Water Level Measurement of the Stratified Flow using Ring-Type Impedance Sensor

Sung Yong Lee [a], Min Seok Ko [a], Bo An Lee [b], Byong Jo Yun [c], Sin Kim [a,b*]
[a]*Department of Nuclear and Energy Engineering, Jeju National University*
[b]*Institute for Nuclear Science and Technology, Jeju National University*
[c]*Department of Mechanical Engineering, Pusan National University*
[*]*Corresponding author: sinkim@jejunu.ac.kr*

1. Introduction

It is very important issues to monitor the phase distribution, void fraction and water level for effective design and analysis of system in various engineering fields such as chemical and nuclear industry.
For these reasons various measurement techniques have been proposed, for example, radiation [1], micro wave [2], ultrasonic [3], and electrical impedance method [4]. However, most techniques have limitations in terms of economic point of view and also these are difficult to apply to the case of the rapid change of phase distributions. The probe level meter which has been widely used for water level measurement tends to disturb the flow fields, in case of ultrasonic level meter water level measurement can be hard when numerous bubbles forms in the interface of two phases.

This study considers electrical impedance method which does not disturb the flow field and is simple to design. In this work, a ring-type sensor was designed to measure the water level in the stratified regime. Also, measured water levels converted from the sensor signal were compared with those captured by high-speed camara.

2. Methods and Results

2.1 Experimental apparatus

The experimental facility consists of a horizontal test section, water and air supply systems, temperature control devices, a pump and a storage tank. The working fluids, air and water, were controlled by Coriolis flow meters and rotameters. The horizontal test section was made from acryl pipe with 40mm inner diameter and its length is roughly 5.4m. The ring-type sensor and high-speed camera were installed in the location 4.6m far from the entrance in order to describe the fully develop condition.

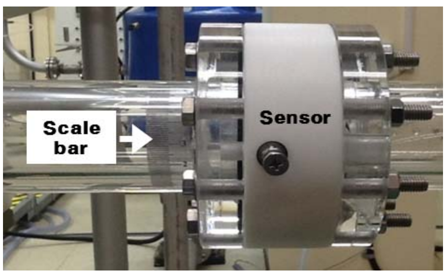


Fig. 1. Photograph of horizontal test section including ring-type impedance sensor and scale bar

2.2 High-Speed Camera

The high-speed camera manufactured by Photron, a Japanese company, can shoot the two-phase flow in the maximum 500,000fps. Along with this, lights and diffuser were used for acquisition of clear image. In order to decipher the water level from high-speed camera images, a scale bar was attached to the inner wall of the pipe as shown in Fig. 1.

The water level from high speed camera images is determined by the following geometrical relation.

$$H = r\left[1-\cos\left(\frac{S}{r}\right)\right] \tag{1}$$

where, H , S , and r denote the water level, measured arc-length of the scale bar, and pipe inner radius, as shown in Fig. 2.

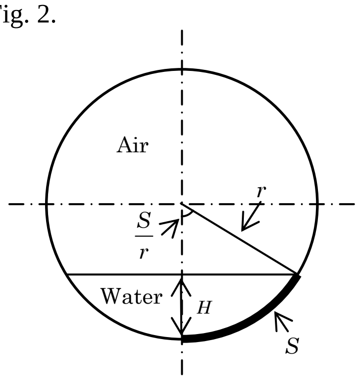


Fig. 2. Geometry of stratified flow

2.3 Ring-Type Impedance Sensor

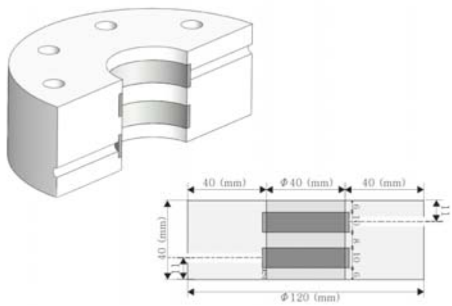
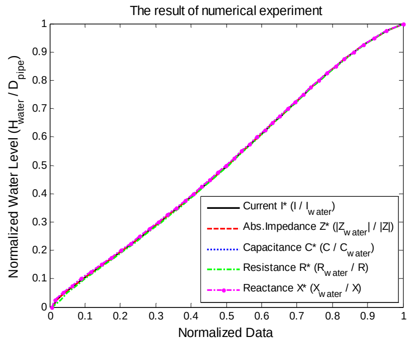
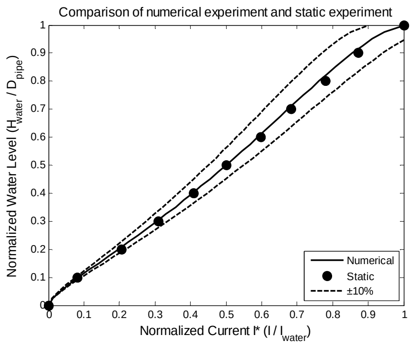


Fig. 3. Drawing of the ring-type impedance sensor

The ring-type sensor was made from Teflon material and SUS 304. The detailed geometry is given by Fig. 3. Prior to application of designed sensor to real situations, in order to make a reference preparatory calculations for the relationship between the electrical signal and normalized water level ($H^* = H / D$) have been performed based on the finite element method. Figure 4(a) shows the relationship between the normalized water level and electrical signal obtained from numerical calculation, and Fig. 4(b) shows the comparison result between calculation and static experiments.



(a)



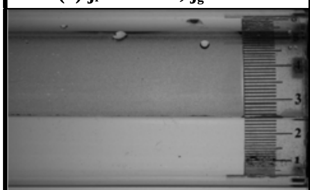
(b)

Fig. 4. (a) Relationship between electrical signals and the water level based on numerical calculation, (b) Comparison of numerical calculation with static experiment

2.4 Experimental results

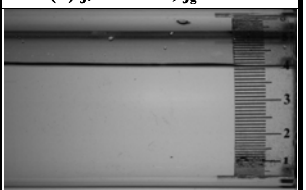
Table I: Comparison of measure water levels between high-speed camera and ring-type sensor

(a) j_l=0.03m/s, j_g=0m/s



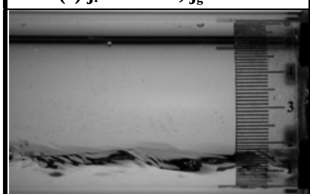
	Cam	Sensor				
		I	|Z|	C	R	X
H*	0.34	0.35	0.35	0.32	0.37	0.32

(b) j_l=0.13m/s, j_g=0m/s



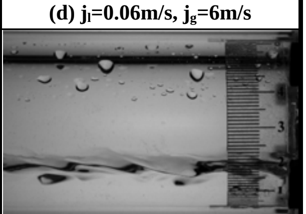
	Cam	Sensor				
		I	|Z|	C	R	X
H*	0.71	0.71	0.71	0.67	0.71	0.69

(c) j_l=0.03m/s, j_g=8m/s



	Cam	Sensor				
		I	|Z|	C	R	X
H*	0.15	0.15	0.14	0.12	0.18	0.12

(d) j_l=0.06m/s, j_g=6m/s



	Cam	Sensor				
		I	|Z|	C	R	X
H*	0.23	0.23	0.22	0.20	0.25	0.20

The electrical signal was converted into the normalized water level by applying measured signal to precalculted water level–electrical signal relationship given in Fig. 4. Table I shows some examples of measured water level from ring-type sensor and those from high speed camera for various flow rate conditions.

In this Table, j_l and j_g denote the superficial liquid and gas velocity, respectively. Also, 'Cam' represents the water levels measured by high-speed camera image analyses, and I, |Z|, C, R, and X denote those converted from the electrical current, impedance, capacitance, resistance, and reactance, respectively. On the whole, measured water levels from ring-type sensor signals well match those of high-speed camera even though some mismatches are observed in case of capacitance and reactance. These mismatches may be due to the sensitive characteristic of these RLC circuit components.

3. Conclusions

In this work, a ring-type sensor was designed to measure the water level in the stratified regime. Prior to loop experiments, as a reference the relationship between the electrical signal and normalized water level was constructed based on numerical calculation and this relationship was compared with static phantom experiments. In addition, a designed ring-type sensor was installed in the horizontal test section and sensor signals for various water levels created by a variety of flow rate conditions were measured. By applying these measured signals to precalculated lookup table, corresponding water levels were evaluated. Also, these results were successfully compared with those of images captured by high-speed camera.

ACKNOWLEDGMENTS

This work was supported by Priority Research Centers Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology (2012-0005855).

REFERENCES

[1] R. W. Pike, Bert Wilkins Jr., H. C. Ward, Measurement of the Void Fraction in Two-Phase Flow by X-Ray Attenuation, American Institute of Chemical Engineers, Vol.11, Issue 5, p.794, 1965.

[2] J. D. Boon, J. M. Brubaker, Acoustic-Microwave Water Level Sensor Comparisons in an Estuarine Environment, Proceedings, MTS/IEEE Oceans'08 International Conference, Quebec, Canada, 2008.

[3] P. Hauptmann, N. Hoppe, A. Puttmer, Application of Ultrasonic Sensors in the Process Industry, Measurement Science and Technology, Vol.13, Number 8, Review Article 73, 2002.

[4] M. W. E. Coney, The Theory and Application of Conductance Probe for the Measurement of Liquid Film Thickness in Two Phase Flow, Journal of Physics E: Scientific Instruments, Vol.6, Number 9, P.903, 1973.