Preparatory research for development of a capacitance sensor monitoring the liquid fraction in an inclined pipe

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1. Introduction

Two-phase flow is a highly general phenomenon in various engineering fields including thermal-hydraulic systems of the nuclear power plant. In particular, the liquid fraction in two-phase system is one of the most important parameters to be considered for efficient system design and analysis. There have been various methods for the liquid fraction measurement. Wojtan et al. employed an optical fiber for liquid fraction measurement [1]. Elkow and Rezkallah adopted the capacitance signal [2], Tsochatzidis et al. [3] and Fossa [4] used the conductance response in order to monitor the liquid fraction in various two-phase flow regimes.

The electrical methods are based on the fact that the liquid and gas have different conductivity and permittivity values, and these electrical properties directly correspond to phase distributions. In the capacitance method, in particular, one or more pairs of electrodes attached inside or outside the pipe wall measure the capacitance between electrode pairs and this measured capacitance signal is directly converted to the liquid fraction.

In this work, as a preparatory research for development of a capacitance sensor monitoring the liquid fraction in an inclined pipe whose diameter and inclination angle are 45mm and 3rad, respectively, a capacitance is designed. Also, data evaluation procedures of a wire-mesh sensor which would be employed for the verification of capacitance sensor performance are verified by comparing static experiments.

2. Experiments

2.1 Capacitance sensor

When the dielectric material occupies inside electrical sensors, the charge flows for given voltage difference, and this charge directly affects the capacitance signal by the relation $C = Q/\Delta V$. Here, C is the capacitance on the sensor, Q denotes the charge on the sensor which can be evaluated by the charge density on the sensor, and ΔV represents applied voltage difference. In general, the charge flow is directly dependent on the dielectric material volume which can be converted into the liquid fraction.

In order to obtain the relationship between the capacitance signal and liquid fraction, COMSOL Multiphysics based on the finite element method is adopted. In numerical simulations, the plate-type capacitance sensor which consists of two electrodes facing each other is considered. For the verification of calculated relationship, the capacitance sensor with 3 rad gap angle is designed, and static phantom experiments are conducted by inserting the measured water volume into the capacitance sensor. Figures 1 and 2 show the designed capacitance sensor and the comparison between the numerical and experimental results. In Fig. 2, the *x* axis denotes the dimensionless capacitance which is defined as:

$$C^* = \frac{C - C_\ell}{C_g - C_\ell} \quad (1)$$

where C represents the capacitance response for an arbitrary liquid fraction, and C_ℓ and C_g are capacitance for $\alpha_\ell = 1$ and $\alpha_\ell = 0$, respectively. Here, α_ℓ is the liquid fraction which is represented by *y* axis of Fig. 2. The comparison results show a very good agreement.

2.2 Conductivity wire-mesh sensor

The wire-mesh sensor consists of 16×16 wires whose thicknesses are 0.125 mm, one layer of 16 wire electrodes serves as transmitter, the other as receiver. The separation distance of each wire electrode is 2.8125 mm and that between each layer is 1.4mm. The photograph of the wire-mesh sensor is given in Fig. 3.

For given applied voltage difference between the transmitter and receiver wires, the electrical current flows through them. If the current is assumed to flow directly proportional to the conductive media volume, that is, the linear relationship between the electrical signal and liquid fraction can be assumed, then the local liquid fraction can be evaluated as:

$$\alpha_{\ell,i,j,k} = \frac{U_{meas,i,j,k}}{U_{liquid,i,j,k}} \quad (2)$$

where *i*, *j*, and *k* denote the indices of crossing points of transmitter and receiver and measurement frame, respectively. Also, $U_{meas,i,j,k}$ and $U_{liquid,i,j,k}$ represents the voltage values for an arbitrary liquid fraction and liquid filled homogeneous case. The area-averaged void fraction can then be obtained by summing Eq. (1) for all crossing points. That is,

$$\bar{\alpha}_{\ell,k} = \sum_i \sum_j a_{i,j} \alpha_{\ell,i,j,k} \quad (3)$$

where $a_{i,j}$ is a geometrical factor which ranges from 3.5 % ~ 99.6%. Finally, the time-averaged liquid fraction can be obtained by averaging the liquid fraction over the frame. That is,

$$\tilde{\alpha}_{\ell} = \frac{1}{N} \sum_{k=1}^{N} \bar{\alpha}_{\ell,k} \quad (4)$$

where N is the number of the frame. These data evaluation procedures are successfully verified by comparing static experiments as shown in Fig. 4.

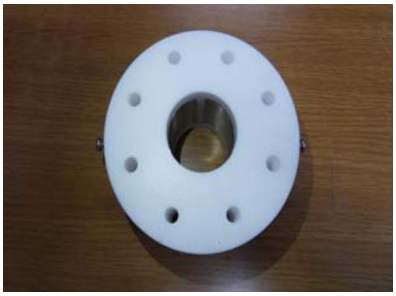

Fig. 1. Capacitance sensor.

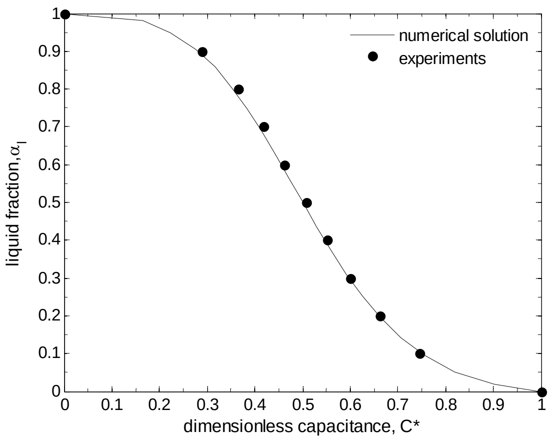

Fig. 2. Relationship between dimensionless capacitance and liquid fraction and comparison of numerical relationship with static experiments.

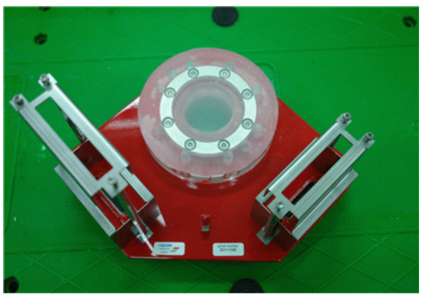

Fig. 3. Conductivity wire-mesh sensor.

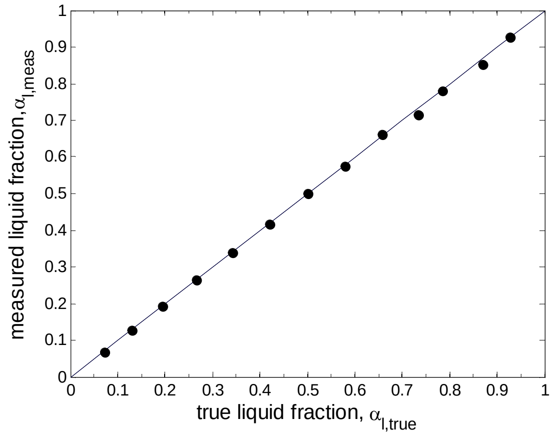

Fig. 4. Comparison between true liquid fraction and measured one from wire-mesh sensor.

3. Conclusion

As a preparatory research for development of a capacitance sensor monitoring the liquid fraction in an inclined pipe whose diameter and inclination angle are 45mm and 3rad, respectively, a capacitance is designed. Prior to loop experiments, numerical results for the relationship between the liquid fraction and dimensionless capacitance are obtained, and this relationship is verified by comparing with static experiments. Also, data evaluation procedures of a wire-mesh sensor which would be employed for the verification of capacitance sensor performance are verified by comparing static experiments.

Acknowledgments

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REFERENCES

[1] L. Wojtan, T. Uresenbacher, J. R. Thome, Interfacial measurements in stratified types of flow: Part II. Measurements for R-22 and R-410 A, International Journal of Multiphase flow, Vol. 30, p.107-124, 2004.

[2] K. J. Elkow, K. S. Rezkallah, Void fraction measurements in gas-liquid flows using capacitance sensors, Measurement Science and Technology, Vol.7, p.1153-1163, 1996.

[3] N. A. Tsochatzidis, T. D. Karapantsios, M. V. Kostoglou, A. J. Karabelas, A conductance probe for measuring liquid fraction in pipes and packed beds, International Journal of Multiphase flow, Vol. 5, p.653-667, 1992.

[4] M. Fossa, Design and performance of a conductance probe for measuring the liquid fraction in two-phase gas-liquid flows, Flow Measurement and Instrumentation, Vol. 9, p.103-109, 1998.