Observation of the fluid pulsation behind a prism in gas-liquid annular flow

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Abstract. The fluid pulsation behind a prism is closely concerned with the design and operation of gas-liquid two-phase flow systems. This paper explored the property of such fluid pulsations in a horizontal pipe using air and water as the tested media. The pressure difference between the upstream and downstream of the prism was adopted to represent the characteristics of the fluid pulsation. Based on the experimental results, it is found that there exit obvious pulsations in the fluid behind the prism in annular flows, and this pulsation is more marked at low gas mass qualities than those at high gas mass qualities. Furthermore, the average pressure basically decreases with the gas mass quality and increases with the gas-liquid total mass flowrate. These findings could be useful for the analysis of flowing characteristics in gas-liquid annular flow across a prism.

1. INTRODUCTION
Annular flow is a major kind of regime of gas-liquid two-phase flow, which is seen widely in the industry such as power, chemical and petroleum engineering etc. Generally, the annular flow happens at high gas phase velocity and low liquid phase velocity (Zaidi et al., 1998). In this flow regime, the liquid phase component flows along the pipe wall and forms a layer of liquid film, whereas the gas phase component entraining some small liquid drops flows along the pipe center (Han et al., 2006; Kim et al., 2006). Due to this special fluid structure of annular flow, fluid pulsation is a common phenomenon that occurs (Inoue et al., 1986; Yokosawa et al., 1986). The consequence of the fluid pulsation may result in piping vibration and it is dangerous to the equipment and the production processes. Especially when there exist some obstacles in the flow passage, the intrinsic pulsation of annular flow will be superimposed upon additional pulsations arising from the block of the obstacles (Sun et al., 2008a). However, investigations on the complex fluid pulsation behind a prism in annular flow are seldom reported so far.

This paper contributes to the study on the fluid pulsation property of gas-liquid annular flow across a horizontal quasi-trapezoidal prism. The pressure difference between the upstream and downstream of the prism was adopted as the characteristic parameter representing the fluid pulsation. Based on the experiments using air and water as the test fluid media, the relationship of average pressure, gas mass quality and total mass flowrate were discussed.

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2. EXPERIMENT

Experiments were conducted on the same apparatus as described in the authors’ previous work (Sun et al., 2008b). The tested media were air and water both flowing horizontally across a quasi-trapezoidal prism which was placed at the center of the pipe perpendicular to the flow direction. Fig. 1 shows the layout of the experiment system. The flowrates of air and water were measured respectively by a vortex flowmeter and an electromagnetic flowmeter, and were regulated by the valves before they entered into a gas-liquid mixer. The air flowrate $Q_G$ at the entrance was $30–120 \text{ m}^3/\text{h}$ and the water flow rate $Q_L$ was $0.5–2.5 \text{ m}^3/\text{h}$. Additionally, pressures of air and water at this part were also measured to calculate their mass flowrates $G_G$ and $G_L$. After passing through the gas-liquid mixer, the mixture of air and water reached the test section, in which the experiments were carried out and signals were acquired. The upstream and downstream straight pipe were $120D$ ($D$ is the inner diameter of the pipe, $D = 50 \text{ mm}$) and $30D$ long respectively. The water was recirculated to the storage pool while the air was exhausted to the atmosphere. The flow regime was recorded manually via a transparent observation window in the test section.

The blockage ratio $b$ ($b = d/D$, $d$ was the width of the prism, $d = 14 \text{ mm}$) of the quasi-trapezoidal prism used was 0.28. The duct-wall differential pressure method (DDPM) (Sun et al., 2007) was adopted to acquire the fluid pulsation signal. From the two pressure tags on the pipe wall which were respectively $1D$ upstream and $0.2D$ downstream of the prism, the dynamic differential pressure was detected by a Honeywell 24PC sensor, then sampled and processed by a computer, as shown in Fig. 2. Signals were acquired only when the annular flow regime appeared.

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Fig. 1 Experimental set-ups

Fig. 2 The prism and signal acquisition system
3. RESULTS AND DISCUSSION

3.1 Fluid Pulsation Induced Pressure Fluctuation

Under the annular flow regime, the flowrates of air and water were adjusted randomly to produce various flow conditions. The pressure difference between the upstream and downstream of the prism was adopted as the characteristic parameter representing the fluid pulsation. A series of experiments were conducted at different gas mass qualities \( x = \frac{G_g}{G_g + G_l} \). Due to the restriction of the laboratory condition, the gas mass quality of the annular flow cannot exceed 0.31. The sampling rate of 1000 Hz was adopted in the experiments and 10000 points were included in each data set. Fig.3 presents the fluid pulsation induced pressure fluctuations under some typical gas mass qualities. It is seen that there are obvious fluctuations in the measured pressure differences, which reveals the fluid pulsation behind the prism in annular flows. Moreover, this pulsation is more marked at low gas mass qualities than those at high gas mass qualities. When \( x \) is less than 0.1, the maximum amplitude of the pressure fluctuation is basically greater than 5 kPa. However, when \( x \) is from 0.1 to 0.31, the amplitude of the pressure fluctuation is basically within 3 kPa. In addition, the power spectral densities of the pressure fluctuation were also calculated, and results show that the major frequency components were concentrated on the frequency band from 1–10 Hz.

![Fig. 3 The fluid pulsation induced pressure fluctuations](image)

2.2 Average Pressure Fluctuation

The pressure fluctuation induced by the fluid pulsation is strongly affected by the gas and liquid component contents of the two-phase flow which is a random and nonlinear process. To analyze the whole property of the pressure fluctuation, the time average value of the pressure fluctuation were calculated. The time average pressure fluctuation can represent the integral energy of the fluid pulsation.

Fig.4 shows the relationship between the average pressure fluctuation and the gas mass quality. It is obvious that the average pressure fluctuation is closely concerned with the gas mass quality. When \( x = 0.05–0.15 \), the average pressure distributes from 1.2 to 2.3 kPa; when \( x = 0.15–0.2 \), the average pressure assembles around 1 kPa; and when \( x = 0.2–0.31 \), the average pressure distributes mainly from 0.6 to 1 kPa. On the whole, the average pressure decreases with the gas mass quality.
Fig. 5 presents the relationship between the average pressure fluctuation and the gas-liquid total mass flowrate. The average pressure increases basically with the gas-liquid total mass flowrate. It is interesting that the average pressure differs from each other under the same gas-liquid total mass flowrate. This difference mainly results from the different gas mass quality of the annular flow in which the signal was acquired.

![Graph](image1)

**Fig. 4** Average pressure fluctuation versus gas mass quality

![Graph](image2)

**Fig. 5** Average pressure fluctuation versus total mass flowrate

3. CONCLUSIONS
The fluid pulsation behind a prism in gas-liquid annular flows was explored in this paper. The pressure difference between the upstream and downstream of the prism was used to represent the characteristics of the fluid pulsation. Based on the experimental results, it is found that there exit obvious pulsations in the fluid behind the prism in annular flows, and this pulsation is more marked at low gas mass qualities than those at high gas mass qualities. Furthermore, the average pressure decreases basically with the gas mass quality and increases with the gas-liquid total mass flowrate.

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**NOMENCLATURE**

- \( b \) blockage ratio
- \( D \) inner diameter of pipe [m]
- \( d \) width of prism [m]
- \( G \) mass flowrate [kg/h]
- \( Q \) volume flowrate \([m^3/h]\)
- \( x \) gas mass quality

**Subscripts**

- \( G \) gas-phase component
- \( L \) liquid-phase component
- \( TP \) two-phase flow

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