Proceedings of the FEDSM2001
2001 ASME Fluids Engineering Conference
May 29-June 1, 2001, New Orleans, USA

FEDSM2001 - 18039

EXPERIMENTAL STUDY OF THE DECAY OF SWIRLING TURBULENT PIPE FLOW AND ITS EFFECT ON ORIFICE METER PERFORMANCE

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ABSTRACT

The present work is concerned with a preliminary study of the decay of swirling turbulent pipe flow and its effect on the accuracy of orifice plate flow meter. The swirl was generated by a double 90 degrees elbows in perpendicular planes. The flow field has been investigated using a tow components Laser Doppler Anemometer. The effect of this piping system on the orifice flow meter accuracy has been assessed with the meter placed at different downstream locations.

INTRODUCTION

All flow meters are affected by the quality of the flow approaching the meter (mean flow distortions, swirl, turbulent fluctuation). Nemerous research workers have investigated experimentally and computationally these effects with reference to the shift in flow meter discharge coefficient

The Algerian petroleum company recorded receipts of 56 10^9 m^3 of gas. The quality of gas measurement receipt and major delivery points distributed through 13000 Km on pipeline is very important. Design, operation and maintenance decision must be cost justified. Therefor it necessary to understand how equipment condition, station design and operational parameters can all affect metering accuracy.

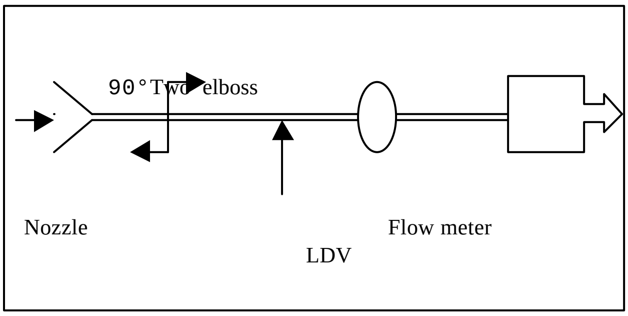
While high accuracy flow measurements are required, disturbances in the flow introduced by contractions, bends and other components, may reduce the accuracy to only 3% (Mattingly & Yeh) [1]. In recent work, Aichouni & Al [2] reported errors up to ±30% on a venturi flow meter while Yeh & Matingly [3] reported errors up to ±17% on an ultrasonic flow meter when the meter is subject to distorted flow conditions.

Given that most industrial installations include bends, valves, expanders and reducers, which are sources of both swirl, asymmetries and turbulence distortions, ensuring that fully developed flow in terms of mean flow and turbulence structure approaches the meter is difficult to achieve in practice. Either very long lengths of straight pipe work upstream of the meter must be provided(and these may need to be of the order of 80 to 100 pipe diameters in length), or some form of flow conditioning device must be introduced into the system, combined with a shortened straight length of piping duct.

The performance of the flow meter, such as orifice plate, is especially sensitive for the appearance of an axial velocity component or swirl, in the flow. In piping systems, swirl may be generated when the the flow passes two consecutive 90 out of plane elbows. An important parameter for the performance of the flow meter is the strength of the swirl. Consequently, comprehension of the decay process of swirl may lead to a better design of flow metering station. The present paper describes preliminary results of an experimental investigation on the decay of swirling pipe flow and its effect on orifice meter performance.

EXPERIMENTAL FACILITY AND PROCEDURE

The basic experimental facility is presented in figure (1). It consists of a long plexy glass pipe with 100 mm inner diameter and 10 m length. Air flow is suction by a fan at the end of the pipe working section. At the pipe entrance, swirl is generated using two 90 degrees elbows out of plan.



Static pressure can be measured from wall pressure tapings at several station along the pipe. The pressure tapings were connected to a multi tube manometer.

The flow rate can be determined from the measured differential pressure across an orifice flow meter with a β ratio equal 0.73 and directly measured from a nozzle at the entrance of the pipe.

The longitudinal mean, fluctuation velocity and turbulent intensity downstream the two elbows were measured using a two component Laser Doppler Anemometer. For measurement with LDA the air flow was seeded with smoke. Tests have been done at Reynolds number ranging from 3 to $11x10^4$. Profiles of the mean velocity and the axial turbulence intensity have been measured at axial stations Z/D=1, 20 and 90 downstream of the double bend. The measured profile of the axial mean velocity is compared to the (1/7) power law profile for a Reynolds number of $4.4\ x10^4$ in figure 2. The agreement is remarkable which indicates the effectiveness of the experimental procedure to investigate such flow development.

RESULTS AND DISCUSSION

The purpose of the present experimental work was to study the decay of the swirl downstream the double elbows and Its effect on the orifice meter performance.

In the first part of programme we examine the development of the velocity profile U/Um, turbulent intensity Ir(%) and the decay of swirl with three different axial station z/D=1, z/D=20, z/D=90.

Figure (3) shows a radial distribution of the measured axial mean velocity at the three axial station (Z/D=1, 20 and 90). the development of the flow after the 90 double bends. The two elbows crate a highly distorted profile at the initial stage with an important asymmetry. The flow distortion is still present at 20 diameter downstream of the elbows. At the late stage (Z/D=90) the flow seems to reach its fully developed profile.

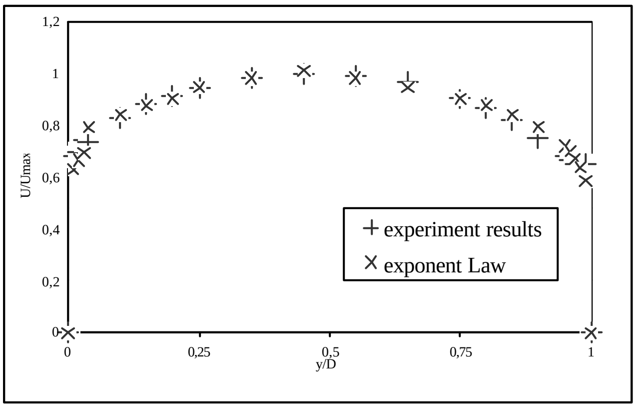


Figure (2) – Comparison of the measured axial mean velocity with the (1/7) th power law profile

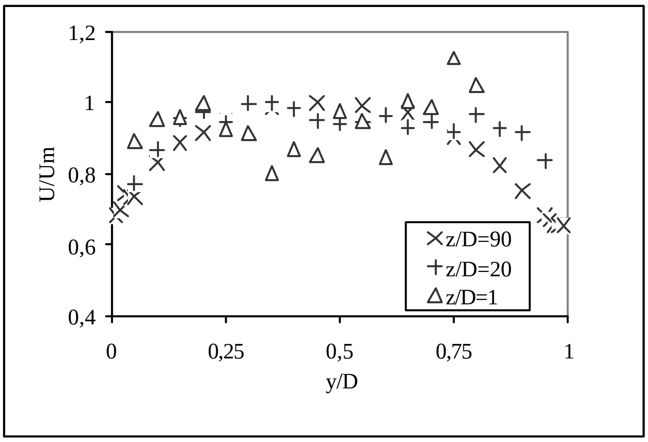


Figure (3) – Axial mean velocity profile distribution at axial stations Z/D=1, 20 and 90 downstream of two 90° elbows 'out-of-plane'

The axial turbulent intensity profiles are shown in figure (4). The profiles develop from higher value at the exit plane of the bends. Though it seems to be almost developed after some 20 pipe diameter, the asymmetry is still present in the profile which indicate that the turbulence structure is still developing. The turbulence level started very high and distorted with a pique about 23% and decreases to attend relatively constant level 7% at some 90 pipe diameter.

The development of the swirl angle is shown in figure (5). It can be seen that the swirl angle at the exit plane of the bends z/D=1 presents different values with an irregular profile α =-14° to α =12 °. At z/D=90 downstream of the bends we can see a regular profile of swirl with approximately α =0 corresponding to fully developed pipe flow. This is in good agreement with results reported by René Parchen [5].

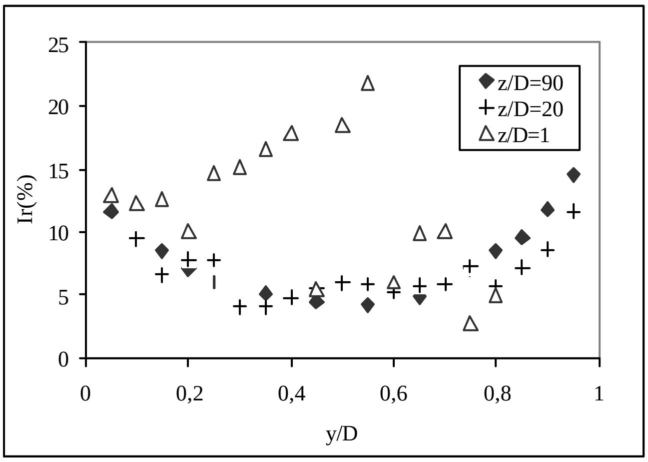


Figure 4 – Turbulence intensity development after the double bend out of plane

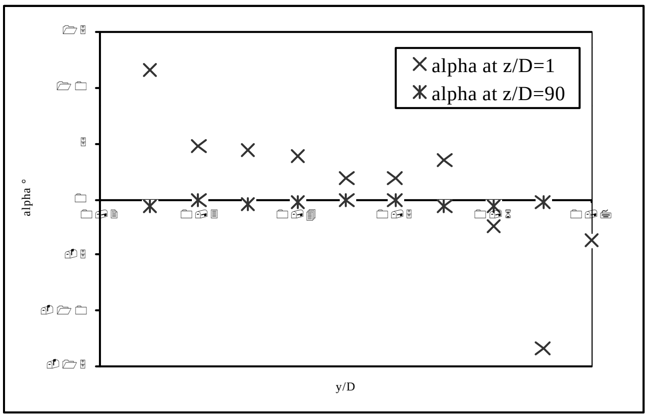


Figure (5) – Swirl angle profiles at Z/D = 1 and 90 downstream of the double bend out of plane

In the second part of programme the installation effect of the double bend upon an orifice flow meter is investigated. According to the standard ISO 5167 [6] the flow rate was determined from differential pressure measured through the orifice plate flow meter. The percentage ΔCd (%) shift of discharge coefficient was determined as bellow :

$$\Delta C_d = \left(\frac{C_{d0} - C_d}{C_{d0}} \right) x\,100$$

where :
Cd_o represents the discharge coefficient measured under standards conditions at fully developed flow condition and Cd being the discharge coefficient measured under non standard operation conditions (the orifice being placed at Z/D=10, 30, 50, 70 and 90 downstream of the double bend pipe fitting).

The variation of the discharge coefficient error ΔCd (%) shown in figure (6) shows almost a linear decrease from about ±2.2% at station z/D=10 and decreases progressively to 0.5% at station z/D=70, to 0 at station z/D=90 were the flow is fully developed.

The general trend of the figure is that the Cd shift is much higher for lower Reynolds number and tends to decrease as the Reynolds number increase. This observation holds for the four measured station z/D=10, 30, 50 and 70 as shown in figure (6). This finding is in agreement with results presented by Aichouni et al [7].

It has to be noted here that the spacer between the elbows is about one diameter; This would produce an intense single eddy swirl that decays slowly in the downstream direction and would take much more length to reach the fully developed flow condition. The higher values of the discharge coefficient shift obtained at axial stations Z/D = 10, 30 and 50 downstream of the two elbows indicate clearly the effect of the swirl on the meter performance.

CONCLUSIONS

The present experimental study shows that the operating flow conditions have a significant effects on the orifice flow meter performance.

The mean velocity and turbulence intensity downstream of two 90° elbows out of plane were measured using LDA system. The study of the swirling flow has been done in order to investigate its effect on orifice flow meter performance.

It is suggested that for an orifice meter installed downstream of two 90° elbows out of plane, to increase the upstream piping length to up to 80 diameters. This is mainly because this pipe fitting would generate a single eddy swirl which decays slowly.

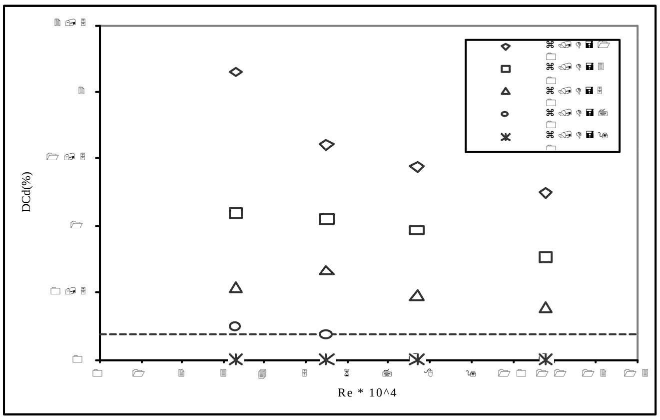


Figure (6) – Discharge coefficient shift of orifice flow meter downstream of two 90° elbows out of plane

SYMBOLS:

I_r (%) : axial turbulence intensity
y, z : radial and axial co-ordinates
alpha : angle of swirl
U : mean velocity components
C_d :Coefficient of discharge
D : Pipe diameter
R_e : Reynolds Number ($R_e = \rho\ U_m\ D / \mu$)

ACKNOWLEDGMENT:

The Sponsoring of the present work under Contract Number OC399701 by the National Agency for Research Development (ANDRU), Algeria, is greatly acknowledged.

All the experimental work has been performed at the Catholic University of Louvaine (Belgium); This is kindly acknowleged.

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