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Measurement uncertainty and flow pattern transition in two-phase bubbly flow through venturi tube

Dong-Wook Oh [a*], Seo Hyun Kim [a], Seok Ho Yoon [a], Kyu Hyung Do [a], Jungho Lee [a] and Heung June Chung [b]
[a] *Energy Plant Research Division, Korean Institute of Machinery and Materials*
[b] *Department of Nuclear Safety Research, Korean Atomic Energy Research Institute*
[*] *Corresponding author: dwoh@kimm.re.kr*

1. Introduction

Precise flow rate measurement in a two-phase fluid flow is one of challenging issues in nuclear engineering. Liquid flow containing air void may cause local pressure perturbations which can distract the sensor reading. Venturi tube is one of the most simple flow rate measurement device that is frequently used in two-phase flow system. Venturi has been widely used to measure flow rate of liquids and gases in a variety of engineering applications due to its relatively low pressure loss and simplicity.

In this study, the effect of different volume fractions of air void (void fraction) on flow rate measurement uncertainty is investigated to analyze flow rate measurement using a venturi tube. The uncertainty of the flow rate measurement has been analyzed based on the ANSI/ASME PTC 19.1-2005 standard. Flow pattern transition, from bubbly flow to slug flow, is also detected through fast Fourier transform (FFT) analysis of the differential pressure signal from flow rate measurement through a venturi tube.

2. Experimental Method and Results

2.1Experimental Details

The schematic diagram of the experimental apparatus is shown in Fig. 1. The test loop consists of a circulation pump, globe and butterfly valves, venturi tube and reservoir. Inner diameter of the main flow pipe is 50.8 mm (2 inch). Inverter controlled vertical multi-stage pump is used for controlling a water flow rate in a test loop. Air bubbles are injected to the main flow through a bubble generator. Bubble generator has a cylindrical porous medium with 20% mean porosity and provides vesicle size of 30~50 μm. For accurate control of the water-air volume ratio, a mass flow controller is used to adjust the air flow rate from the compressor [1].

Venturi has a diameter ratio of 0.5 and the discharge coefficient of 0.994. The electromagnetic flow meter (FMG606, OMEGA), with measurement uncertainty of approximately 0.2%, is installed in front of the venturi tube for reference flow rate measurement. The differential pressure of Venturi is measured by a pressure transmitter (EJA110-DMS, YOKOGAWA) with range varying from 0 to 2,500 mmH_2O. The temperature of the working fluid is monitored by K-type thermocouple and its temperature is also used to calculate the density of water. Differential pressure reading from the venturi is recorded by a data acquisition board with 50 Hz of sampling rate for FFT analysis. Data from the electromagnetic flow meter and thermocouple are recorded in 1 Hz for the uncertainty analysis.

2.2 Uncertainty Analysis

The flow rate measurement through a venturi can be determined by 5 independent variables and can be expressed as the following equation.

$$Q_{mass} = \rho C_D A_2 \sqrt{\frac{2\Delta p}{\rho\left(1-\beta^4\right)}} \quad (1)$$

Here A_2 is throat area, C_d is discharge coefficient, Δp is the measured differential pressure, ρ is density of the working fluid, and β is diameter ratio of the Venturi.

Each of the variables in equation (1) should be carefully considered to determine the individual uncertainties and their propagations to other dependent variables. Firstly, random standard and systematic standard uncertainties are fundamentally defined. Then the combined standard uncertainty is calculated using each calculated uncertainties. The expanded uncertainty can be achieved within 95% confidence level. Throughout this study, the uncertainty analysis has been accordingly estimated by the ANSI/ASME PTC 19.1-2005 [2]. The details of uncertainty analysis procedure are minutely described in authors' previous study. [1]

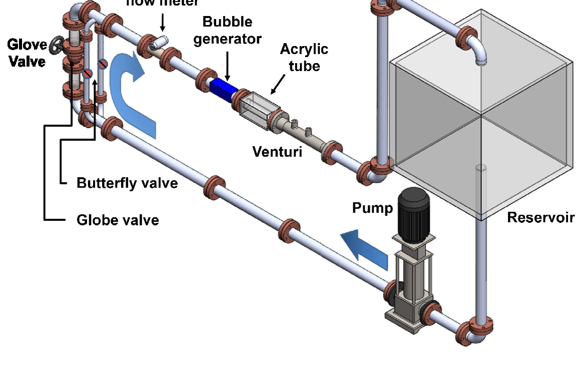

Fig. 1. Experimental apparatus of a closed water flow loop with air bubble generator and a venturi tube.

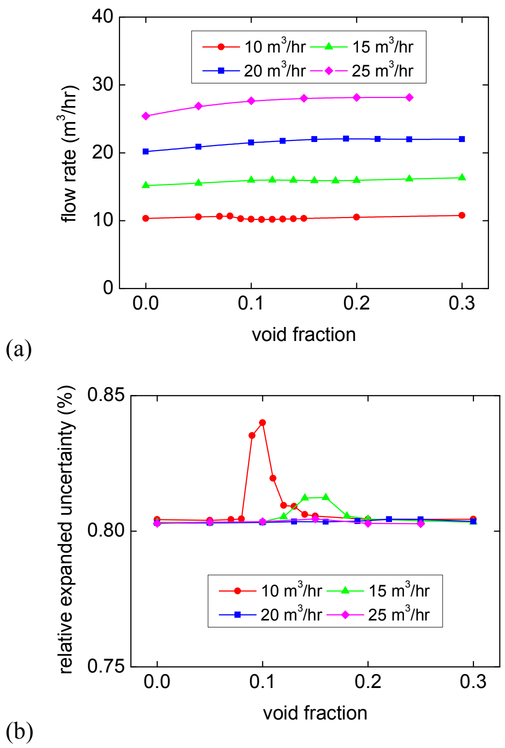

Fig. 2. Experimental results are shown. (a) Flow rates measured from the venturi with various void fractions. (b) The evaluation of measurement uncertainty by void fraction variation.

2.3 Result and Discussion

Fig. 2 shows the calculated flow rate by measuring Δp and using Eqn. (1). Gradual increase in measured flow rate exhibits an increase in void fraction, when comparing to the electromagnetic flow meter reading. At lowest flow rate (10 m^3/h), venturi flow rate is slightly decreased as the void fraction exceeds around 0.09, as shown in Fig. 2 (a). Sudden increase in uncertainty can be shown in void fraction ranging from 0.09 - 0.15 and 0.12 - 0.18 for 10 m^3/hr flow rate and for 15 m^3/hr flow rate, respectively as shown in Fig. 2 (b). This is due to differential pressure fluctuations at such void fraction ranges, which caused by sudden increase of random standard uncertainty of Δp in Eqn. (1). At higher flow rates (over 20 m^3/hr), the uncertainty remains constant regardless of the void fraction.

Flow pattern is also observed through a transparent acrylic tube installed at upstream of the venturi tube. The flow pattern is changed to slug flow from bubbly flow with increasing the void fraction. At low void fraction rates, separated air bubbles rises to the top of the tube. As the void fraction increases, though air bubbles are not longer present and so bulky voids takes up the top part of the pipe.

It has been found that the onset of flow pattern transition, from bubbly flow to slug flow, unsteady signal of 0.5 Hz is detected in the electrical impedance probe embedded in water-air flow loop [3].

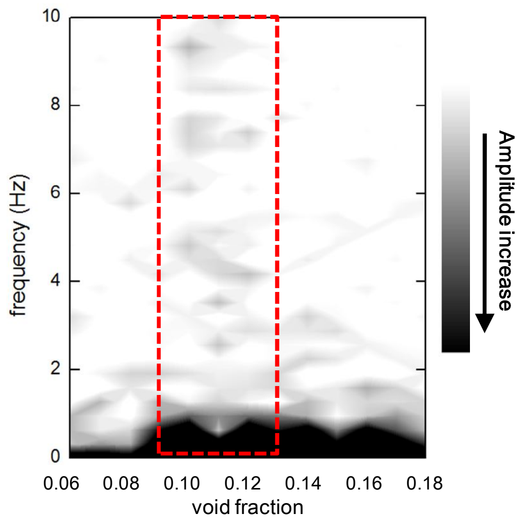

Fig. 3. FFT result of differential pressure signal recorded for the water flow rate of 10 m^3/hr.

To verify the reason of uncertainty peak and its relationship with the flow pattern transition, FFT analysis is performed for recorded Δp data at 10 m^3/hr flow rate measurement. The differential pressure signal recorded in sampling rate of 50 Hz and its FFT result is shown in Fig. 3. Clear increase in frequency signal of 0.5 Hz (black area) indicates that the void fraction is increased above the void fraction of 0.09. Furthermore, higher frequency component of 2 - 10 Hz is also visible for void fraction ranging from 0.10 to 0.12 as shown in red dotted area. Presence of this distinct frequency component implies that the uncertainty peaking is due to flow pattern transition which from bubbly to slug flow.

3. Conclusions

In this study, uncertainty analysis of flow rate measurement of a venturi is performed at water flow containing various air void fractions. The relative expanded uncertainty of the venturi is found to be around 0.8%. Sudden increase in the uncertainty value is observed at low water flow rate case. Through the frequency domain transformation of the differential pressure signal of the venturi, flow pattern transition from bubbly to slug flow is found to be a reasonable peak in the uncertainty. As the water flow rate is increased, some delay in flow pattern transition with increasing flow rate is also observed.

REFERENCES

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