International Journal of Mechanical, Industrial and Aerospace Sciences
ISSN: 2517-9950
Vol:6, No:8, 2012

Experimental Study of the Metal Foam Flow Conditioner for Orifice Plate Flowmeters

B. Manshoor, N. Ihsak, Amir Khalid

Abstract**—**The sensitivity of orifice plate metering to disturbed flow (either asymmetric or swirling) is a subject of great concern to flow meter users and manufacturers. The distortions caused by pipe fittings and pipe installations upstream of the orifice plate are major sources of this type of non-standard flows. These distortions can alter the accuracy of metering to an unacceptable degree. In this work, a multi-scale object known as metal foam has been used to generate a predetermined turbulent flow upstream of the orifice plate. The experimental results showed that the combination of an orifice plate and metal foam flow conditioner is broadly insensitive to upstream disturbances. This metal foam demonstrated a good performance in terms of removing swirl and producing a repeatable flow profile within a short distance downstream of the device. The results of using a combination of a metal foam flow conditioner and orifice plate for non-standard flow conditions including swirling flow and asymmetric flow show this package can preserve the accuracy of metering up to the level required in the standards.

Keywords**—**Metal foam flow conditioner, flow measurement, orifice plate.

I. Introduction

FLOW measurement is a critical issue when it comes to determination of the amount of fluid purchased and sold, especially for oil, gas and water supply companies. In addition, accurate flow measurement is essential both in laboratory experiments and in many engineering applications, such as power and chemical plant, and fluid engineering systems. There are many flowmeters available on the market. A popular and robust method relates the fluid mass flow rate to a pressure drop. This kind of differential pressure flowmeter accounts for about 50% of all flowmeters used in industry whilst the next most common flowmeter is used for less than 15% of flow measurements[1]. The simplest version of such a flowmeter is an orifice plate. The pressure drop across the plate is measured and the relationship between the pressure difference and the mass flow rate can be established by using fluid mechanics theory corrected and calibrated with experiments. For this type of flowmeter to work properly, a homogenous, fully developed flow must be established before and after the orifice plate. For practical reasons, a flow conditioner is often used upstream of the orifice plate to produce a homogenous, fully developed flow prior to the orifice plate.

B. Manshoor is a senior lecturer in the Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Pt Raja, Batu Pahat, Johor MALAYSIA (phone: +607-453-8404; fax: +607-453-6080; e-mail: bukhari@uthm.edu.my).

N. Ihsak is a research officer at Centre for Energy and Industrial Environment Studies (CEIES), Universiti Tun Hussein Onn Malaysia, 86400 Pt Raja, Batu Pahat, Johor MALAYSIA (phone: +607-453-8404; fax: +607-453-6080; e-mail: shida.ihsak@yahoo.com)

Amir Khalid is a senior lecturer in the Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Pt Raja, Batu Pahat, Johor MALAYSIA (phone: +607-453-8484; fax: +607-453-6080; e-mail: amirk@uthm.edu.my).

A. Flow Conditioner and Flow Metering

Generally, all flow conditioners aim either to supply a flow as a settled, fully developed flow before the orifice plate or to achieve a repeatable constant velocity profile independent of the source of disturbances. In practical applications, this is very difficult because swirl and distortion in the flow can be generated by features present in the pipe, such as valves, joints, branches, bends, heat exchangers, compressors and other pipe fittings. So the velocity profile for actual applications is in most cases far away from the standard fully developed flow and will provide some detrimental effects on the accuracy of the flow measurement.

Using a sufficient length of straight pipe before the orifice plate can produce a uniform and axis-symmetric flow. A long enough straight pipe can also give a fully developed velocity profile to the flow. However, long straight pipe lengths increase the cost of installation and also require more space for flow measurement [2, 3]. The British Standard or ISO recommends a minimum straight length of pipe which depends on the Reynolds number, pipe diameter orifice diameter, ratio of orifice to pipe diameter, β, and also any pipe fittings. In general, for orifice plates with small holes, at least 10 pipe diameters of smooth straight pipe is needed, increasing to 36 pipe diameters for orifice plates with the large holes [4].

There are a large number of flow conditioners that can be used in flow measurement, some of which are included in the British and ISO Standards, and others can be found in technical reports [5]. The efficiency of standard flow conditioners in reducing the effect of disturbed flow consisting of asymmetric velocity profile and swirling flow had been discussed among the researchers in a lot of technical papers [6].

B. Metal Foam Flow Conditioner

Figure 1 shows the metal foam with pore sizes of 10mm. The metal foam was made with 10mm crashed salt tables and was infiltrated under 0.5 bar argon gas. The porosity and the relative density of the sample used were calculated with the following procedure. The sample was weighted and its respective mass was obtained. This value was divided by the density of the solid material to obtain the volume of the solid in the sample. The volume of the solid part of the sample is subtracted from the total volume of the sample to get the volume of the air inside the foam sample. This value is then divided by the total volume of the sample and so the porosity of the foam is obtained. From the calculation, this metal foam forms a porosity of 78.8% with an average cell diameter of 10mm.

The metal foam flow conditioner was designed to be immersed in pipe flow where there is a need to control the turbulence generated by object and was formed and fashioned as a flow conditioner measuring 50mm diameter and 25mm thickness.

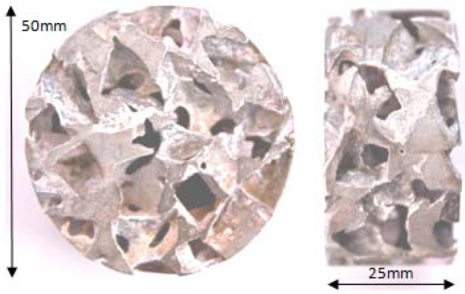

Fig. 1 Metal foam flow conditioner

II. Equations for Flow Measurement and Fluid Flow

A. Pressure Drop and Flow Rate for an Orifice Plate

In a standard orifice plate, the pressure drop, ΔP across the orifice plate and mass flow rate q_m are linked by [1, 7].

$$q_m = \frac{C_d}{\sqrt{(1-\beta^4)}} \varepsilon \frac{\pi d^2}{4} \sqrt{2\rho \Delta P} \qquad (1)$$

where C_d is the discharge coefficient that depends on the type of differential flowmeter and β is the ratio of an orifice diameter, d, to a pipe diameter, D. For a D and $D/2$ pressure tapping and concentric orifice plate flowmeter, which is used in this study, the standard C_d is given in equation (2).

$$\begin{aligned} C_d &= 0.5961 + 0.0261\beta^2 - 0.216\beta^8 + 0.000521\left[\frac{10^6\beta}{\mathrm{Re}_D}\right]^{0.7} \\ &+ \left[0.0188 + 0.0063\left(\frac{19000\beta}{\mathrm{Re}_D}\right)^{0.8}\right]\beta^{3.5}\left(\frac{10^6}{\mathrm{Re}_D}\right)^{0.3} \\ &+ 0.04289\left[1 - 0.11\left(\frac{19000\beta}{\mathrm{Re}_D}\right)^{0.8}\right]\frac{\beta^4}{1-\beta^4} \\ &- 0.031\left[\frac{0.94}{1-\beta} - 0.8\left(\frac{0.94}{1-\beta}\right)^{1.1}\right]\beta^{1.3} \\ &+ 0.011(0.75-\beta)\left[2.8 - \frac{D}{25.4}\right] \end{aligned} \qquad (2)$$

The pressure loss coefficient of a flow conditioner, k, is defined as;

$$k = \frac{\Delta P}{\frac{1}{2}\rho u^2} \qquad (3)$$

where ΔP is the pressure drop caused by the flow conditioner and u is the average velocity in the pipeline or the bulk velocity in the pipe (volume flow divided by the cross-sectional area).

B. Variation of Discharge Coefficient

To evaluate the effect of disturbances and the metal foam flow conditioner on flow metering, the variation from the standard discharge coefficient has been analysed.

For a fully developed velocity profile, the mass flow rate and standard discharge coefficient C_{dO} can be calculated from equations 2 and 3 respectively. The mass flow rate can be measured by experiment for a disturbed flow and then a new discharge coefficient, C_d, appropriate to the disturbed flow can be calculated. Thus the percentage error, ΔC_d of the standard discharge coefficient due to disturbances can be determined as:

$$\Delta C_d = \left[\frac{C_d - C_{dO}}{C_{dO}}\right] \times 100\% \; (4) \qquad (4)$$

This equation can be used to show the effect of disturbances and flow conditioners on flow metering. This type of comparison has also been used in the majority of the literature [8, 9] to assess the effect of disturbed flows on metering accuracy.

III. Experiment Method and Facility

A. Water Test Rig

To assess the effect of disturbed flows on the performance of an orifice plate flowmeter, an experimental rig was built using water as a working fluid. As mentioned above, this water test rig can achieved a Reynolds number up to 85,000 and this can give a good range for testing at high Reynolds number. In this rig, a 50 mm internal pipe diameter was used with 25 and 20 pipe diameters upstream and downstream of the orifice plate respectively, see Fig. 2. In this rig, the mass flow rate of the orifice plate with standard and non-standard velocity profiles was measured for different Reynolds numbers. Throughout the experimental work, the accuracy of the standard orifice plate with no disturbances was compared with the ISO Standard [7] using equation 2.

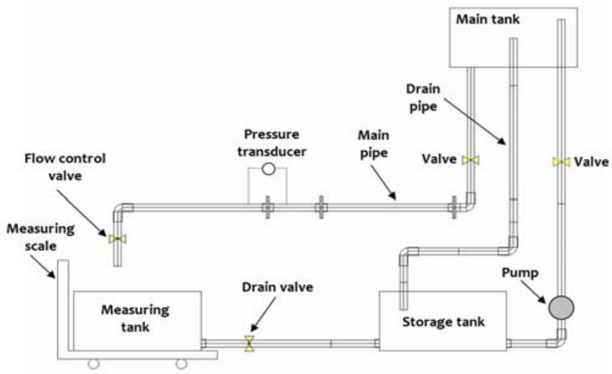

Fig. 2 Schematic diagram of the water test rig

For measuring the pressure difference across the orifice plate, two pressure tappings were used located D upstream and $D/2$ downstream of the orifice plate. The pressure difference across the orifice plate was measured by using both a U tube water manometer and a differential pressure transducer, which were connected to the pressure tappings. The experimental mass flow rate was measured by using the dynamic weighting method [6]. This mass flow rate was compared to the mass flow rate calculated across the orifice plate according to the British Standard [2].

International Journal of Mechanical, Industrial and Aerospace Sciences
ISSN: 2517-9950
Vol:6, No:8, 2012

B. Disturbances

Velocity profiles different from the fully developed flow can be produced using disturbances upstream of the orifice plate. These disturbances can be used to provide either asymmetric velocity profiles or swirling flows. In order to assess the effect of the flow conditioners on the disturbed flow, two types of disturbances were used in water test rig. To provide an asymmetric velocity profile, two elbows in the same plane and a 50% open ball valve were used. Other disturbances used to achieve swirling flows were two out of plane elbows and a one piece swirler with an 180^o twist.

C. Experimental work

The flow conditioner, based on the metal foam, was positioned a short distance upstream of the orifice plate. It was envisioned that the metal foam will create a predetermined flow condition, independent of the upstream conditions. Therefore, the strong turbulence introduced by the metal foam flow conditioner can absorb other unknown and unwanted disturbances and achieve a repeatable velocity profile independent of disturbances.

Four different sets of experiments for measuring mass flow rate were conducted. The first was done for a standard velocity profile to estimate the accuracy of rig and to compare it to the ISO standards. Then the effect of disturbances was examined. The effect of the metal foam flow conditioner on the mass flow rate was then investigated with and without disturbances. These mass flow rates were used to calculate the C_d and the change in discharge coefficient (equation 4). For this experiment the metal foam flow conditioner was located 2.5D upstream of the orifice plate in water test rig. The configuration of the metal foam, flow conditioner and the orifice plate is shown in Fig. 3.

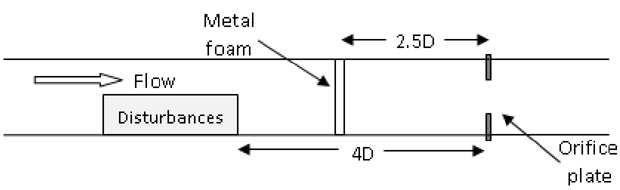

Fig. 3 Positions of disturbances and metal foam flow conditioner relative to the orifice plate

IV. Results and Discussions

During the experimental work, the differential pressure across the orifice plate was recorded and the corresponding mass flow rate for this pressure was measured. The changes in C_d due to the different disturbances upstream of the standard orifice plate and the effect of the metal foam flow conditioner in attenuating these disturbances work are plotted in figures 4 to 6.

The results from the experimental work using a 50% open valve as a disturbance, both with and without the metal foam flow conditioner are shown in Fig. 4. It can be seen, that with a standard orifice plate, the disturbance gives a relatively small error in the discharge coefficient when compared with the standard flow. By examining the change in discharge coefficient caused by the metal foam flow conditioner on its own, it can be seen that it provides a change of less than 1%.

This means that the metal foam flow conditioner configuration did not significantly affect the reported mass flow rate, thus showing that it can attenuate the effects of asymmetric velocity profiles.

Fig. 5 shows the effect of a swirl disturbance on the orifice plate. It can be seen that the swirl makes the standard orifice report 5% errors in flow rate. When compared to the discharge coefficient for the swirl disturbance with the metal foam flow conditioner, it can be seen that it is similar to the change in discharge coefficient due to the metal foam on its own (with about 0.5% tolerance), and is also the same as the orifice plate on its own with fully developed flow. This therefore shows that the metal foam flow conditioner can not only attenuate the effect of asymmetric velocity profile but can also dampen the effect of swirling flow without appreciable deviation from the standards.

Fig. 6 shows the same type of result, but in this case, the disturbances are created using two elbows in the same plane and two elbows out of plane. Once again the orifice plate combined with the metal foam flow conditioner provides better results than the standard orifice plate. Thus, the use of a metal foam flow conditioner upstream of the orifice plate successfully damped the disturbed flow due to the two elbows in the same plane and the two elbows out of plane. Therefore, it could be concluded that the metal foam flow conditioner is a good geometry for the flow conditioner, and this metal foam will achieve less than a 1% variation in the metering when faced with a standard flow. This compares well with the standard orifice plate without any disturbances, which can also obtain a 99% accuracy.

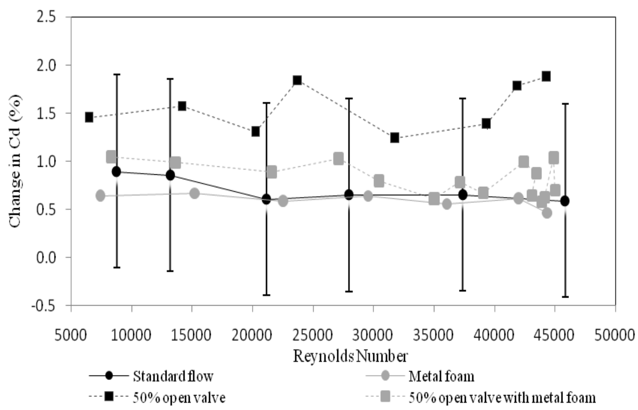

Fig. 4 Variation of C_d with a 50% open valve disturbance

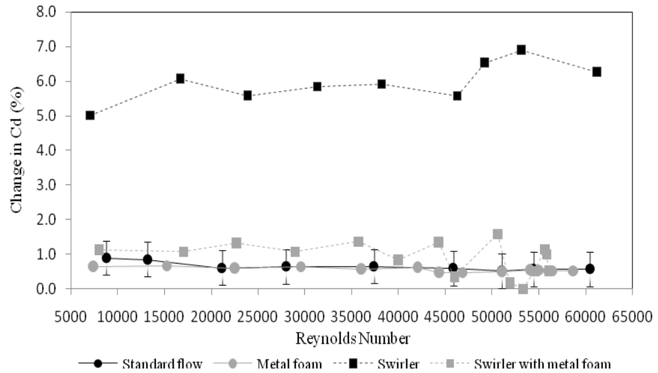

Fig. 5 The variation of C_d for swirler disturbance with and without the metal foam flow conditioner

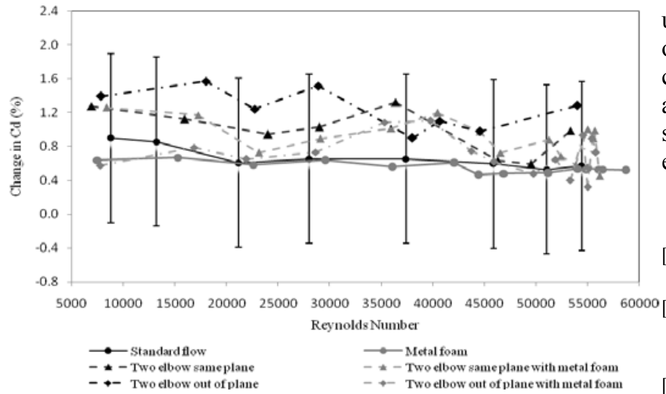

Fig. 6 The variation of C_d for twin elbow disturbances with and without the metal foam flow conditioner

In order to find out the effect of the metal foam flow conditioner with different size orifice plates, the experimental rig was set up to the orifice plate with $\beta = 0.38$ and $\beta = 0.72$, using the same procedures as before. The results for all the orifice plates tested are shown in Fig. 7. Generally, a comparison of results for $\beta = 0.38$ and $\beta = 0.72$ shows that the flow conditioner had a same effect on measuring the mass flow rate as shown in previous results. Therefore, it can be concluded that using a metal foam flow conditioner in front of the orifice plate gives no more than a 0.5% change in standard discharge coefficient for different values of β.

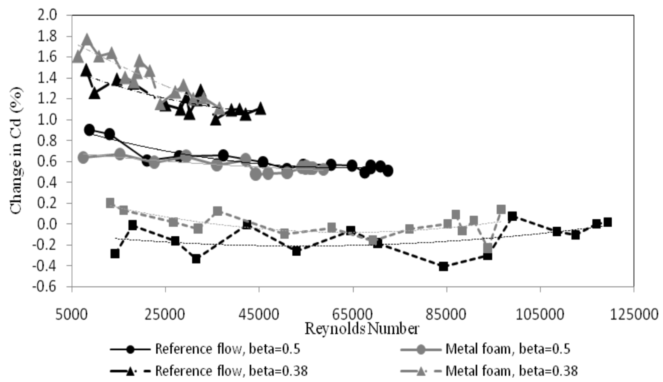

Fig. 7 Comparison of C_d with an without metal a foam conditioner for three values of β

V. Conclusion

The present study has shown that the novel idea of using a metal foam flow conditioner can reduce the errors in metering caused by disturbances in flow to an acceptable level. The results show that a metal foam flow conditioner with 78.8% porosity located 2.5*D* upstream of the orifice plate can reduce the distortion due to asymmetric velocity profiles and also swirling flows on metering for high and low Reynolds numbers. The location of the metal foams upstream of the orifice plate as short as 2.5*D* clearly show the advantages of the metal foam flow conditioner in comparison with other these flow conditioners.

This is only initial work to test the viability of the concept, using metallic foam with large pores as a multi-scale object which would function as flow conditioner. Further work involving more experiments is required to get a better understanding of the flow properties across the multi-scale object like metal foam and also to optimise it for flow conditioning through changes to the structural parameters such as pore size, shape and density. Also, as each foam will be somewhat different, the generality of the approach will also be elucidated.

References

[1] British Standard 1042-1.4, Measurement of fluid flow in closed conduits, Part 1: Pressure differential devices. 1992

[2] E. Kelner and T.B. Morrow, “Compact orifice meter station project,” *4th International Symposium on Fluid Flow Measurement,* Denver, Colorado USA, 1999

[3] E. Kelner, T.B. Morrow and E. Bowles, “*Minimizing Orifice Meter Installation Lengths*,” Pipeline & Gas Journal

[4] R.W. Miller, “*Flow Measurement Engineering Handbook,”* London: McGraw-Hill, 1989

[5] “*Flow conditioners performance review*,” National Engineering Laboratory, 1998

[6] B. Manshoor, F. C. G. A. Nicolleau, and S. B. M. Beck, “*The fractal flow conditioner for orifice plate flow meters,”* Flow Measurement and Instrumentation, 2011. 22(3): p. 208-214. 2011

[7] ISO 5167-2, Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full, Part 2: orifice plates. 2003.

[8] S.B.M. Beck and J. Mazille, “*A study of a pressure differential flow meter that is insensitive to inlet conditions*,” Flow Measurement and Instrumentation **12** 379-84, 2001

[9] Reader-Harris, S.P. Hutton and E.M. Laws, “*Flow straighteners and flow conditioning devices*,” Flow measurement and instrumentation consortium, 1989