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Characterization of gas-liquid two phase flows using dielectric Sensors

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ABSTRACT

Two phase flow regime identification and void fraction measurement is an area of considerable interest because of its wide applications in process industries. The principle involved in dielectric measurement is that the two phase flow regime is characterized by the changes in effective permittivity of the two phase fluid mixture. In the present work, a pair of parallel copper electrodes on the two sides of a glass tube acts as a dielectric sensor. As the void fraction in the glass tube changes, the effective permittivity of the medium changes. This causes a variation in the capacitance value across the electrodes. A standard IC, Oscillator 555 is employed as a tool to generate a rectangular wave. The variation in dielectric constant is analyzed based on the change in time period of the trough (T_0) of the rectangular wave that is recorded online by a data acquisition system. Experiments were performed in a 4.7 mm diameter tube with air-water, air-palmolein oil two phase fluids to study the variation in dielectric constant which is indicated as a change in time period of trough. The effect of conductivity of water on the capacitance variation is examined with water having Total dissolved solids (TDS) which is a measure of movable ions in the range 10-4000 ppm (16 μS/cm–6.3 mS/cm). The novelty in the present work is the determination of changes in capacitance value based on the change in time of trough of the rectangular wave. The technique does not require amplification or a filtering circuit, thereby leading to a precise identification of two phase flow regime.

1. Introduction

Two phase flows are the simultaneous flow of two phases of matter. Gas liquid flows occur in many industrial applications such as heat exchangers, boilers and condensers. Gas-liquid two-phase flows in micro tubes occur frequently in electronic cooling, refrigeration systems and in micro propulsion devices. The advantages offered by micro reaction technology make it suitable for use in processes with decreased hazard potential while removing strong heats of reaction, handling toxic chemicals, explosives and other unstable products. By providing large interfacial areas, the mass transport is significantly accelerated over the phase boundary layers compared to macroscopic processes and thereby an increase in the rate of reaction.

Characterization of multiphase flow is essential to understand the interactions between the different phases. Coleman and Garimella [1] conducted experiments on flow of air-water mixtures in rectangular and circular tubes with hydraulic diameters ranging from 1.3 to 5.5 mm. They identified bubbly, dispersed bubbly, elongated bubble, slug, stratified, annular-wavy and annular flow patterns using high speed videography. Techniques like X-ray or Gamma ray based measurements are useful where it is not possible to directly observe the two-phase flow [2,3]. Advanced signal and image processing techniques are employed to study the flow regime in the case of transparent materials like glass tubes [4–10]. Chen et al. [11] used a flat co-Planar electrode to distinguish the flow regimes in Glycerol-air two phase flows. They used RF oscillator with a operating frequency of 80 MHz for a 3 mm wide rectangular channel. Elkow and Rezkallah [12] used an impedance meter to measure the void fraction in a helical tube with a pair of electrodes. Ahmed and Ismail [13] used a capacitance meter with 1 MHz excitation frequency to determine the volume of air in air-oil two phase flow. Jaworek et al. [14] used a RF oscillator to distinguish steam from water. Unlike previous methods which were based on direct measurement of capacitance values, Jaworek and Krupa [15] used a Phase Shift measurement technique to determine accurately the void fraction. Othman et al. [16] used cross sectional capacitance measurement system with 64 electrodes to determine the particle concentration in a micro channel. Banasiak et al. [17] used a combination of 3D capacitance tomography and fuzzy-logic classification to visualize and identify the two phase flow regime. Pieter and Robert [18] used a microcontroller based capacitance measurement system to determine void fraction in microfluidics. Hu et al. [19] developed a measurement technique

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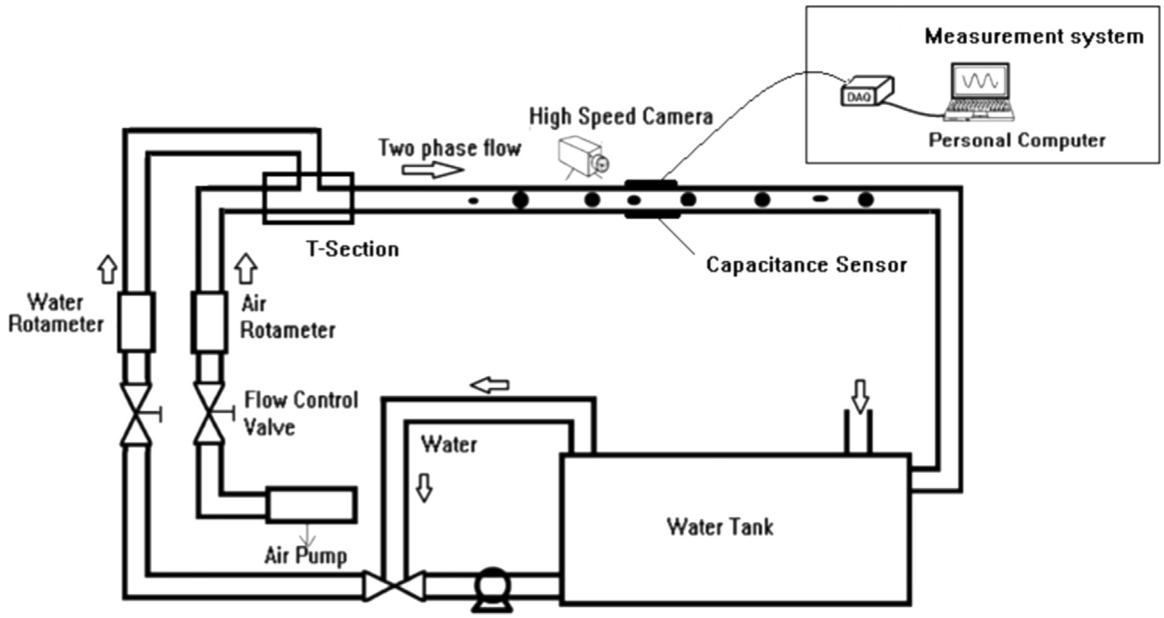

Fig. 1. Experiment setup.

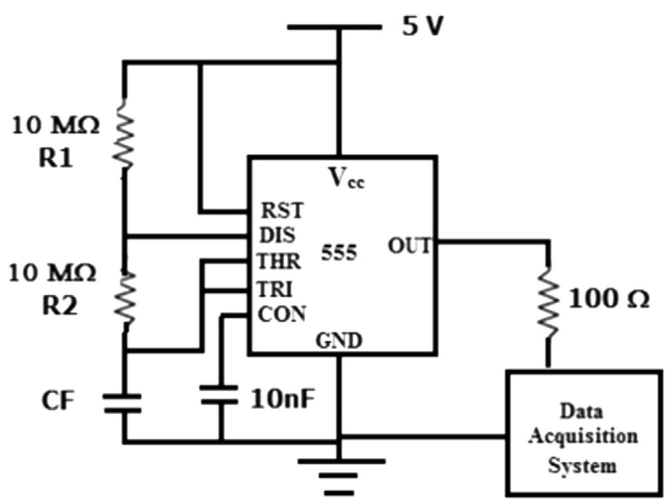

Fig. 2. Measurement circuit.

for two phase flow characterization based on a combination of capacitance and Artificial Neural Networks.

It can be seen from the above literature that there has been a considerable improvement in the application of capacitance sensors for the characterization of two phase flow. In the case of capacitance based invasive sensors, the conductive effects of the fluids dominate the change in dielectric nature of the fluid. A detailed study to investigate the effect of conductivities for invasive sensors was done by Huang et al. [20]. Conductivity in general is measured in terms of total dissolved solids (TDS) which is a measure of movable ions in the liquid. When it comes to non-invasive sensors, the change in capacitance value for variation in effective permittivity is very low. The measurement of such low capacitance values requires amplification of signals which in turn necessitates the development of noise filters. Moreover, in many of the measurement techniques, non – linearity in the measurement of the capacitance has been observed. The significant deviations from the actual value demanded non- linear sensor calibrations. The calibration was found to be different for different tube diameters. The novelty in the present work is in the method of

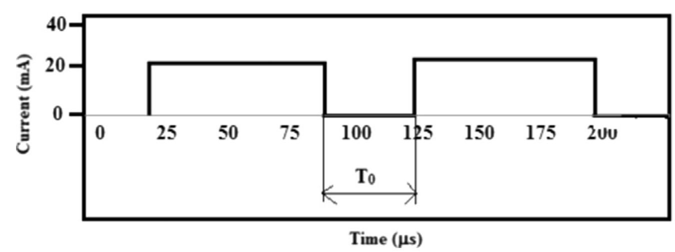

Fig. 3. Multisim Simulation.

measurement of phase fraction in two phase flows. Here a 555 timer is operated in a stable mode where the end of the electrode on the sides of the tube diameter is connected across the trigger and ground pins. The change in frequency of the rectangular wave indicates the dielectric nature of the two phase fluid from where the phase fraction is measured. Though the use of 555 timers for capacitance measurement is found in literature, the application of it based on time of trough measurement for two phase flow has not been comprehensively investigated. The technique does not require any amplification and filtering circuit leading to precise identification of the two phase flow regime. The study thus leads to a development of cost effective capacitance based method of two phase flow regime identification. The capacitance measurement range of the designed system depends on the choice of resistors R1 and R2 (Fig. 2) and the resolution of data acquisition system. The device is found to work accurately in the range 0.01 pF to 10 F by varying the resistors. In the present case for a 10 MΩ resistor the range was from 0.01 pF to 10 nF. Effect of conductivity on the measurement device is tested by performing analysis with water having different TDS values.

2. Experimental setup

The experimental setup used to carry out the experiments is shown in Fig. 1. The volumetric flow of air and water is measured using separate Rotameters. Flow control valves are used to adjust the flow rate of air and water. Air is blown slightly above