DEVELOPMENT OF A OPTIC SENSOR FOR VOID FRACTION MEASUREMENTS IN A SMALL TUBE

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Abstract. The objective of this research is to develop an experimental design for measuring void fraction using optical sensor in a horizontal mini-channel of 2.6 mm internal diameter with air-water two-phase flow. The measurement system consists of a light emitting diode (led) with high brightness, light dependent resistor (ldr) and data acquisition circuit. A glass tube, which passes air-water mixture lies between led and ldr. The flow pattern attenuates ldr's light and changes resistance varying voltage, measured by data acquisition circuit. Through the analysis images from high speed camera is proposed a methodology for comparing the number pixels of the image with bubble average area produced by curve created of the optical sensor signal.

Keywords: void fraction, optic sensor, mini-channel

1. INTRODUCTION

In the study of two phase flows into mini-channels, it is important to characterize void fraction for a complete understanding of the hydrodynamics of fluids associated with multiphase flow. Measurement for void fraction in mini-channel has difficulty to insert a sensor, which would also cause a change of flow. The solution for monitoring without disturbing the measurement is to use non-invasive sensors.

In the technique of ultrasound, sensors are arranged radially on the mini-channel surface at same cross section. These sensors can operate either as transmitters and receivers according to the mounting chosen, so that when a transmitter is being excited, all other function as receivers. The received images are manipulated by an algorithm, making an estimation of the spatial distribution of the phases to be constructed. Murakawa *et al.* (2005) developed ultrasound for measuring flow of bubbles in vertical tube with internal diameter of 3 mm, using different sizes of ultra sonic transducers and comparing results with theoretical model correlations, indicating that method can be applied in multiphase flow consisting of several types of particles whose sizes are considerably different.

The technique of electrical impedance is defined as the relationship between voltage and current when alternating current is applied and the frequency changing of alternating current of the used method can be resistive or capacitive. The resistive method considers the fact that conductance varies with composition of phases and it is used when dielectric between the electrodes is conductive and from an alternating current imposed on electrodes voltage values are obtained between them, which allows to correlate the void fraction to conductance. Garimella (2012) studied to identify micro-channel flow patterns with 0.78 mm diameter, based on the electrical impedance. The impedance sensor is calibrated against the time-averaged void fraction determined from flow visualization using a high-speed movie camera. The calculated time-average void fraction appears reasonable with those predicted by homogeneous flow and drift flux models. However, a summary conclusive in favor of a particular model cannot be done since the model parameters (e.g., the distribution parameter and the drift velocity for the drift-flow model) are not available to the microchannel flows.

The capacitive method is based on the difference between dielectric constants of two phases, which means that the greater the difference is the better the ability is for the sensor to perceive differences. The dielectric constant of liquid is different compared to gas. The capacitance measurement is made with electrodes fixed to the mini-channel wall. As the areas of electrodes and distance between them are constant, the only contribution to change capacitance is change of dielectric. Carniére (2008) developed a capacitive sensor to observe two-phase flow in horizontal tubes of 9 mm internal diameter containing air-water. Test results with demineralised water show clear distinctions between the sensor signals for all flow regimes. Therefore capacitance measurement technique is successfully applied for demineralised water, but suffers from conductivity effects when used with tap water. The electrical properties of refrigerants are compared with the properties of water. Because the conductivity of refrigerants is negligible, the capacitance measurement technique is useful, but the transducer will have to deal with smaller capacitance differences. Time-averaged sensor signal values, combined with the variances and a high frequency contribution factor, are studied to quantify the differences in flow pattern compared with visual analysis.

The image processing uses films or photographic cameras of high speed. One can obtain a sequence of images flow at very short intervals or simply record a snapshot flow. An algorithm interprets each information contained in the frame from each pixel's hue, calculating the size of void fraction. Ahmed (2011) used capacitance signals with air-oil flow in a tube of 15.8 mm internal diameter, along with data obtained by image processing the flow. The captured image was scanned in the MatLab program to count the contour of bubble and the gray levels of each pixel of a single bubble to determine the speed, the length and size of bubble area. The average area of void fraction was also obtained calculating the area under the curve traced divided by the total area of the captured image but this work doesn´t show how to calculate the area under the curve traced.

The technique with optical sensor is based on the phenomenon of refraction that occurs with light when it passes from a homogeneous and transparent environment to another one also homogeneous and transparent but different from the first. In this environment alteration changes in speed and direction of light propagation occur. Janal *et al.* (2007), developed optical sensor only to observe the behavior of two-phase flow in tubes of 25.4 mm diameter with objective to identify the flow patterns and their transitions with tubes horizontally and vertically.

The purpose of this work is to use technique with optical sensor for measurement void fraction in mini-channel 2.6 mm internal diameter with horizontal air-water two-phase flow. Develop a methodology for comparing the pixels number of the image with bubble average area produced with the signal's optical sensor.

2. SENSOR DESIGN AND INSTALLATION

The light source used is a light emitting diode (led) white high bright and installed in opposite direction to a light dependent resistor (ldr) horizontally. The installation of led and ldr was mounted in nylon solid cylinder with 15 mm diameter in a hole for perpendicular direction to the length of the cylinder. An operational amplifier is installed together with the ldr to attenuate the noise in the signal obtained by the sensor and to send measurement data as the block diagram of Fig. 1. The cylinder is covered with a black ribbon so that external light does not interfere with the ldr. A glass tube of 6 mm external diameter and 2.6 mm internal diameter, is installed at the center of the nylon cylinder in a hole parallel to the length Fig. 2. The air is injected directly into the mini-channel by a needle valve for controlling the air flow. The water flowing through the mini-channel enters and exits through the same tank´s pump. The tank is open to the atmosphere to be used as a separator of air and water flow, Fig. 3.

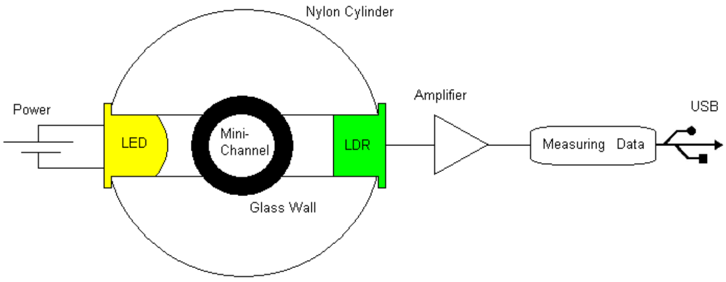

Figure 1: Block diagram of the optical sensor.

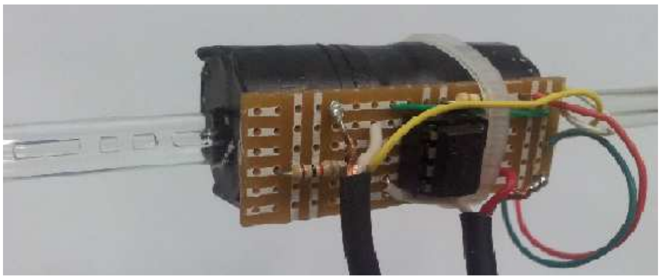

Figure 2: Optical Sensor.

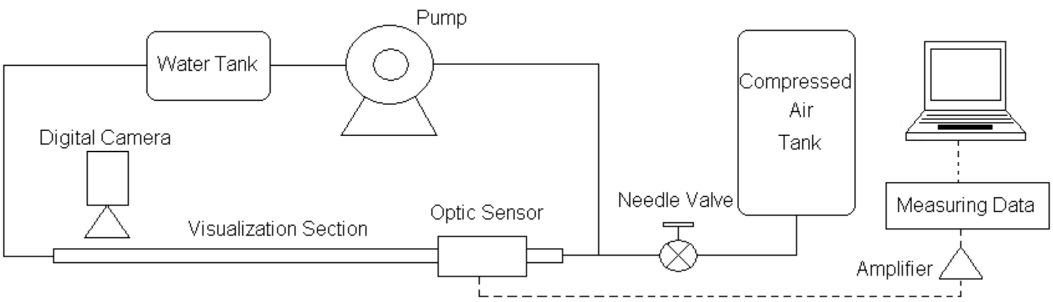

Figure 3: Schematic diagram of experimental apparatus.

3. EXPERIMENTAL METHOD AND RESULTS

For a better understanding of the optical sensor measurements, tests were made with the air-water mixture at a rate of 5.2 g / s. The amount of air injected into the system is controlled by a needle valve. The response of the optical sensor is the voltage level. If there is only liquid flow, the voltage level is zero volt, if there is only gas voltage level is 0.45 volts. For a two-phase flow the response of the optical sensor is in function of the bubble area. The signal amplitude refers to the diameter of the bubble and the period of the signal refers to the length of the bubble. The air flow rate was adjusted so that the bubbles did not change the flow pattern. Measurements were performed with the mini-channel containing only air, liquid, and bubble plugs and small isolated bubbles to understand the signal generated by optical sensor. The methodology used in optical sensor for measuring void fraction with the images obtained by high-speed camera that shows a single frame with the passage of the bubble mini-channel, Fig. 4. The adjustment of light intensity so that the bubble is highlighted within the mini-channel is an important factor so that it is well defined the outline of the bubble.

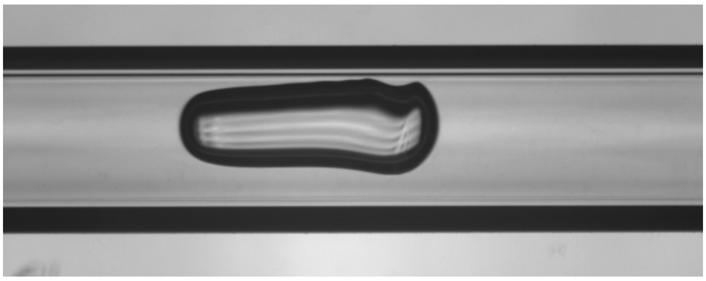

Figure 4: Bubble image.

To count the number of pixels within the area of the bubble it is necessary to remove the shades of gray and make the picture only in two colors, white and black, called a mask file, using developed using PhotoShop. Knowing that the internal diameter is 2.6 mm, a measurement is made of the dimensions of the internal diameter of the mini- channel on computer screen using Pixel Ruler software to make a square with one side mm informs that the number of pixels in 1 mm^2, show in Fig 5.

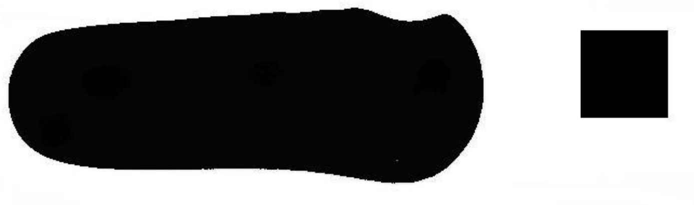

Figure 5: Mask file.

The file mask of respective bubble is used by an algorithm developed in Matlab for counts black and white pixels. In Fig. 6, show the reference square of 1 mm^2 with 6561 pixels and the shape of bubble with 59.207 pixels. In this case, the value of the bubble area is 9.02 mm^2.

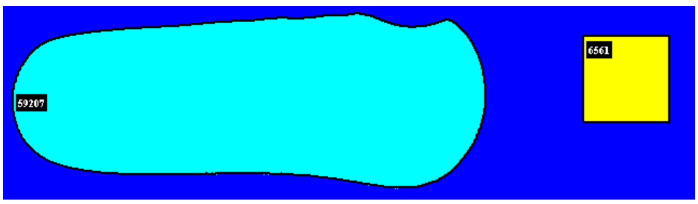

Figure 6: Bubble area in pixels.

The signal generated by a bubble is transferred to LabVIEW software that generates a curve where the variation of voltage as a function of the time, as shown in Fig 7. After that, it is found the function that best represents the behavior of this curve using the Curve Expert program. This function is included in an algorithm developed in MatLab to estimate the area under of curve.

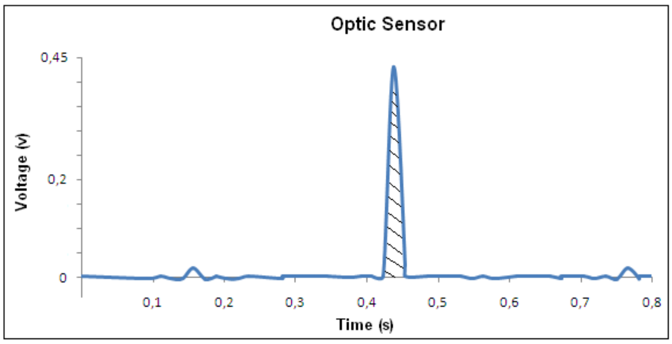

Figure 7: Curve representing variation of the voltage obtained from optical sensor.

This methodology was applied to thirty tests with imaging. Each void fraction obtained in pixels per frame, called reference value (val_{ref}), is compared with values obtained from the traced curves areas, called optical value (val_{opt}). Since these values are in different scales and units to be able to relate them became a normalization relative to the maximum value of each. Thus, it is obtained dimensionless values between 0 and 1 which represent the dimensionless areas of images obtained by the optical sensor. Applying statistical methodology of the mean bias error (MBE) in measurements of the optical sensor, Eq. (1) we have a mean bias error of 28.15% in measurements of the optical sensor with respect to measurements in pixels captured by the image Fig. 8.

$$MBE = \frac{1}{n}\sum\frac{|val_{ref} - val_{opt}|}{val_{opt}} \tag{1}$$

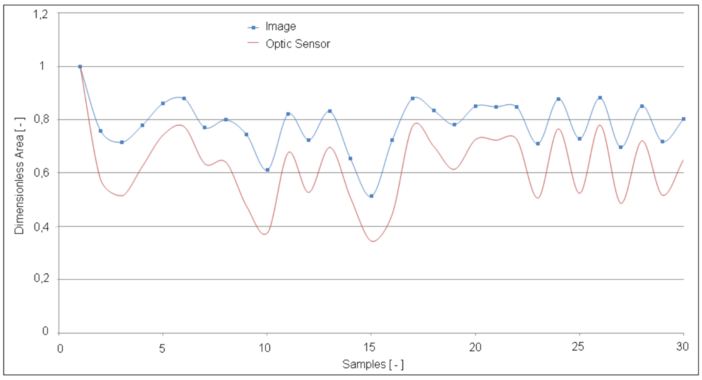

Figure 8: Samples of dimensionless areas.

As the curves show similar behavior, but with displacement between them, it is necessary to equalize them using the value of the mean absolute error of 28.15%, as a correction coefficient (C_c) in the area of optical equation (A_{opt}), Eq. (2).

$$A_{opt} = val_{opt} + C_c\, val_{opt} \tag{2}$$

Thus the areas provided by pixel image can be compared with the areas of optical, show in Fig. 9. Repeating the same statistical methodology, the mean bias error is of 8.96% in measurements of the optical sensor relative to measurements in pixels captured by the camera.

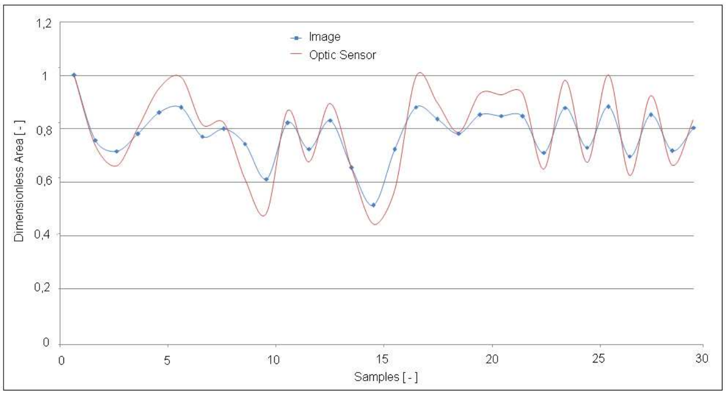

Figure 9: Comparison area's image with area's optical sensor.

4. CONCLUSIONS

The work demonstrates that the measurements with the optical sensor showed average values reasonable for void fraction with the slug flow and smaller bubbles patterns in air-water two-phase flow. Other adjustments are still needed in the project to measure the annular and bubbly flow. It's necessary to observe that the adjustment of the light used for shooting with high-speed camera will not interfere in the results of the optical sensor.

In the method for image processing when bubbles longer than the length of a frame cannot measure the amount of total pixel bubble to determine the area, but with the methodology presented here it will be possible to measure the bubble's average area independent of its length. Bubbles smaller than the light beam of the led which are close together, the optical sensors identify them as a single bubble. With the development of the algorithm for the sum of the areas under the curve traced it will be possible to estimate the average void fraction and its pattern flow without the need for visualization of images.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

Abuaf, N., Jones, O. C. and Zimmer, G. A., 1978. "Optical Probe for Local Void Fraction and Interface Velocity Measurements", Review of Scientific Instruments. Vol. 49, pp.1090.

Ahmed, W.H. 2011. "Experimental Investigation of Air–oil Slug Flow Using Capacitance Probes, Hot-film Anemometer, and Image Processing", International Journal of Multiphase Flow, Vol. 37, pp. 876-887.

Caniére, H., T'Joen, C., Willockx, A., Paepe, M. D., 2008. "Capacitance Signal Analysis of Horizontal Two-phase Flow in a Small Diameter Tube". Experimental Thermal and Fluid Science, Vol. 32, Issue 3, pp. 892-904.

Collier, J.G. and Thome, J.R., 1994. Convective Boiling and Condensation 3. Ed. Oxford Science Publications, New York , USA.

Berthold, J.W., Reed, S.E. and Nash, C.A., 1994. "Fibre Optic Sensor System For Void Fraction Measurement in Aqueous Two-Phase Fluids, Flow Measurement and Instrumentation", Vol. 5, Issue 1, pp. 3-13.

Janal, A. K., Mandall, T. K., Chakrabarti1, D. P., Das, G. and Das, P. K., 2007. "An Optical Probe For Liquid–Liquid Two-Phase Flows, Measurement Science & Technology", Vol. 18, Issue 5, pp.1563 -1575.

Jaworek, A. and Krupa, A., 2010. "Phase-shift Detection for Capacitance Sensor Measuring Void Fraction in Two-Phase Flow". Sensors and Actuators A: Physical, Vol. 160, pp. 78-86.

Garimella, S. H.V., Paranjape, S. and Ritchey, S.N, 2012. "Electrical Impedance-based Void Fraction Measurement and Flow Regime Identification in Microchannel Flows Under Adiabatic Conditions". International Journal of Multiphase Flow, Vol.42, pp. 175-183.

Hamad, F. A., Imberton, F. and Bruun, H. H., 1997. "An optical probe for measurements in liquid–liquid two-phase flow", Measurement Science & Technology. Vol. 8, Issue 10, pp.1122 -1132.

Murakawa, H., Kikura, H. and Aritomi, M., 2005. "Application of Ultrasonic Doppler Method for Bubbly Flow Measurement Using Two Ultrasonic Frequencies", Experimental Thermal and Fluid Science, Vol. 29, pp. 843-850.

Thome, J. R., 2004. Engineering Data Book III, Swiss, Printed by Wolverine Tube Inc.

Tibiriçá, C. B., Nascimento, F. J. and Ribatski, G., 2009. " Film Thickness Measurement Techniques Applied to Micro-scale Two-phase Flow Systems", Experimental Thermal and Fluid Science, Vol. 34, Issue 4, pp. 463-473.