Study on a void fraction measurement method of gas-liquid two-phase stratified flow

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Abstract

Void fraction as one of the basic parameters of gas-liquid two-phase flow is of great significance to the development and transportation of petroleum pipelines and the design of nuclear reactor cooling towers. This paper proposes a void fraction detection method based on PIV technology, which can obtain the velocity distribution and void fraction of the cross-section at the same time. During the experiment, the truth-value of void fraction of the cross section is obtained by installing an endoscopic camera at the back of the test section. The deviation of the void fraction obtained by the two detection techniques is calculated and corrected, and the maximum deviation is only 0.0246. The results show that the method proposed is effective for measuring the void fraction of gas-liquid two-phase stratified flow.

1. Introduction

Gas-liquid two-phase flow is a very important flow form in the field of two-phase flow, which widely exists in industrial production processes such as petroleum, chemical industry, natural gas exploitation, and nuclear reactor [1]. As one of the key parameters in the process of gas-liquid two-phase flow, the void fraction reflects the real proportion of gas phase in the pipeline flow and has an important impact on the flow pressure drop, phase separation metering, and heat transfer characteristics in the process of two-phase flow in industrial production [2-3]. Qian and Hrnjak [4] measured flow pattern and void fraction in horizontal and vertical circular smooth tubes with R134a at adiabatic conditions and low mass flow with a high-speed camera and a quick-closing valve in ID7mm. The results of void fraction measurements in horizontal and vertical were compared with some correlations and the effects of column orientation and mass flow on void fraction were discussed. Lynch and Segel [5] with nuclear magnetic resonance technology to measure the linearity of porosity in gas-liquid two-phase flow over a full range (0-1), independent of the liquid mass distribution, and demonstrated the feasibility of this method. Park and Kim [6] with a single sensor optical fiber probe to measure bubbles' void fraction and velocity under subcooled boiling conditions. The results show that the distribution of void fraction along the radial direction of the flow path changes with the change of flow conditions. Kyle and Yang [7] developed a compact X-ray density measurement system for two-phase flow measurement, in which the voids and velocity distributions of bubble and slug flows were measured in a 25.4 mm inside diameter gas-water two-phase flow test loop. Compared with the gas flowmeter, the apparent gas velocity error measured by this system is within ±4%. Jia and Wang [8] with a pressure sensor to calculate void fraction in gas-liquid flow and re-derived the pressure differential model based on energy conservation based on several assumptions. The experimental results show that the void fraction obtained by the differential pressure model is in good agreement with that obtained by electrical resistance tomography (ERT) and wire-mesh sensor (WMS). Pochet and Teyssedou [9] proposed using the microwave to a non-invasive reflective void fraction measurement system that accurately controls the water injection and gas volume of the system. Compared with the simulation results, it is verified that the system is suitable for the study of water air two-phase mixture. Olerni, Jia, and Wang [10] with ERT and WMS to simultaneously measure the upward air-water flow. The results show that the two instruments have good consistency in the overall porosity of bubble flow. For slug flow, ERT underestimates the porosity when the porosity exceeds 30%, but there is still a linear relationship between ERT and WMS.

Based on different physical principles such as optics, electricity and acoustics, predecessors have proposed many methods to measure the void fraction of cross-section, which can be divided into two categories: intrusive and non-invasive, which is of interest to more and more researchers because of its advantages of not disturbing the flow field. In this paper, a new cross-section void fraction measurement method is studied by using particle image velocimetry (PIV) technology, and it is verified by the real cross-section void fraction captured by the pipeline endoscope camera, which shows the feasibility of this method.

2. Experiment setup

The experiment was completed on a set of gas-liquid two-phase flow standard circulation devices. The main pipe section of the experiment consists of stainless steel front straight pipe section (1300cm length, 5cm inside diameter, and 0.5cm wall thickness), high transparency acrylic test pipe section (40cm length, 5cm inside diameter, and 0.5cm wall thickness) and stainless steel rear straight pipe section (830cm length, 5cm inside diameter and 0.5cm wall thickness) The distance between the test section and the front/back straight pipe section at the gas-liquid mixing point is 260D / 166D respectively, which can ensure the full flow of fluid in the pipeline, and the fluid in the test section is not disturbed by the local resistance loss of the fluid flowing out of the back straight pipe section. The experimental fluid is air and city water. The liquid phase and gas phase flow are measured by Coriolis liquid mass flowmeter (range: 0-2 m/s, accuracy: 0.5%) and Coriolis gas mass flowmeter (range: 0-15 m/s, accuracy: 0.1%). The flow is controlled by regulating the valve.

The 2D3C PIV system is used to measure the test section. The system adopts a double pulse laser with wavelength of 532nm. The laser passes through the light guide arm and sheet light source lens and hits the normal direction of the pipe vertically in the form of surface light. Based on the principle similar to biological binocular vision, the two CCD cameras with a resolution of 6600 * 4400 pixel focuses on the cross-section illuminated by the laser at the angle of the vertical optical correction box viewable window. The endoscope is installed at the rear 15D of the test section, and is connected with the PIV system through the synchronous controller to obtain the real value of the void fraction. The experimental device is shown in Figure 1.

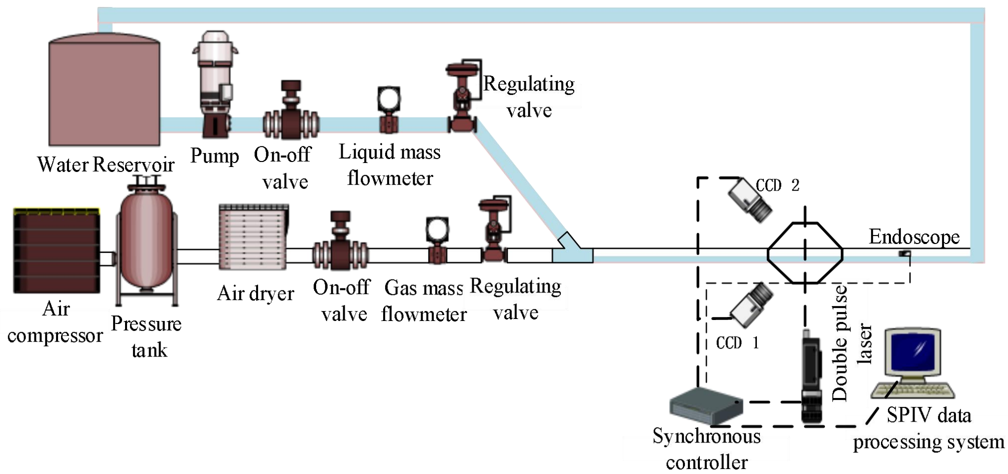

Figure 1: System diagram of experimental device.

3. Study on void fraction detection technology

3.1 PIV technology obtain void fraction

The PIV technology is used to obtain the gas phase velocity distribution in the cross section of smooth stratified flow in horizontal pipeline, in which the gas phase tracer particles are DEHS particles with a particle size of about 5 microns under high pressure atomization. The experimental flow points are shown in the Baker[11] horizontal gas-liquid two-phase flow pattern diagram. The 14 flow points are located in the stratified flow region, as shown in Figure 2. The particle images captured by two cameras can be obtained by a series of methods, such as two-dimensional cross-correlation operation, the establishment of spatial computing grid, three-dimensional velocity field calculation, velocity field correction algorithm, and so on, to obtain the instantaneous and time-averaged velocity field. The area of the gas phase velocity field is obtained by binarization of the velocity nephogram, and compared with the full pipe velocity area under the same working conditions, the void fraction obtained by 2D3C PIV technology is obtained. As shown in Figure 3.

3.2 The endoscope obtain void fraction

The endoscope is installed at the back of the test section (the central position of the cross-section of the pipe). Figure 4 shows the flow chart of using the endoscope to obtain the void fraction. Figure 4 (b) identifies the boundary of the original image of the cross section of the pipe captured by the endoscope camera, A-obtains the intersection line between the gas-liquid interface and the pipe wall, B- determines the clear cross-sectional profile of the pipe illuminated by laser, C- draw a horizontal line at the intersection of step A and B, which is the gas-liquid interface.

4. Verification of measurement method for void fraction

Through the experiment of smooth stratified flow at different flow points, the experimental results are shown in Figure 5. V0.1 and V0.07 represent the liquid phase volume flow of 0.1m^3/h and 0.07m^3/h respectively, the abscissa is the gas phase volume flow, and the ordinate is the value of the corresponding section void fraction at different flow points. The dotted line represents the sectional void fraction value obtained by PIV technology, and the solid line represents the sectional void fraction value obtained by endoscope. It can be seen from the figure that when the liquid phase is fixed, the section void fraction increases with the increase of the gas phase volume flow value, which indicates that due to the effect of the shear force between the gas and liquid phases, the gas phase increase will push the liquid phase fluid in the pipeline out of the pipeline, resulting in the decrease of the liquid level in the pipeline, the decrease of the liquid phase holdup, and the increase of the gas phase holdup. As shown in Figure 6, the results of the two detection techniques after correction have good consistency, and the maximum deviation is only 0.0246, which is an acceptable deviation.

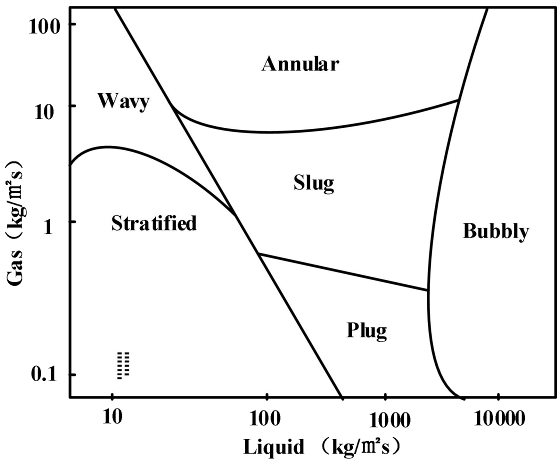

Figure 2: Flow pattern map.

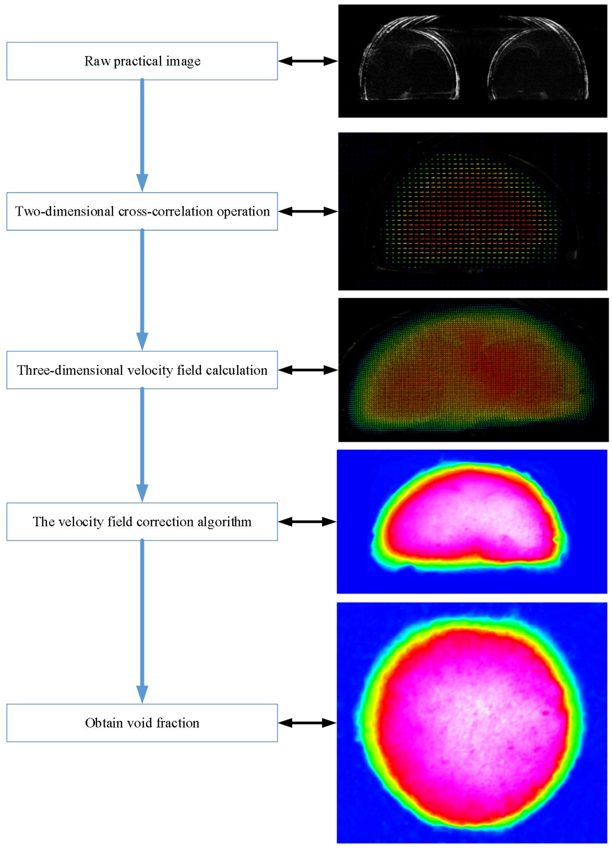

Figure 3: Velocity Field in Cross Section of Pipeline obtained by 2D3C PIV Technology.

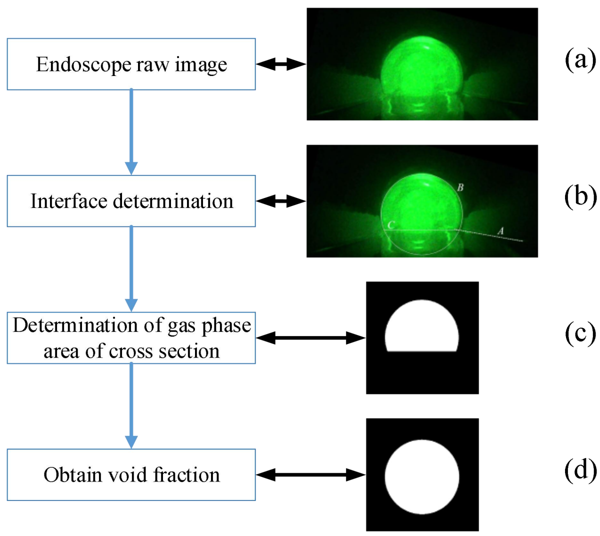

Figure 4: Void fraction obtained by endoscope.

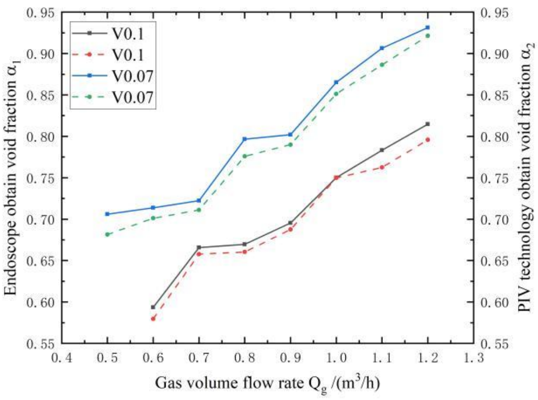

Figure 5: Variation of void fraction at different flow points

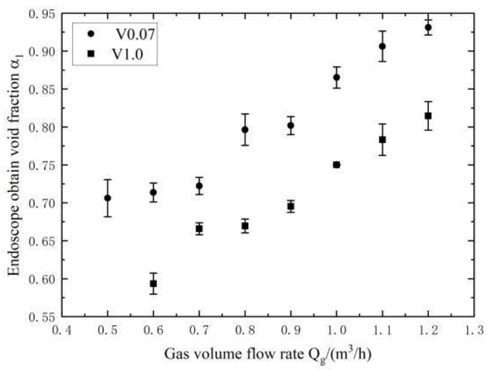

Figure 6: Deviation diagram of the measurement results with two void fraction detection technologies

7. Conclusion

In this paper, the PIV technique is used to measure the gas phase velocity field distribution of the horizontal pipeline gas-liquid two-phase smooth stratified flow pattern at different flow points. The velocity nephogram is binarized, and compared with the full pipe velocity field, the void fraction is obtained. At the same time, the raw image of the cross section is obtained directly at the back of the test section by endoscope camera, and the truth-value void fraction is obtained by boundary recognition and binarization. By comparing the interface void fraction obtained by PIV technology with the endoscope void fraction, the maximum deviation is only 0.0246, which shows that the void fraction detection method proposed in this paper is effective.References

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