An Average Bidirectional Flow Tube for the Measurement of Two Phase Flow Rate in the Horizontal Stratified Flow Condition

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1. Introduction

An average BDFT (*Bi**D**irectional **F**low **T**ube*), was suggested for a measurement of the two phase stratified flow in the horizontal pipe. Its working principle is similar to that of the Pitot tube. The pressure measured at the front of the flow tube is equal to the total pressure, while that measured at the rear tube is slightly less than static pressure of flow field due to the suction effect at the downstream. The proposed instrumentation has the characteristics that it could be applicable to low flow condition and measure bidirectional flow. It was already tested in the vertical pipe under the single and two phase flow condition[1,2,3]. In this paper, the application of the bidirectional flow tube was extended to the measurement of the stratified two phase flow in the horizontal pipe. For this, the average BDFT was tested in the air-water horizontal test section. The pressure difference across the average bidirectional flow tube, system pressure, average void fraction and injection phasic mass flow rates were measured on the measuring plane. In order to measure directly each phasic flow rate, two differential pressure transmitters were installed on the top and bottom of the flow tube. For the calculation of the phasic flow rates from them, a momentum balance was set up at inside the flow tube. The test results showed that the suggested bidirectional flow tube is applicable to the measurement of the phasic velocity in a stratified two phase flow.

2. Experimental Facility and Instrumentations

The horizontal air/water loop consists of a test section, an inlet reservoir, an outlet reservoir, a water supply system, an air supply system, a water storage tank and a data acquisition system. Fig. 3 shows schematics of the horizontal loop. The test section is composed of a transparent acryl pipe whose diameter is 0.08m and length is 4.2m. The inlet reservoir is an entrance of the test section for a single or air-water two phase flow. The outlet reservoir is mainly for a phase separation of the two phase flow out of the test section. The separated air is vented to the atmosphere and the water is drained into the water storage tank. The system pressure is not controlled. The water supply system consists of four vertical pumps and a flow control valve. The maximum water flow rate is 12 kg/s. The air flow system consists of four roots type blowers and the maximum air flow rate is 1.6 kg/s at atmospheric pressure.

In the test facility, several instrumentations are equipped for a precise measurement of the single and two phase flow parameters. A CVM(Capacitance Void Meter) is installed at 36 L/D from the entrance of the test section. The uncertainty of the average void fraction measured by the CVM is estimated at less than ±1.75% for a reading above 20% of the void fraction range. An average bidirectional flow tube is installed at 37 L/D from the entrance. The pressure difference across the flow tube is measured by two Rosemount SMART type 3051CD differential pressure transmitters. A static pressure transmitter is also installed between them. The uncertainty of the measured pressure and differential pressure transmitters are ±0.11% of the span. A Coriolis mass flow meter(Rosemount CMF 200) is installed at the inlet of the test section to measure the water flow rate. The measurement error of the water flow is estimated as ±0.4%. The air flow rate is measured by a combination of a vortex meter, a pressure transmitter and a TC which are installed at the inlet pipe of the test section. The uncertainty of the measured air flow rate is estimated as ±1.1% of a reading. The estimated uncertainty of the temperature measurement is ±2.2K.

3. Experiments and Results

Test was performed in the stratified flow condition. In the test, the flow regime was limited to a stratified flow. The void fraction was changed from 35% to 94%, and the phasic velocity ranges were 0.3-1.2m/sec and 3.0-18m/sec for the water and air flows, respectively. Here, the two differential pressure transmitters are installed at the top and bottom of the average bidirectional flow tube, respectively. One is for the pressure difference of the gas phase and the other is for that of the two phases. In order to calculate the two phase mass flow rate from the measured differential pressures across the flow tube, a physical modeling should be implemented. Fig. 4

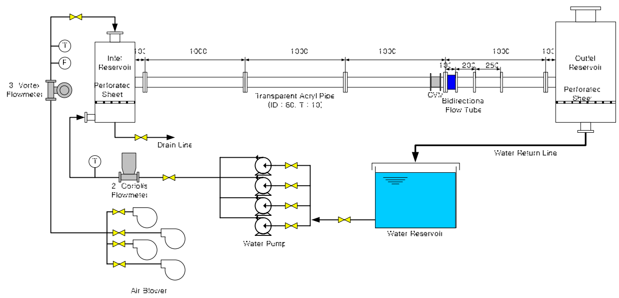

Figure 1. Schematics of horizontal test facility

shows an illustration of a momentum balance inside the average bidirectional flow tube. From the momentum balance of a gas phase, the measured pressure difference is expressed as follows,

$$\Delta p_g = k_g{}^2 \frac{1}{2}\rho_g V_g^2 \qquad (1)$$

While, the momentum balance at the bottom of the flow tube is somewhat complex because it contains both momentums of the two phases. In the front inside of the flow tube, the momentum of water is converted to the head of water column. However, the water column may be suspended by the approaching gas phase and thus the measured pressure difference at the bottom may be reduced. In order to consider this liquid hold up phenomena, the liquid holdup factor, J is introduced. Finally, the measured pressure difference at the bottom is expressed as follows,

$$\Delta p = \Delta p_g + J \cdot k_f{}^2 \frac{1}{2}\rho_f V_f^2 (1 - \frac{\rho_g}{\rho_f}) \qquad (2)$$

Here, the liquid holdup factor, J is obtained by a substitution of the measured Δp_g and liquid mass flow rate into the eqs.(1) and (2). The liquid holdup is similar with that of flooding phenomena in the counter-current flow, and thus it is correlated by the ratio of the Wallis number, β_w, as follows,

$$J = (1 - \beta_w{}^{3.2})^{1.15} \qquad (3)$$

where

$$\beta_w = \frac{j_g}{j_g + \sqrt{\rho_f / \rho_g}\, j_f}$$

The phasic velocity is obtained by combination of eqs (1),(2) and (3) . Figures 4 and 5 show the plots of measurements. They show that the suggested instrumentation and a measurement method can predict the phasic velocity to within a ± 15% error.

4. Conclusion

An average bidirectional flow tube was suggested for a measurement of the mass flow rate in the stratified two phase flow condition. For this, a momentum balance at the BDFT is set up and a correlation of the liquid holdup factor is suggested. The experimental results show that the suggested instrumentation and a measurement method can be used successfully to the measurement of a stratified flow.

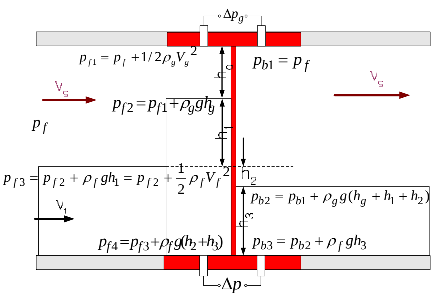

Figure 2. Pressure balance model in the BDFT

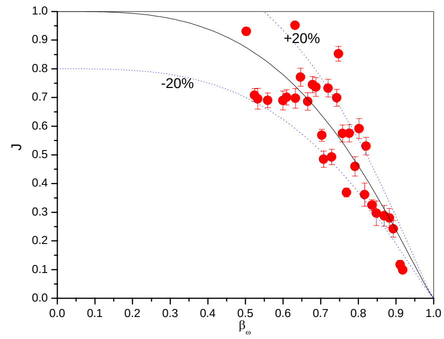

Figure 3. Liquid holdup factor J

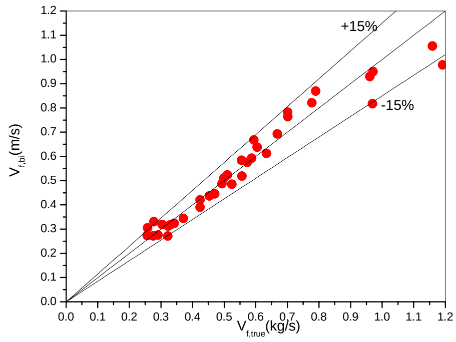

Figure 4. Comparison of predicted and true V_f

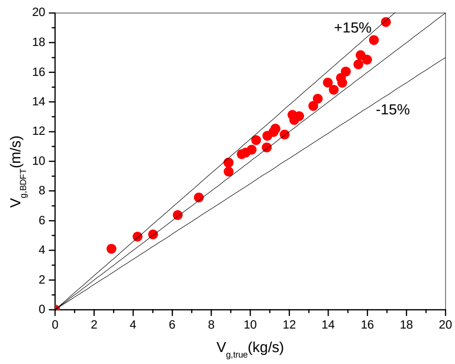

Figure 5. Comparison of predicted and true V_g

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