

A PIV EXAMINATION ON THE PERFORMANCE OF ULTRASONIC HEAT METER RELATED TO INSTALLATION

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Abstract

An experimental investigation was carried out on the performance of an ultrasonic heat meter with interference of non-uniformity from the upstream installation of a ball valve, which it is partly opened. It was found that the existence of the ball valve may under-report the flow, especially when the flow rate is low. From the measured PIV results, it can be found that the velocity distribution is obviously non-uniform inside the meter, and the change is remarkable when the inlet is added with a ball valve. The time resolved PIV results also demonstrate that the flow field becomes unsteady when slow down the flow rate, which might be responsible for the measurement deviation.

1.Introduction

Ultrasonic heat meters are widely used in households heating systems, due to its advantages such as less interference to the pipe flow, no moving parts, little pressure loss, wide measurement range and high accuracy. Recently, ultrasonic heat meter is spread out very fast in large apartment complexes or large buildings with centralized district heating method, which is considered to be much more economical than individual heating system. In China, according to the Building Energy conservation 9th Five-Year Plan and the 2010 plan, issued by China's Ministry of Construction, household measuring and charging systems of China's domestic centralized heating systems will be fully implemented in recent years[1].

There is a considerable amount of literature available on ultrasonic transit-time flowmeters. Al-Khazraji discussed the effect of distorted profile on ultrasonic flowmeter based on theoretical calculation[2]. Hejholt

provided a lot of test results mainly about the performances of both single and dual-beam systems downstream of various kinds of disturbance conditions[3]. Jerker Delsinghas reported the dynamic installation effects on ultrasonic flowmeters [4].

There are some types of an ultrasonic propagation line in ultrasonic flowmeter, such as V-, 2V- and Z-methods. But, currently, the mainstreams of ultrasonic heat meter used for household adopt so-called 'two reflections' method. Figure 1 shows the geometry of this type of ultrasonic heat meter.

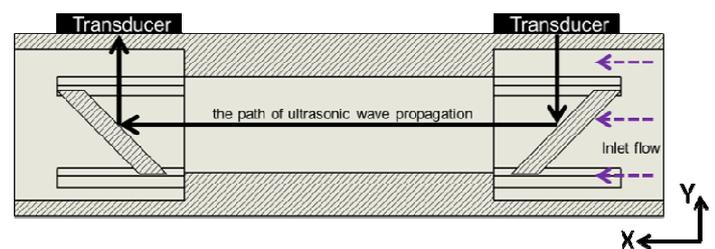


Fig.1 Configuration of ultrasonic heat meter

Most of the works concentrated on the installation effects with either numerical simulation or experimental calibration [5] [6]. Since ultrasonic heat meters have complex internal structure, it is difficult to accurately simulate the flow field numerically. The purpose of this article is to observe the flow field quantitatively in order to figure out the influence of the inlet condition with the help of Particle Image Velocimetry (PIV)[7][8].

2.Experimental set-up and apparatus

In order to simulate an installation-generated measurement error, a ball valve was mounted at the inlet of an ultrasonic heat meter [9]. The velocity field of the

heat meter with and without the ball valve was measured with PIV system.

Figure 2 shows the diagram of the test bed for both measurements of a usual ultrasonic heat meter and PIV visualization. The water contained in a reservoir tank is driven by a pump and the calibration of the flowrate is obtained using weighing method. There are two test sections working during the whole experiment, namely part I and II.

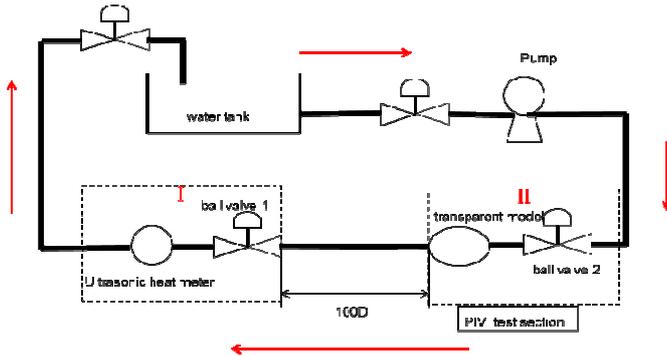


Fig.2 Schematic diagram of experimental apparatus

Test section part I, as shown in Fig.2, is designed to observe the performance of a commercial ultrasonic heat meter manufactured by Hefei Runa Metering Company Ltd, upstream of which a ball valve is connected with a 22 mm inner-diameter straight pipe. A transparent model located in part II has the same configuration with the ultrasonic heat meter in part I. The inner diameter of the inlet is 22mm correspond with the middle beam-path pipe of 14mm diameter. The material of the transparent model is acrylic (PPMA), whose transmittance index is 92% or more. The working condition of part I and II is always the same throughout the experiment and there are sufficient length of the straight pipe before and after each of them. The distance between the two section is 100D (D is the inner diameter of the pipe), which is long enough to ensure the two sections will not interfere with each other.

The PIV test section, as shown in figure 3, consists of a plexi-glass model and ball valve of nominal diameter 22 mm. The laser-light beam emitted from a 2 W laser is transmitted through optical cylindrical lens and then changed into a light sheet. The laser-light sheet is adjusted to a thickness of about 1 mm to illuminate the flow field. In order to eliminate the effects of the difference of refraction indices between air and the

curved plexiglass, a rectangular glass tank filled with still water is enclosed around the whole test section and it was proved that the deformation of the image is negligible.

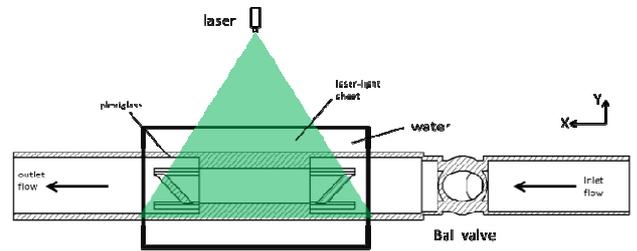


Fig.3 Schematic diagram of flow visualization

The Particle Image Velocimetry (PIV) method is employed to reveal the velocity distribution. Plastic particles made of polystyrene are seeded to the whole piping system to scatter the laser light via a partial seeding mechanism. The diameters of the polystyrene particles are between 40 and 60 μm and the density is 1.06 at 25 $^{\circ}\text{C}$. In addition, a high speed camera with frame rate of 1000 fps was used to get the time resolved PIV data, and 0.1 ms shutter speed was used to freeze the flow field.

3.Experimental Result and Discussion

3.1 Experimental conditions

There were two working conditions conducted during our experiment, namely, with and without ball valve. The distance between transparent model and the ball valve is 5D and the angles of the ball valve was set to be $\alpha = 45^{\circ}$. A series of flow rate conditions were tested between 0.028 m^3/h and 1.0 m^3/h .

3.2 Results and discussions

As shown Figure 1, the path of the ultrasonic wave propagation between the two reflectors provides the information of the flow rate. Therefore, our focus is the velocity distribution along this line. Figure 4 shows the averaged velocity (\bar{U}) of the path line under various test conditions, from which we can see that the linearity are quite acceptable for both cases with and without ball valves.

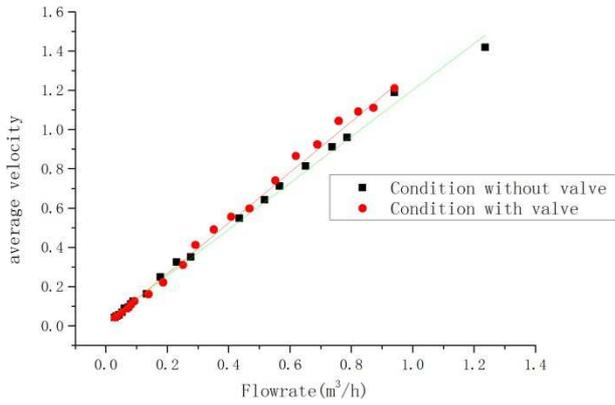


Fig.4 Averaged velocity obtained from PIV data

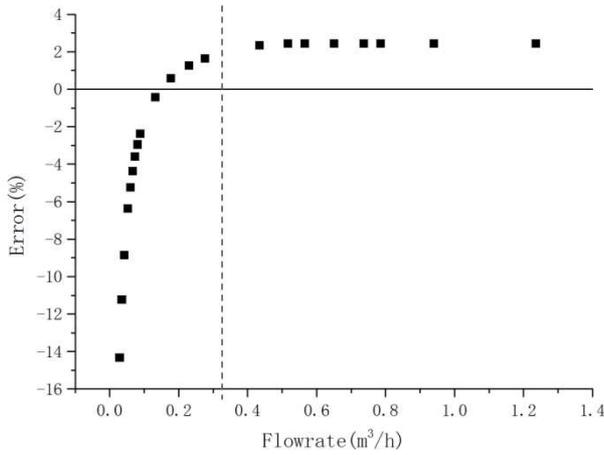


Fig.5 Deviation of PIV results with ball valve

Figure 5 shows the deviation of the interference generated by the ball valve compared with the case of uniform incoming flow (without ball valve), which were obtained based on the two fitted lines in Fig. 4. When flow rate is lower than about $0.32 \text{ m}^3/\text{h}$, the degree of deviation is relatively large, although it decreases with increase of the flow rate. On the other hand, the deviations are almost constant and overall small when the flow rate is higher than $0.32 \text{ m}^3/\text{h}$. Therefore, the information shown in Figure 5 represents the adaptability of the ultrasonic heat meter and the results indicate a poor performance at low flow rate points. For comparison, the read out data of the real ultrasonic heat meter located in the test section part I is shown in Fig.6, from which we can get the same conclusion.

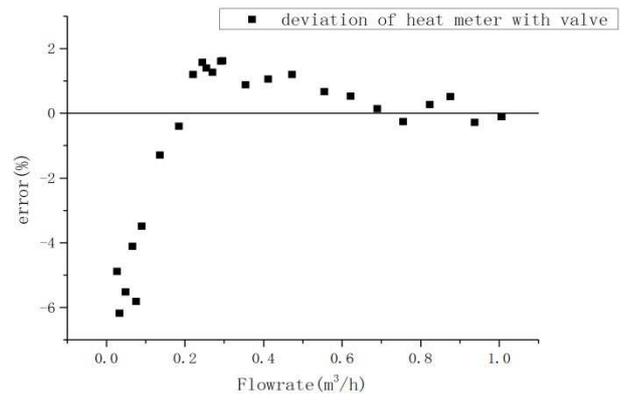


Fig.6 Deviation of heat meter with ball valve

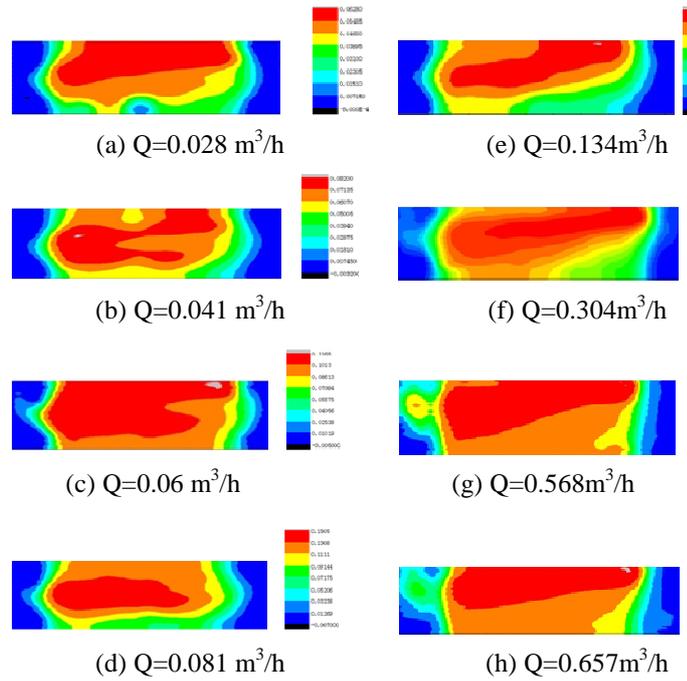


Fig.7 PIV Data of velocity distribution.

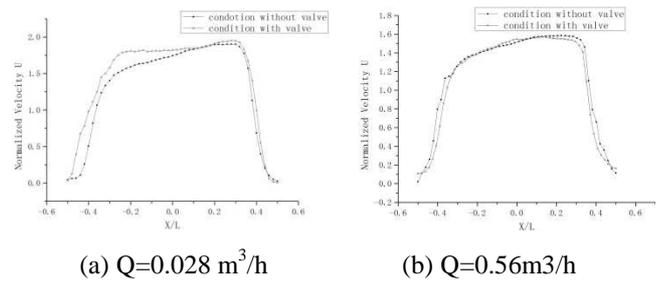


Fig.8 Velocity distribution(U)along the path of the ultrasonic wave propagation by PIV (time smoothed)

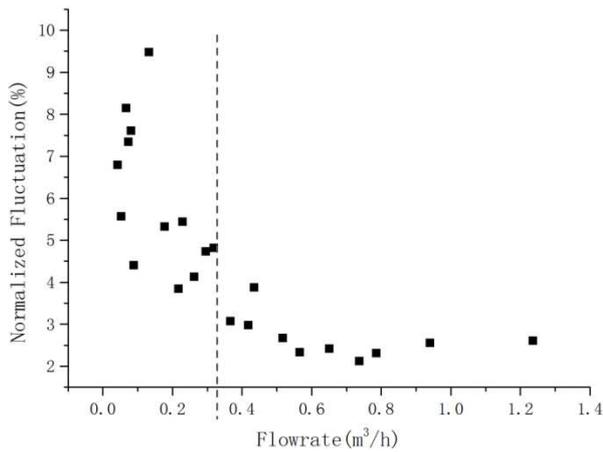


Fig.9 The level of the fluctuation at different flow rate points (by PIV)

In order to figure out the mechanism of the above mentioned deviation, velocity contours along x-axis direction are extracted for the analysis. Limited by the space, Fig. 7 only shows a few typical flow fields. We can see that when the flow rate is less than about 0.32 m³/h, the flow field changes remarkably with slight variation of flow rate, which may indicate a relatively poor adaptability. Figure 8 shows the velocity distributions along the path of the ultrasonic wave propagation for the flow rates of 0.028 m³/h and 0.56m³/h, respectively. We can see that the velocity distribution are markedly different affected by the ball valve. Furthermore, the time-resolved PIV results also reveal that the flow field is unsteady especially for the conditions of low flow rate (note that the curves in Fig. 8a are time smoothed). In order to further analyse level of the fluctuation at each flow rate points, one variable is defined as $N_d = \sigma / \bar{U}$, where σ is the standard deviation of instantaneous velocity U at different times, and \bar{U} is the averaged velocity, respectively. Figure 9 shows the variation of N_d with different flow rates. As can be easily found from the figure, that the magnitudes of N_d in the range of 0.028m³/h to 0.32 m³/h are obviously larger than the other side.

4. Conclusion

A transparent model of ultrasonic heat meter is designed for the PIV access, and a ball valve is connected at the inlet of the meter. The effects of the ball valve to the performance of the meter is mainly

analysed through the comparisons of both flow field and the variation of the flow rate. The main results can be summarized as follows:

1. For the small-diameter ultrasonic heat meters as tested in this work, reliable and useful results can be obtained with PIV method, especially when combined with another heat meter under the same working conditions.

2. In the case where the error of 2% can be allowed, the least point can be set at flow rate about $Q > 0.15 \text{ m}^3/\text{h}$ (Fig.6). And the overall good performance of adaptive appears at high flow rate $Q > 0.32 \text{ m}^3/\text{h}$.

3. The flow field becomes unsteady when slow down the flow, which might be responsible for the measurement deviation in the case of low flow rate.

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