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EXPERIMENTAL STUDY OF AERODYNAMIC BEHAVIOR DOWNSTREAM OF THREE FLOW CONDITIONERS

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ABSTRACT

The present work is concerned a comparative study of the decay of swirling turbulent pipe flow downstream of three flow conditioners, the Etoile, the Tube bundle, and the Laws perforate plate, and its effect on accuracy of orifice plate flow meter. The swirl was generated by a double 90° degrees elbows in perpendicular planes. The discharge coefficients were measured with 3 different orifice meters with β =0.5, 0.62, 0.70 at different Reynolds number.

As a conclusion, the experimental study of the three flow conditioners used separately shows that the flow need longer distance for close to fully developed pipe flow and some errors, by reason of the swirl, on the discharge coefficient were inevitable for distance less 12D.

INTRODUCTION

Orifice plates have been used for flow measurement for many years for process and fiscal proposes. The ability to accurately measure the flow rate of gas in a conduit is of major concern and vital importance where large volumes are handled. The Algerian petroleum company recorded receipts of 56 x 10^9 m^3 of gas. The quality of gas measurement receipt and major delivery points disturbed through 13000 km on pipeline is very important. .Errors in flow measurement can have large cost and efficiency implications in such a case.

The majority of the meters must be calibrated. This is done in fully developed pipe flow, axisymmetric pipe, that is free from swirl and pulsation. Standards such as ISO5167 [1] and ASME [2] define a satisfactory flow as one which has a swirl angle of less than 2 degrees, and the ratio of the axial velocity to the maximum axial velocity on that cross-section is within 5% of the corresponding ratio in fully developed flow measured in the same pipe after 100 pipe diameter of development length. While high accuracy about 0.3% mass flow measurement are required, disturbances in the flow caused by contractions, bends, and other component introduce errors of accuracy to 3% [3].

Given that most industrial installations include bends, valves, expanders and reducers, which are sources of both swirl, asymmetries and turbulence distortions, insuring that fully developed flow in terms of mean flow and turbulence structure approaches the meter is difficult to achieve in practical situations.

For best accuracy, a flow meter needs to be presented with an axisymmetric, fully developed velocity profile with zero swirl. Either very long lengths of straight pipe work upstream of the meter must be provided (recommended by ISO 5167 [1]) and these may need to be of the order of 80 to 100 pipe diameter, which will give a higher installation cost and greater space requirement. Alternatively, upstream disturbances can be attenuated by using flow straightener and/or flow conditioner to control the quality of the flow approaching the metering device.

A fundamental understanding of the approaching velocity profiles and their effects on the discharge coefficient of a metering device is essential knowledge for the rational design of a flow conditioners-meter package that minimises installation effects.

Research work in the USA (Morrison, et al. [4]; Morrow and Park [5]), in the U.K (Reader-Harris and Keegans [6]; Ouazzane [7]; Ouazzane and Laws [8, 9]), in France (Gajan and Hebrard [10]), in Algeria (Aichouni and Laribi [11, 12]) has reported a number of experimental and computational studies of installation effects on orifice meter performance. Most of these studies investigated the effect on the discharge coefficient of flow conditioner location with respect the orifice meter. It was found when the mean velocity profile upstream of the orifice had a deficit on the centre line and higher velocities at the outer edges of the pipe. the pressure drop across the orifice was greater than fully developed flow.

In a recent study, Ouazzane and Barigou [13] conducted an investigation into the effects of two flow conditioners on the performance of orifice plate flow-meter. The first flow conditioner is the Vaned-plate flow conditioner, the second is the NEL-plate flow conditioner. Experiments were conducted to determine the relative change in the orifice meter (with the two flow conditioners) discharge when subject to non standard approaching flow conditions. Three different velocity profiles were generated by different valve settings based on flow area (fully open, 50% closed, 70% closed) upstream of the orifice plate. Three orifice plates were examined on the orifice-pipe diameter ratio β = 0.5, 0.6, 0.7 over a range of Reynolds number from 0.33 x 10^5 to 2.5 x 10^5. Their conclusion has shown that the distortion in the approaching flow caused by pipe fittings upstream of the orifice meter can cause significant shifts in the meter's calibration, hence leading to considerable errors in flow-metering.

In this paper, the effect of entrance flow velocity profile, generated by a 90° out of plane double-bend. In many investigations on installation effects, the double bend is taken as a standard disturbance, which is known to produce an asymmetry of the velocity profile and swirl (Fielder [14], Merzkirch [15]). Three flow conditioners were compared: the 19 tube bundle flow straightener, the Etoile flow straightener, and the Laws perforate plate.

NOMENCLATURE

ΔP : pressure variation at different location z/D
ΔP_o : pressure variation at z/D=97
ΔCD : discharge coefficient error
D : inner diameter of the pipe
Z :axial distance
β : beta ratio
Rey : Reynolds number

EXPERIMENTAL FACILITY AND PROCEDURE

Air Flow Rig

The basic experimental facility is presented in figure 1. It consists of a long Plexiglas pipe with 100 mm inner diameter. The flow was powered by a motor driving a centrifugal fan. The air flow rate was controlled by the motor for different difference of potential.

The air enters the pipe through a nozzle then flows through a straight pipe of 11D length, which is followed by the disturbance, the 90° double-bend out of plane. At station 4.5D downstream of the bend is the position of 19 tube bundle, the Etoile, and the Laws perforated plate.

The first orifice meter, was installed at 97D downstream of the flow disturbance, where the flow is fully developed. A second orifice meter, the same as of the first, was installed at 1.5D downstream the two double bend and at different location downstream the flow conditioners. The two orifice plates were of standard geometry and had pressure tapings one D upstream and D/2 downstream, where D is the inner pipe diameter. The static pressure was measured by four pressure tapings connected together to give the pressure upstream and downstream of orifice meter. The opening diameters d of the orifices used are 50, 62 and 70 mm, so the ratios of the opening diameter to the pipe diameter, d/D, are β=0.5, 0.62 and 0.70.

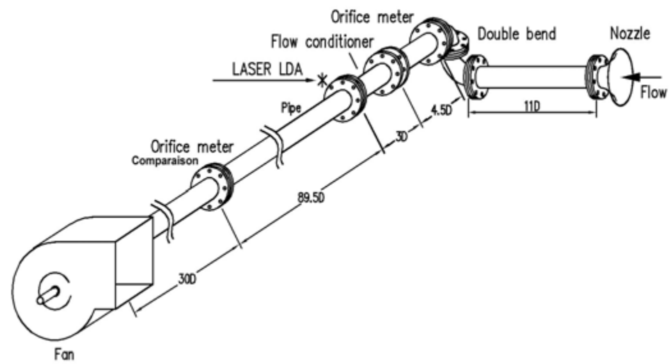

Figure 1. Experimental facility

Flow conditioners

The geometry and dimensions of three conditioners investigated in the present study are shown in figure 2 (a, b, c). The Laws plate shown in figure 2-a, is a perforated plate with specific arrangement of the circular holes. The holes are arranged so that a central hole of diameter d1=0.224D is surrounding by an inner ring of 6 holes having equal diameter d2=0.213D, and an outer ring of 12 holes of equal diameter d3=0.177D. The values for the ratio of open area to total cross-section is 0.70, and the pressure loss coefficient defined $\xi=\Delta p/0.5\rho u^2_m$, is reported 0,9.

The Etoile, figure 2-b, was described by the ISO 5167. It consists of eight radial vanes at equal angular with 2D of length and the pressure loss coefficient is approximately 0,25.

The 19 tube bundle, is a standard straightener described by the ISO 5167. It consist of 19 tubes with 2D of length and is arranged in a cylindrical pattern as shown in figure 2-c. The pressure loss coefficient is approximately 0,75.

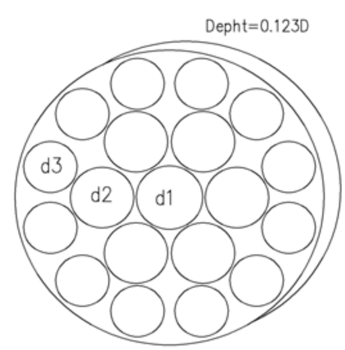

Figure 2-a. Laws Perforated Plate

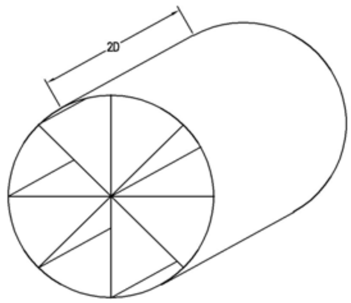

Figure 2-b. Etoile straightener

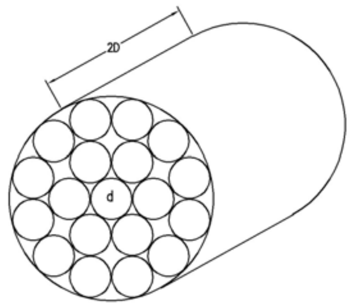

Figure 2-c. Tube bundle straightener

Variation of the Discharge Coefficient

In testing the effects of the 90° double-bend on the discharge coefficients of the orifices, the quantities *(Cdo-Cd)/Cdo* are calculated as fellows, by measuring the pressure difference Δp at different position in the of the pipe and Δpo at the comparison one at the same time at z/D=97 were the flow is fully developed.

$$\Delta Cd(\%) = \sqrt{\frac{\Delta Po}{\Delta P}} - 1 \qquad (1)$$

In all cases, the distance between the two orifices meter was not less 77D.

This formula was applied for the three orifice plates at different Reynolds numbers, with the three flow devices. The test sections were 1.5 D, 6D, 7.5D, 12D, 13.5D and 17.5D downstream the double bend and.

RESULTS AND DISCUSSION

Effects of Upstream Flow conditions on Orifice Meter Performance without flow conditioners

Experiments were conducted to determine the relative change in the orifice meter discharge coefficient when subjected to non-standard approaching flow conditions as the two bends in perpendicular plane. The test sections were 1.5 D, 6D, 7.5D, 12D, 13.5D and 17.5D downstream the double bends. The effect of the double bends on the orifice meter with a β=0.70 over a wide range of Reynolds numbers from 0.79x10^5 to 3.21x10^5 is shown in figure 3. The absolute value of the errors ΔCd was from 2.74% at station z/d=1.5 to 0.69% at station z/d=17.5 downstream the double bends, and every value of ΔCd approaches zero with increasing z/d. It's clearly that the flow need more than 17.5D to be fully developed and if we would like to have a error less than 0.5% as request by the ISO.

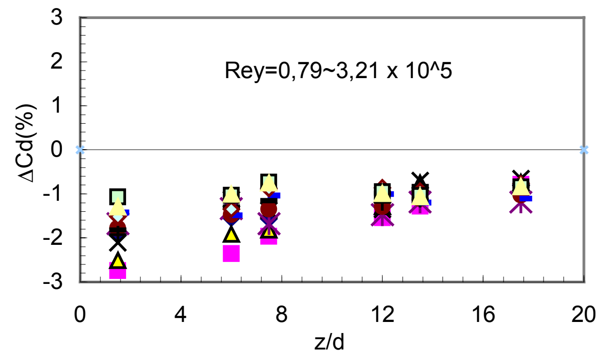

Figure 3. Discharge coefficient error downstream the double bend without flow conditioners in line, β=0,7.

Performance of the three flow conditioners with β=0.70

The figures 4, 5 and 6 show the discharge coefficient errors downstream the double bends with three flow conditioners used separately with β=0,7 at Reynolds number = 0.79 ~3.21 x 10^5. We can see in figure 5 the efficiency of the Etoile to reduce the discharge coefficient errors from 2% at station z/D=1.5 to 0.2% at station z/D=7.5. For the tube bundle, this error is obtained over 17.5D as we shown in figure 6. For the perforated plate figure 4, the discharge coefficient errors change from 2% at station z/D=1.5 and to be constant and equal to 0.5 over z/D=7.5.

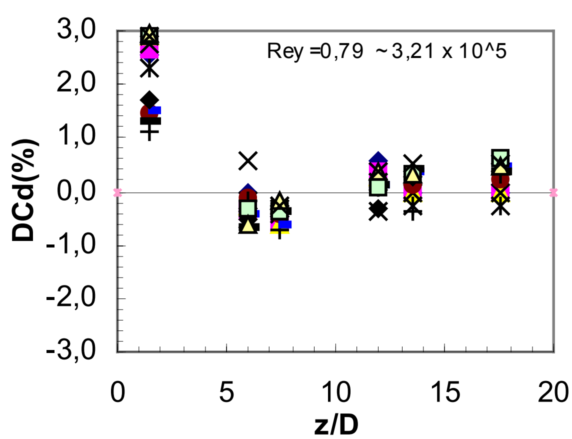

Figure 4. Discharge coefficient error downstream double bend with perforated plate flow conditioner, β=0.70.

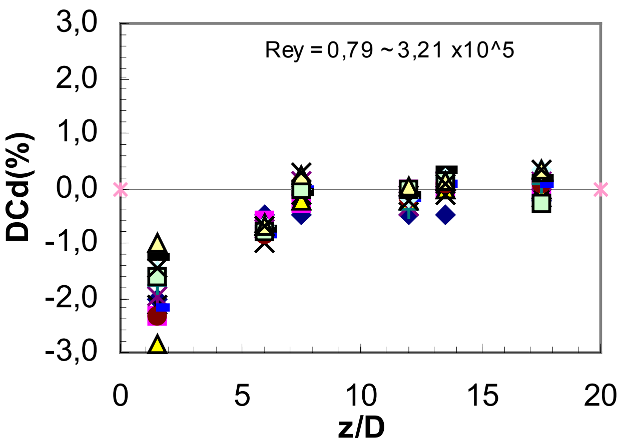

Figure 5. Discharge coefficient error downstream double bend with Etoile flow conditioner, β=0.70.

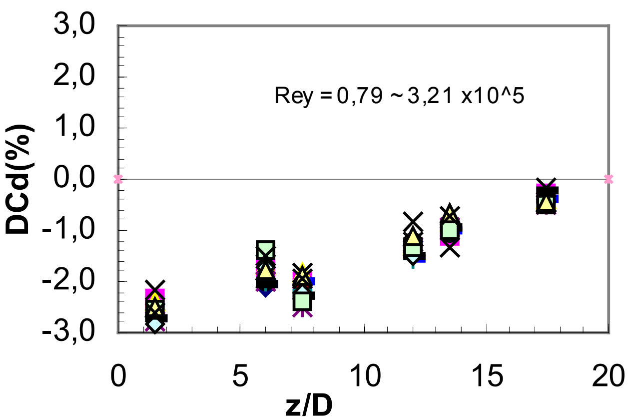

Figure 6. Discharge coefficient error downstream double bend with tube bundle flow conditioner, β=0.70.

<u>Performance of the three flow conditioners with β=0.62</u>

The figure 7 shows the efficiency of the perforated plate to reduce the discharge coefficient errors from 2,7% at station z/D=1.5 to 0.5% at station z/D=12. For the Etoile, this error is obtained over 13.5D as we show in figure 8. For the tube bundle figure 9 the discharge coefficient errors change from -2% at station z/D=1.5 and to be constant and equal to 0.3 over z/D=13.5.

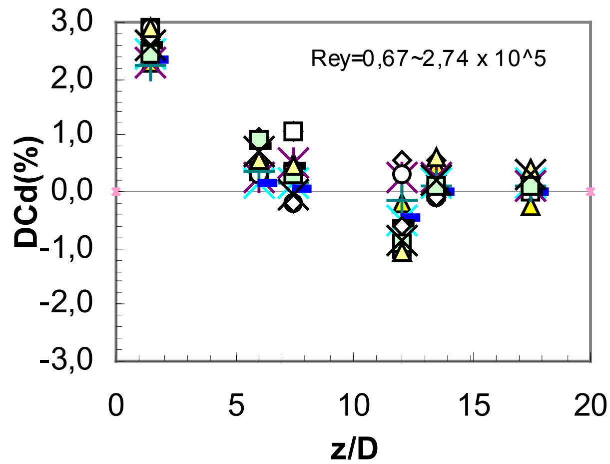

Figure 7. Discharge coefficient error downstream double bend with perforated plate flow conditioner, β=0.62.

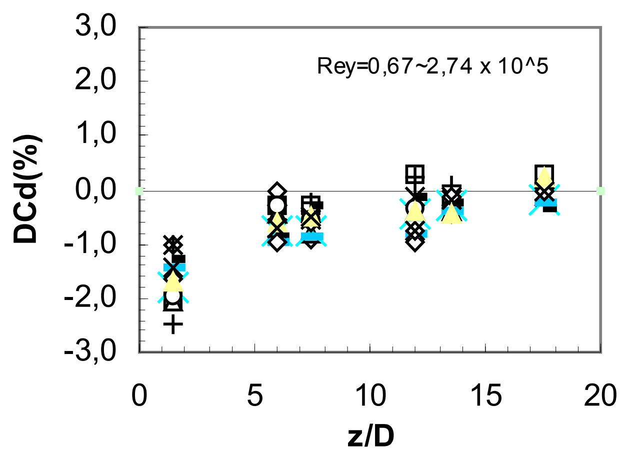

Figure 8. Discharge coefficient error downstream double bend with Etoile flow conditioner, β=0.62.

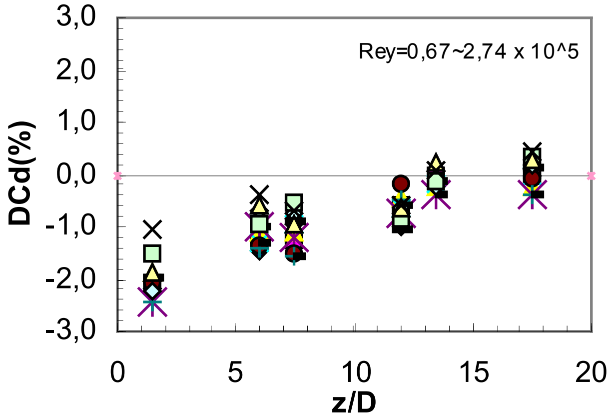

Figure 9. Discharge coefficient error downstream double bend with tube bundle flow conditioner, β=0.62.

Performance of the three flow conditioners with β=0.50

We can see in figure 10 the efficiency of the perforated plate to reduce the discharge coefficient errors from 2,5% at station z/D=1.5 to 0.5% at station z/D=12. For the Etoile, this error is obtained at station 7.5D as we shown in figure 11. For the tube bundle figure 12 the discharge coefficient errors change from -2% at station z/D=1.5 and to be constant and equal to 0.3 over z/D=13.5.

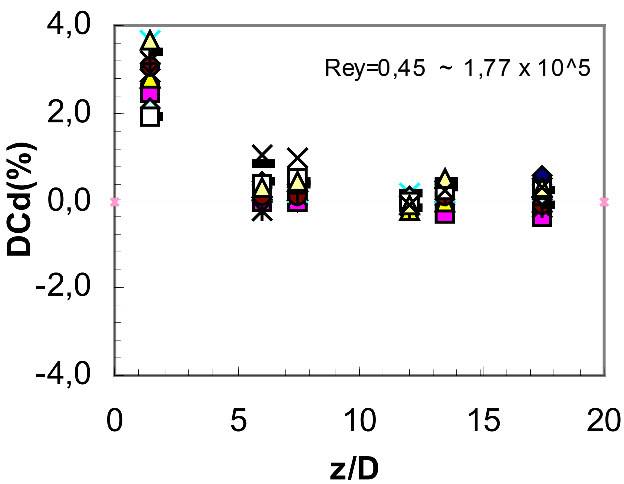

Figure 10. Discharge coefficient error downstream double bend with perforated plate flow conditioner, β=0.50.

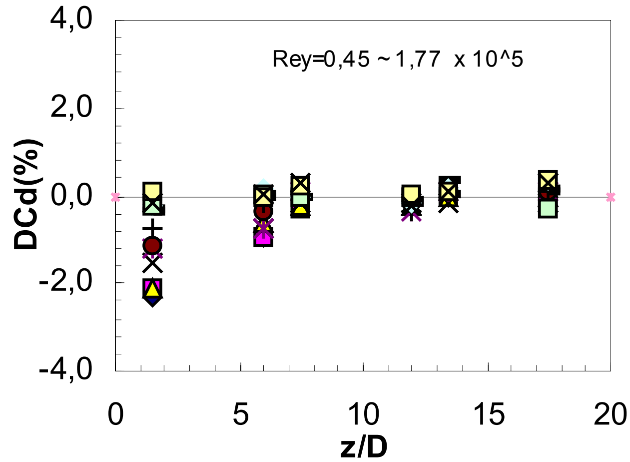

Figure 11. Discharge coefficient error downstream double bend with Etoile flow conditioner, β=0.50.

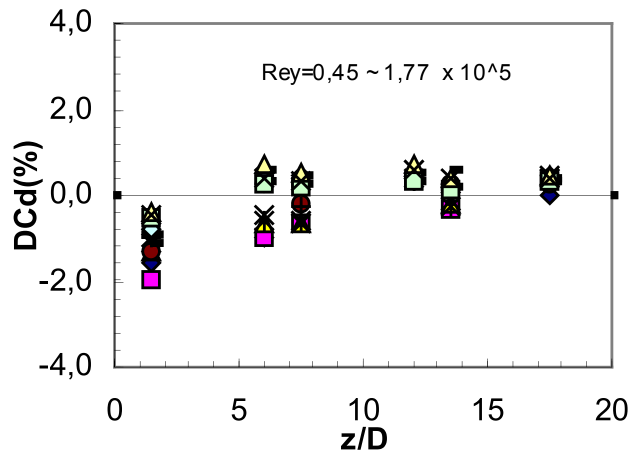

Figure 12. Discharge coefficient error downstream double bend with tube bundle flow conditioner, β=0.50.

The result of the shift of discharge coefficient error for different value of β with the three flow conditioners at station z/D=7.5 (3D downstream the double bend is shown in table 1.

	Discharge coefficient error DCd (%)		
	β=0.70	β=0.62	β=0.5
	ΔCd	ΔCd	ΔCd
Without flow conditioners	-1,96	1,49	2,44
Laws Plat	-0,5	0,5	0,7
Etoile	-0.2	-0.5	0.3
Tube Bundle	-1.9	-1.0	0.5

Table 1. Discharge coefficient error 3 D downstream flow conditioners

The efficiency of the tube bundle to reduce the discharge coefficient errors ΔCd from -1,96% to -1,90% for β=0,70, followed by the perforated plate which reduces the discharge coefficient errors ΔCd to -0,50% and the Etoile to –0.2%. The efficiency of the Laws perforated plate to reduce the discharge coefficient errors ΔCd is shown for β=0,62 from 1,49% to 0,50% followed by the Etoile which reduces the discharge coefficient errors ΔCd to –0.50%. The efficiency of the Etoile to reduce the discharge coefficient errors ΔCd is shown for β=0,50 from 2,44% to 0,30%.

CONCLUSIONS

The present experimental study examines the effect of upstream conditions on orifice meter. Three flow conditioners were used and exposed to the flow disturbed by a 90° double bend in perpendicular plane. The discharge coefficient were measured with three different orifice meter with β=0.5, 0.62, 0.70 at different Reynolds nimber.

If we examine the figure 3, we can see that the flow can't be measured on longer less then 20D were the error of the discharge coefficient is approximately –1%. Figure 4 to 12 show clearly the effect of flow conditioners on the discharge coefficient Cd.

We can see the effect of β ratio on the behavior of conditioners. Figures 4, 5 and 6 for β=0.70 show the good results for ΔCd obtained by the Etoile approximately 0,30% at station z/D=7.5. Figure 7, 8 and 9 for β=0.62 show the good results for ΔCd obtained by the three flow conditioners approximately 0,50% at station z/D=13.5. From figures 10, 11 and 12 for β=0.50, it seems that all the conditioners give good results for ΔCd approximately 0,58% at station z/D=12.

The conclusion with this experimental study of the three conditioners used separately that the flow need longer distance for close to fully developed pipe flow and some errors on the discharge coefficient, by reason of the swirl, were inevitable for distance less 12D with an error of 0.5%. However, we believe that a combination of two flow conditioners can reduce this error less than 0.5%.

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