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Development of Single Optical Sensor Method for the Measurement Droplet Parameters

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1. Introduction

The SPACE code is being developed for the safety analysis of Korean nuclear power plants. The SPACE code adopts three governing equations to treat separately the gas, continuous liquid, and dispersed droplet fields. However, the droplet model in the SPACE code is not sufficiently validated against experimental data such as entrained droplet mass flow rates, and velocity and size of droplets. It is mainly caused by the fact that measurement of droplet parameters is difficult and so available experimental data is rarely found from open literatures.

Recently, Cartellier[1,2] and Saito[3] have developed optical fiber sensor methodology for the measurements of velocity, chord length and void fraction of bubble/droplet in two-phase flow. In this study, we tried to develop single optical fiber probe(S-TOP) sensor method to measure droplet parameters such as diameter, droplet fraction, and droplet velocity and so on. To calibrate and confirm the optical fiber sensor for those parameters, we conducted visualization experiments by using a high speed camera with the optical sensor.

2. Development of Single Optical Sensor Method

2.1 Single optical fiber probe sensor

A single-tip optical probe sensor classifies phases of air and water by utilizing different refractive index of gas and liquid phases. That is, the beam from laser source is reflected when it encounters air at the sensing tip of single optical fiber senor, whereas it penetrated to the medium when it encounters liquid. According to the Snell's law, a refractive index difference of probe and fluid leads to total reflection. For example, when the tip of probe is exposed to the air, the laser beam is back scatter by the relatively large amount of total reflection. The backscattered laser beam passing through the photomultiplier is converted into the electrical signal. The Figure. 1 shows a typical signal output of the optical fiber system by the S-TOP. The electrical signal is sharply decreased when the tip pierces interface between air and droplet phases. Mizushima and Saito[4] developed at first measurement method of bubble with the single tip optical fiber. They proposed a correlation between rising signal and bubble velocity as follows.

$$U_{bubble} = \alpha g_{rd,bubble} \quad (1)$$

where $g_{rd,bubble}$ is the gradient between upper and lower level of output signal. Each level is determined by the predetermined reference levels for gas and liquid phases. In order to correlate $g_{rd,bubble}$ with U_{bubble}, the authors proposed α as a coefficient of the relation. This value is affected by the tip shape of probe and properties of fluids.

We tried to apply Mizushima and Saito's[4] methodology to the measurement of the droplet parameters. In our experiment conditions, the properties of fluids are not influenced on the α, since working fluid is restricted by air and water. Therefore, we proposed an following equation for the determination of droplet velocity.

$$g_{rd,D} = \alpha U_D^2 + \beta U_D \quad (2)$$

In this equation, α and β are decided from calibration tests. To define coefficients, we measured $g_{rd,D}$ and U_D at simultaneously by applying both S-TOP and high speed camera. Here, the $g_{rd,D}$ is defined as follows,

$$g_{rd,D} = \frac{\Delta V}{\Delta t} \times \frac{1}{V_{Gas} - V_{Liquid}} \quad (3)$$

where V_{Gas} and V_{Liquid} are the reference signal output level of air and droplet, respectively. $\Delta V / \Delta t$ is changing rate of falling signal.

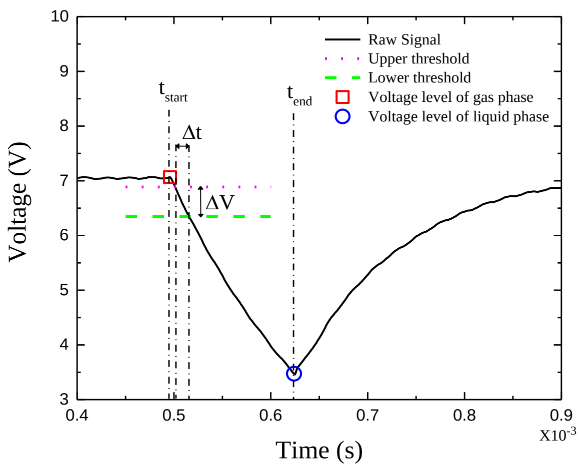

Figure. 1 Electrical signal during the penetration of droplets to tip of the optical probe

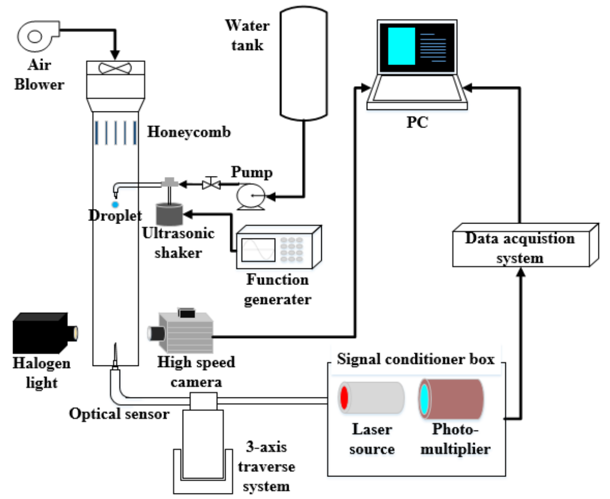

Figure. 2 Schematic diagram of the calibration loop for the droplet velocity

2.2 Experimental setups

The Figure. 2 shows a schematic diagram of the calibration loop for the droplet parameters. An ultrasonic shaker is used to generate uniform size of droplet. The range of droplet size generated by the ultrasonic shaker is from 0.2mm to 0.8mm. The images were taken with 120000 frames per sec and 128 X 128 pixels resolutions by the high speed camera. The electrical signal is recorded by data acquisition system with 2 MHz sampling rate.

2.3 Results

To evaluate the performance of the S-TOP accurately, we repeated calibration experiments at a given droplet flow condition. Figure. 3 shows the result of the calibration. In this graph, the x axis is the droplet velocity measured by visualization and the y axis is $g_{rd,D}$ which is obtained from S-TOP. In order to obtain a calibration curve by the form of equation, a 2nd order polynomial fitting method is adopted. We assumed that the $g_{rd,D}$ becomes zero as the droplet velocity approaches zero. We also could measure chord length of droplet (L_D) as follows.

$$L_D = U_{D,\text{probe}} \times (t_{end} - t_{start}) \qquad (4)$$

In this equation $U_{D,probe}$ is the droplet velocity measured by the optical probe with calibration curve and t_{end}-t_{start} is the passing time of droplet at the sensing tip of the S-Top. Figure. 4 shows typical chord length distribution (CLD) of the droplet and it can be fitted to a lognormal distribution. Droplet fraction is also calculated as follows.

$$\alpha_{Droplet} = \sum_{i=1}^{N} (t_{end,i} - t_{start,i}) / T \qquad (5)$$

where N is number of droplets in measured time T.

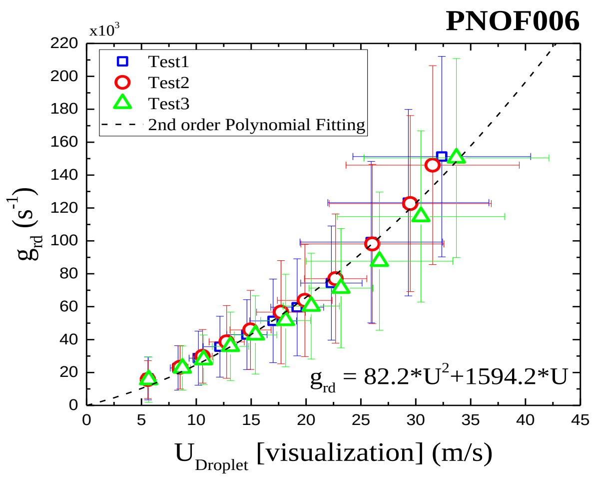

Figure. 3 The results of calibration experiments

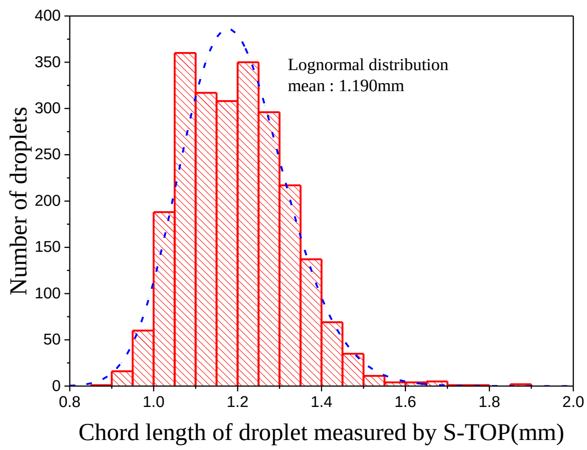

Figure. 4 Chord length distribution of droplets

3. Conclusion

In this study, we have developed the single tip optical probe sensor to measure the droplet parameters. From the calibration experiments with high speed camera, we get the calibration curve for the droplet velocity. Additionally, the chord length distribution of droplets is measured by the optical probe. In the further studies, we will investigate the relation between the chord length distribution and droplet size.

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