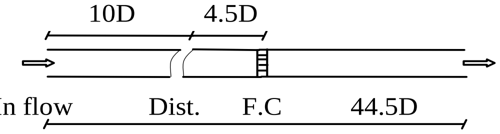

Fig. 1. Conduit

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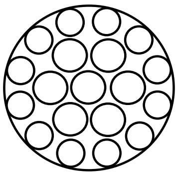

Fig. 2. Perforated plate

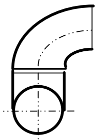

Fig. 3. Double bend

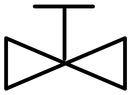

Fig. 4. Valve

IV. RESULTS AND DISCUSSION

A. Reference Velocity Profile

To validate the numerical predictions obtained, the profiles of velocity *U/Umax* are compared with ±5% of established profiles obtained for each Reynolds number at station 100D downstream the flow conditioner where the flow is fully developed as suggested by the standards ISO5167[2], [3].

B. Reference Turbulence Intensity Profile

The profiles of turbulence intensity *I(%)* are compared with established profiles obtained for each Reynolds number at 100D downstream of the conditioner where the flow is fully developed (ISO 5167). These profiles are determined by the following equation [8].

$$I(\%) = \frac{\sqrt{\frac{2}{3}k}}{U_{avg}} \tag{2}$$

where U_{avg} is the average velocity in the section of pipe.

C. Reference Swirl Angle

The The swirl angle A(°) is obtained from the ratio of the two components of the velocity field *U* and *V* with a tolerance of ±2 °as recommended by the ISO 5167. It is represented by the following equation [8]

$$A(°) = arctg\left(\frac{V}{U}\right) \tag{3}$$

where U_{avg} is the average velocity in the section of pipe.

D. Development of the Parameters of the Flow with Valve 50% Closed

Fig. 5 shows the development of the flow in the presence of the valve 50% closed and for values of the Reynolds numbers of 10^4, 10^5 and 10^6. The results show the variation of the three parameters studied at four stations, a first station is *Z/D* =0 (out of the disturbance).

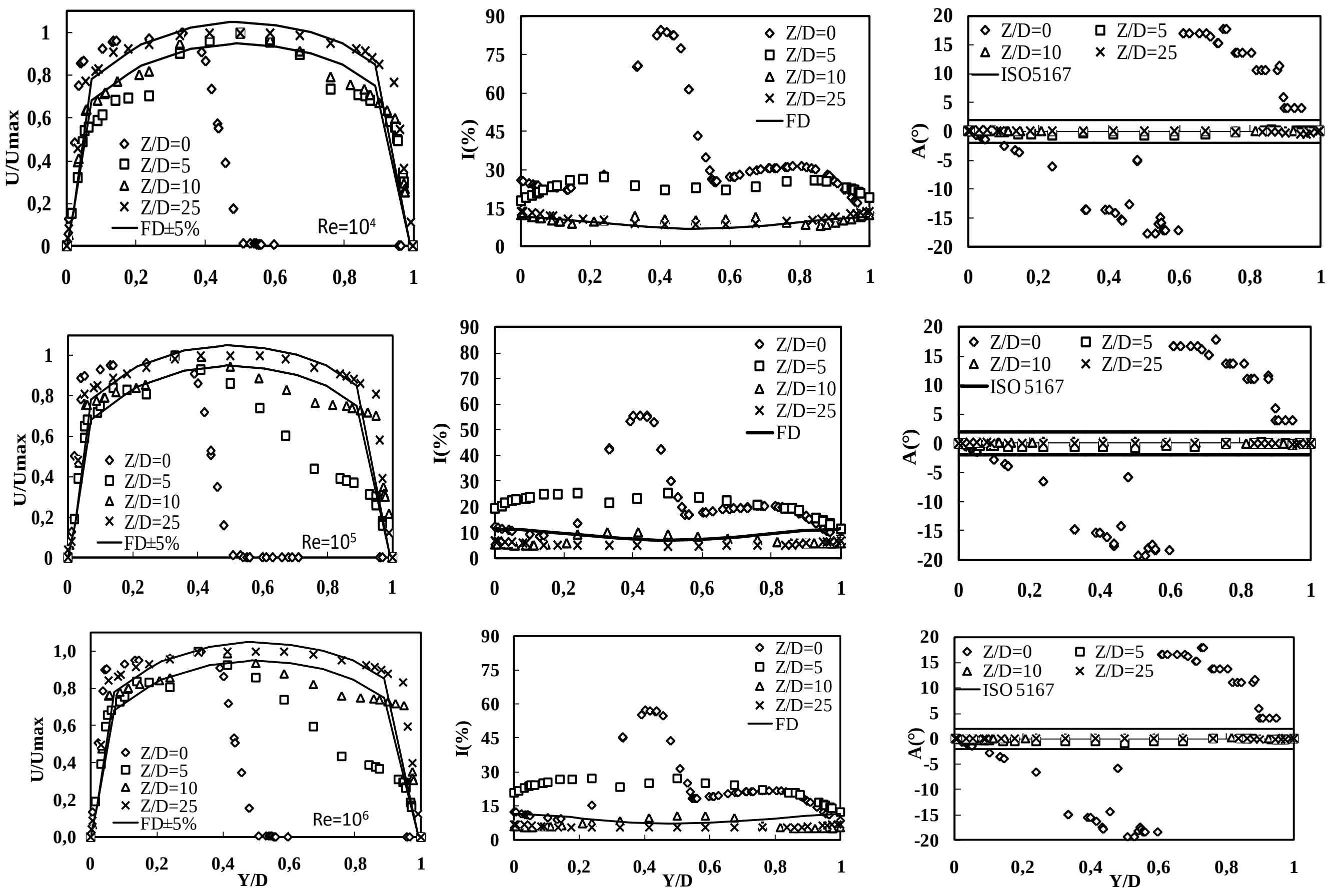

Fig. 5. Distribution of axial velocity U/Umax, turbulence intensity I(%) and swirl angle A(°) with the valve 50% closed for three different Reynolds numbers.

The other three stations are respectively *Z/D*=5, *Z/D* =10 and *Z/D* =25 downstream of the disturber (*Z* is the axial distance). From (5), at station *Z/D* =0, we see that the valve 50% closed because a strong disturbance for the three parameters and away from recommendations of ISO 5167 which is obviously unfavorable conditions for the flow measurement accuracy [2]. At station *Z/D* =25, we see the effectiveness of the perforated plate to reduce the disturbance around the standard value. The velocity profile begins to reach the fully developed pipe profile FD±5% regardless of the Reynolds number. The same remark is recorded for the profile of turbulence intensity. Indeed, after a strong disturbance at the exit of the valve (Z/D =0) with a value depending on the Reynolds number, progressive attenuation of this disturbance is very remarkable for downstream stations. For the angle of gyration there is a high performance of the perforated plate to reduce its value at ±2°, as recommended by the standard ISO 5187.

A. Development of the Parameters of the Flow with 90° Double Bend

Fig. 6 shows the development of the flow in the presence of double bend for values of the Reynolds numbers of 10^4, 10^5 and 10^6 .The results show the variation of the three parameters studied at four stations identically with the valve.

Contrary to the valve, at station Z/D =25, velocity profiles, and at some Reynolds number, did not yet join the fully developed pipe flow FD±5% profile and present a relatively flat profile. It is also noted that the level of turbulence is relatively low of an average value of 10%, whereas for the valve we had an average value of 70%. For the angle of gyration, at Z/D =0, a maximum value of -9° presents whereas for the valve we had ±20°. It is interesting to note that more the Reynolds number is significant more the deviation of the angle of gyration is significant.

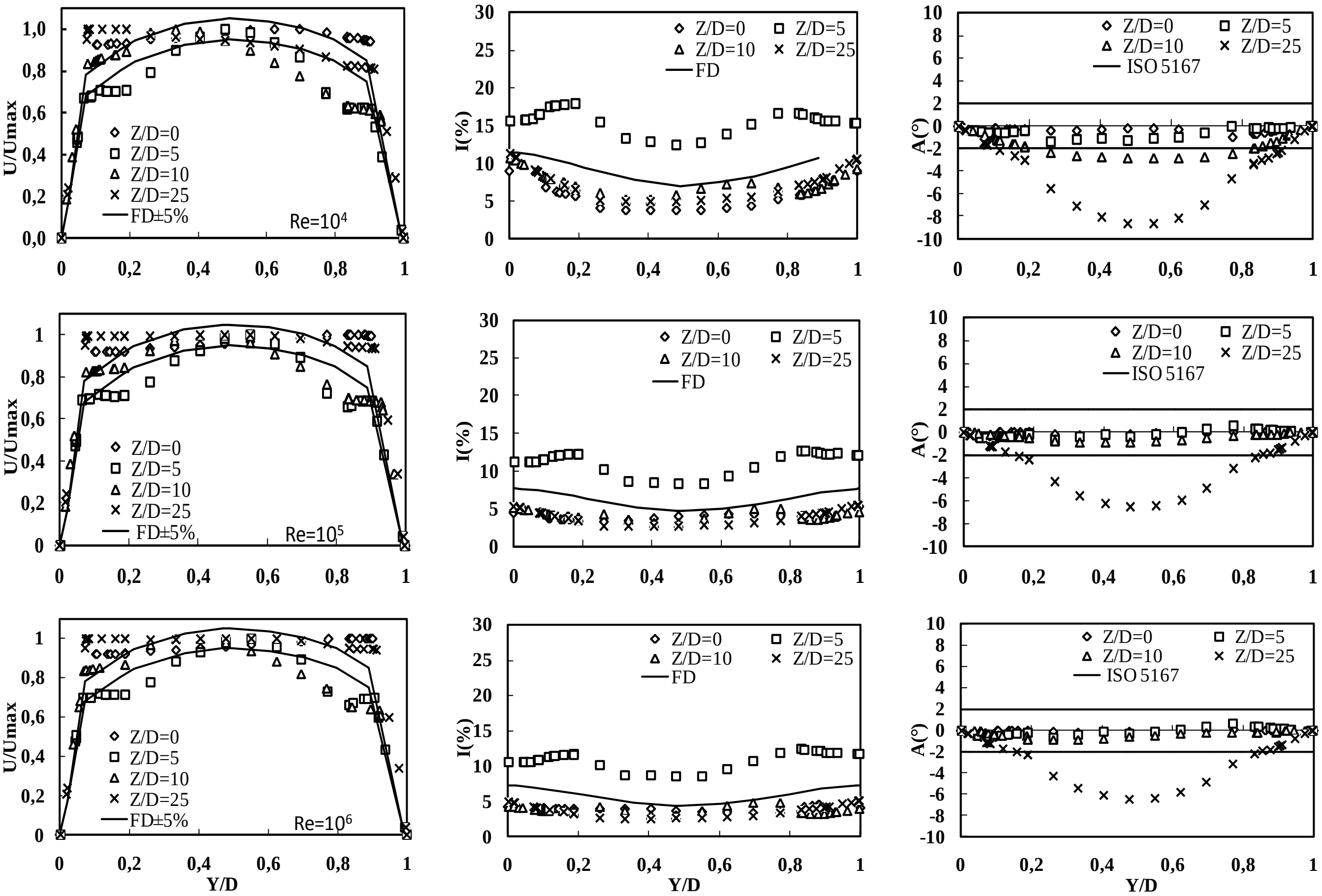

Fig. 6. Distribution of axial velocity, the intensity of turbulence and swirl angle with 90° double bend for three different Reynolds numbers.

I. Conclusion

The purpose of this study was to examine the effect of a closed valve with 50% and the 90° double bend in plans perpendicular to the development and the establishment of turbulent flow and the effectiveness of the perforated plate flow conditioner in the production of the established flow which is a necessary condition for flow measurement accuracy as stipulated by the ISO 5167. Our simulation is led with the fluent code. The studied parameters are the velocity profile, the intensity of turbulence and the swirl angle of the fluid. The results obtained show that the perforated plate could be the subject of a good flow conditioner. Indeed the elimination of swirls of the plate is remarkable. We note also a very good performance of the perforated plate with respect to the turbulence intensity. We note that if the Reynolds number increases, the turbulence intensity decreases. This shows how much the turbulent mixing is important to reach the fully developed pipe flow for better metrological performances.

In all cases, it would be necessary to re-examine these disturbances in an experimental study in order to validate a standard disturbance to take into account for the design of the conditioners of flow.

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Mr Mokrane was a student and He lift the University this year.Biographies with photo of Dr Laribi.

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