Flow characteristics behind a butterfly valve

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ABSTRACT

The characteristics of mean flow and turbulence behind a butterfly valve are studied experimentally using a Laser-Doppler anemometry. Velocity and turbulence intensity are measured at downstream locations 0.086D, 0.5D, 1D and 2D (D = pipe diameter) for three valve angular positions corresponding to fully open, partly open and relatively closed positions. Comparison of the isovels for the three positions indicates flow patterns with quite distinct features. Levels of turbulence intensity may increase up to 150% of the mean velocity for relatively closed valve, indicating the complex structure of such a flow.

1. INTRODUCTION

The knowledge of the flow structure behind a valve is quite essential for the development and the optimum design of the valve.

Experimental and computational studies of the flow behind a butterfly valve are limited and pay attention to the bulk flow characteristics rather than to the detailed flow structure. (Eom, 1988). Some studies deal with the static pressure drop, the man flowrate and the aerodynamic torque of butterfly valves (Sarpkaya, 1961, Miller, 1988). Recently, Morris and Dutton (1988) performed some experiments in order to study the performance of butterfly valves in compressible flow. They presented experimental results which included Schlieren surface flow visualisation and flow field static pressure distributions. The results indicated the complex flow field with regions of flow separation and reattachment. They also reported results (1991) of the operating characteristics of two similar butterfly valves mounted in series.
Hirch and Lacor (1988) have developed a three-dimensional model for predicting the flow around and behind a butterfly valve, but no detailed experimental results were available to validate their predictions. To the authors knowledge, detailed measurements of flow characteristics around a butterfly valve together with information about the disk geometry are not available in the open literature.

In this study detailed measurements of flow velocity behind a butterfly valve are performed using a one-component LDA system of a forward scatter type. Distributions of the longitudinal and circumferential velocity components are obtained at selected locations 0.086D, 0.5D, 1D and 2D (D=pipe diameter) downstream of the valve. Velocity measurements are taken for three valve angular positions. The first corresponds to a fully open position (a=0°) the second to a partly open position (a=27°) and the third to a relatively close position (a=50°). The characteristics of the wake formed immediately downstream of the valve are studied in detail. Examination of the circumferential velocity component reveals a two vortex structure, one in each half of the section with a varying size, depending on the angle a. Comparison of the flow characteristics for the three angular positions studies indicates flow patterns with quite distinct features.

2. EXPERIMENTAL APPARATUS AND PROCEDURE

The experiments were performed in a flow rig (Fig. 1) consisting of a reservoir, a pump and the associated pipe work. The flow is controlled using both a ball valve in the main pipe and a by-pass pipe from the pump exit to the reservoir. Hence, a wide range of flow rates is achieved without problems either of pump cavitation at high flowrates or pump instabilities at low flowrates. The flowrate is measured using an orifice plate, designed according to BS1042 (1983) the performance of which was checked by measuring the velocity distributions along a pipe diameter and integrating this to obtain the volume flow rates. In all the measurements reported here the flowrate was kept constant at $Q=8.2 \times 10^3$ m$^3$/s.

The pipe work was made of PVC with an internal diameter of 63.5 mm with the exception of two sections, each 350 mm long, which were located upstream and downstream of the butterfly valve which were made of perspex. So optical access in the region of measurements was possible.

The butterfly valve (Fig. 2) consisted of a body, the valve disk and a handle with 10 equally spaced angular positions corresponding to openings between 0° (fully opened) and 90° (fully closed). Figure 2 indicates the untypical geometry of such a valve with the minimum thickness of the disk being at the symmetry axis and the maximum thickness at the pipe wall. Also, in the same figure the various diameters along which velocity measurements were taken, for the three angular valve positions (a=0°, 27° and 50°) are shown.
Measurements of longitudinal $U_l$ and circumferential $U_\theta$ velocity components were taken by an LDA system of a forward scatter type manufactured by DANTEC. It consists of a He-Ne Laser tube (15 mW), a Bragg cell with a 55N10 shifter, a 350 mm front lens and a photomultiplier. The distance between beams was 60 mm which when combined with the 300 mm local length of the front lens gave a half angle of the two beams $5.57^\circ$. This corresponds to a spacing of $3.257 \mu m$ between fringes. The photomultiplier signal was processed using a DANTEC counter type 55L90a. The analog signal from the counter was sent via an A/D cord (Data translation DT2811) to an IBM-XT computer where the mean velocity and turbulence intensities were calculated using a sample of at least 10000 data points. Frequency shift was applied to one of the Laser beams in order to bring the output signal within the 0 to 1MHz region and low and high pass filter were used to remove any unwanted signal.

When measuring the circumferential velocity component a correction was applied to the half angle formed by the two beams as well as to the actual point of measurement relative to the LDA traverse table, due to the small pipe diameter and the resultant wall curvature.

As shown in figure 3 because of the Laser beam refraction at the air-perspex and perspex-water interface the half angle becomes $\mu$ instead of $\delta$ and the measuring point moves from c' to c. Point A is known from the positioning of the LDA relative to the pipe. Point B is calculated from the intersection of a line with a given gradient with the inner circle. The angle $\alpha_2$ is calculated from the normal to the circle at B and line AB from which angle $\alpha_3$ is obtained using the relation $m_2 \sin \alpha_2 = m_3 \sin \alpha_3$.

Measurements were taken at selected cross sections behind the valve located at 0.085D, 0.5D, 1D and 2D distances from the valve. Three sets of measurements were obtained corresponding to the three angular valve positions (fully open, partly open and partly closed), which are analysed in the following section.

3. ANALYSIS OF EXPERIMENTAL RESULTS

Measurements of the velocity in the longitudinal direction are presented at two cross sections, located at 0.085D and 2D downstream of the valve for the three above mentioned valve positions. Hence the flow characteristics (wake development, secondary flow, etc.) could be studied in detail.

Fig. 4 (a and b) shows the velocity contours at the two sections mentioned above for a fully open valve position ($a=0^\circ$). In the first downstream station (0.085D) a wake is observed in the central region of the pipe (Fig. 4a) which, further downstream, due to mixing and decrease of velocity gradients becomes more shallow. At 2D downstream of the valve (Fig. 4b) the wake has completely dissipated and a developing velocity profile is formed with a constant velocity.
in the central region. At all stations the flow is nearly axisymmetric with a slight move of the velocity minimum towards one wall, due to a misalignment of the valve with the pipe centreline.

Also turbulence intensities were measured and representative contours are presented for the two stations (Fig. 5a and b). It is shown that the intensities are increased in the wake at the first station (Fig. 5a). Intensities are up to 20% of the mean velocity in the wake region much higher than those observed in the near-wall region of pipe flow (approximately 10-12%). In the remaining cross-section turbulence levels are relatively low and increase as the pipe wall is approached. Valves of turbulence intensities in the horizontal diameter are found to be similar to those of fully developed pipe flow. At the last station (Fig. 5b) the wake effect on mean velocities is negligible, however some effects on the turbulence levels are present. This indicates that at this station mean flow characteristics may be in equilibrium but turbulence levels have not reached an equilibrium state yet.

When the valve is partly open (a = 27°) the flow is highly non-symmetrical with a maximum velocity occurring near the wall for both stations (Fig. 6a and b). At the first downstream station (Fig. 6a) negative velocities exist near the one wall indicating a recirculation region in there. Also a region of low velocity is observed besides the wake of the disk due to high circumferential velocity present in this region. Near the opposite wall the velocity maximum is observed at the next measuring station (Fig. 6b). High turbulence mixing causes a thinning of the boundary layer which has a result the velocity increase close to the wall with increasing downstream distance.

Similar phenomena are observed for a = 50° (Fig. 7a and b). Measurements at the first downstream station (Fig. 7a) indicate highest velocities near the one wall, due to the small opening available for the water to flow downstream. The region of the high velocities covers almost half of the pipe periphery with a maximum width at the horizontal radius. Also, high velocities are observed in the central part of the pipe where the flow accelerates while in most part of the cross section the velocities are very low due to the "diffuser" type of flow. In the last downstream station (Fig. 7b) the flow has become more uniform, however, the maximum velocity remains near the wall. Also, a wake still remains on the other side of the pipe which covers almost half of the pipe radius. The region of high velocities is smaller at this station and is near the horizontal plane. The velocity decreases from its maximum value near the wall until the wake is approached and then increases towards the other wall. The intensity levels are greatly increased at this station (Fig. 8) with values ranging from 50% of the mean velocity in the wake region up to 150% in the region of the small valve opening (region of high velocities). Such high levels of turbulence are due to the much higher local velocities in the region (with regard to the mean pipe flow) and also to the highly disturbed flow caused by the partly closed valve. Such turbulence levels are much
higher than those observed in wake or boundary layer flows and are expected to be reduced further downstream.

4. CONCLUSIONS

The structure of flow behind a butterfly valve is studied experimentally using Laser-Doppler anamomtry. Mean velocities and turbulence intensities at selected locations behind the valve are measured for three angular valve positions. For fully open valve a wake, observed in the central region of the pipe, dissapears at a location two diameters downstream of the valve. For relatively closed position strong recirculation regions appear and the highest velocities occur near the one wall. The intensity levels are increased significantly with values ranging from 50% of the mean velocity in the wake region up to 150% in the region of the small opening.

REFERENCES

Fig. 1: Experimental Apparatus

Fig. 2: Geometric characteristics of butterfly valve

Fig. 3: Characteristics of measuring location
Fig. 4: Isovel patterns for $a=0^\circ$
(a) $x/D=0.086$  (b) $x/D=2$

Fig. 5: Contours of turbulence intensity $u'/U_\infty$ for $a=0^\circ$
(a) $x/D=0.086$  (b) $x/D=2$
Fig. 6: Isovel patterns for $\theta = 27^\circ$
(a) $x/D = 0.086$  (b) $x/D = 2$

Fig. 7: Isovel patterns for $\theta = 50^\circ$
(a) $x/D = 0.086$  (b) $x/D = 2$

Fig. 8: Contours of turbulence intensity $u'/U_*$ at $x/D = 2$ ($\theta = 50^\circ$)