Preliminary Experimental Research on Flow Pattern Recognition

Madhusudhan Kolar and Jerry K. Keska
University of Louisiana at Lafayette, College of Engineering
Lafayette, LA 70504, USA

Abstract

This is a research project reporting detection and documentation of dynamic parameters like velocity, concentration, pressure and interfacial phenomenon in the two-phase flow. Four different measurement methods are used to detect the special concentration or other related parameters to flow patterns in two-phase flow. This paper attempts to describe an effective experimental approach to detect the different flow patterns in the two-phase flow.

The paper reports results of experimental work on the use of a concomitant method to detect flow patterns. All four of these methods demonstrated sensitivity to flow patterns in reference to the relative RMS values obtained through the experimental work. Out of the four different methods, pressure and resistance signals indicated full concomitancy in the range of all flow patterns.

Category: Student Project

Nomenclature

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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<tbody>
<tr>
<td>(b_c)</td>
<td>capacitor plate width (m²)</td>
</tr>
<tr>
<td>(C)</td>
<td>capacitance (pF)</td>
</tr>
<tr>
<td>(c_v)</td>
<td>mixture in situ concentration by volume (-)</td>
</tr>
<tr>
<td>(D)</td>
<td>channel diameter, plate width (m)</td>
</tr>
<tr>
<td>(h)</td>
<td>height (m)</td>
</tr>
<tr>
<td>(l_c)</td>
<td>length (m)</td>
</tr>
<tr>
<td>(e_0)</td>
<td>dielectric permeability (pF/m)</td>
</tr>
<tr>
<td>(e_l)</td>
<td>dielectric constant of liquid</td>
</tr>
<tr>
<td>(e_a)</td>
<td>dielectric of air</td>
</tr>
<tr>
<td>(\rho_a, \rho_w, \rho_m)</td>
<td>resistivity of air, water, mixture (Ω·m)</td>
</tr>
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</table>
R resistance (ohm)
L length (m)
A area (m²)
p pressure (kPa)

Subscripts
a air
j range
l liquid
m mixture
v volumetric
w water

**Introduction**

The process of two-phase flow is significantly more complicated when compared to the single-phase flow because of the presence of various other parameters like the special concentration, flow patterns, velocities of gas and liquid, and the momentum exchange between the vapor and liquid phases in case of the two-phase flow. It is even more complex not only due to the mentioned parameters, but also as a result of the limitations and difficulties faced by the researchers in the measurement of these parameters. Ultimately all this leads to an experimental research linked with the study of various parameters like concentration, void fraction, mixture and component velocities, viscosity, pressure, and most challenging, flow patterns, with their distributions in time and space. The comparison of signals measured using different measurement methods are significantly simplified if done in the same space and time. In order to study all the above parameters, different sets of flow patterns are to be obtained.

In a two-phase flow, the flow depends on various dynamic parameters. It shows different patterns for every imperceptible change. If a flow is passed through vertical round tube, a bubbly flow regime is found at low gas fraction and as the gas fraction increases, the flow coalesces into slug, churn and so on till the annular flow appears. All these different observations of mixture components in the time and space constitute the flow patterns. The flow patterns of two-phase flow when observed by many researchers employing different methods came up with different results for the same type of flow. The reason for the different flow patterns is methods of flow pattern detections. The results obtained by use of various methods, undefined calibration procedures and the validation process make it extremely difficult to analyze and compare those results.
In order to avoid all the problems faced earlier, a set of techniques of flow pattern determination were employed. This paper would discuss about the procedures and results obtained from the four different measurement techniques. This analysis would give us a clear-cut view of the flow patterns in two-phase flow and its behavior in time and space.

**Background**

In recent years, there has been a major attempt to thrive in the field of fluid dynamics for test fluids of turbulent flow, in general, and multiphase flows in particular. The study of the fluids is a must to accommodate the increasing needs of a better and more reliable environment in which to work. We are aware of the complexity of the two-phase flow, which involves lot more obstacles in predicting its flow patterns.

The researchers are in progress of discovering the new techniques to measure and predict the flow patterns. The different two-phase flow parameters are to be measured in order to identify the flow patterns. There is no objective or well-established definition of flow pattern.

Out of the many methods employed and reported in this section, one of the most frequently used is the capacitive method. This measures the volumetric spatial concentration in the channel. The capacitance of the sensor used is a function of the geometric parameters of the sensor and resulting dielectric constant of the mixture, which for a given mixture is a function of the concentration. This can be shown by equation (1).

\[
C = \frac{1.01 \varepsilon_0 l_c}{\ln \left( I + \frac{\pi D}{b_c} \tan h \frac{D}{b_c} \right)} \left( \varepsilon_r c_v + \left( 1 - c_v \right) \varepsilon_a \right) \tag{1}
\]

In literature JK Keska et al. \(^2,3,4\), reports use of a capacitive system capable of measuring spatial concentration fluctuation by volume up to a frequency of 1 KHz. The experimental waveform images of concentration versus time were statistically evaluated in the form of both power spectral density (PSD) and cumulative power spectral density (CPSD) images.

They noted that there is a clear difference in both the PSD and CPSD distribution of time traces caused by changes in average sizes of solid particles. He also explained that with a smaller particle size, the PSD and CPSD would be spread over a wider frequency band. Increasing the particle will lower the saturation frequency of the CPSD.

He concluded, that this method, in conjunction with statistical analysis (PSD, CPSD) of time traces, is clearly a viable means in the definition and determination of flow patterns in multiphase flow. The other significant conclusions from this are, the RMS values of concentration, film thickness and pressure, are possible indicators of the flow patterns. \(^4\)

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The resistive method was also generalized as one of the best detection techniques to identify a flow pattern in a multiphase flow. Here, the concentration of the mixture is measured by measuring its electrical resistance. The multiple probes and auto correlation function were used to measure bubble velocity. The probability density function (PDF) and PSD functions were also used in the data from these probes to characterize the signals in the amplitude, time and frequency domains.\textsuperscript{5,6,7}

Person used the optical method to determine the flow conditions in a channel. His method produces a signal with respect to the interfacial phenomena in the mixture in the channel. The detector placed in the path of the light beam on the opposite side of the channel generates a voltage signal depending on the intensity of the light. Person described by his observations that the interfaces can the surfaces of the bubbles in the liquid or the surfaces of the droplets of liquid in the gas.\textsuperscript{7}

A research done by J. M. Le Corre and associates identified the two-phase flow patterns by using a fuzzy methodology. They described the flow by using local void fraction and interfacial area as the geometrical parameters, which they later used as inputs for the algorithm. They used a multi-sensor conductivity probe to achieve their results. They noticed that the summation of all the flow regime contributions is unequal and a simple normalization is sufficient to get a relevant percentage of the contribution of each flow regime to the two-phase flow system.\textsuperscript{8}

Another non-intrusive technique developed for flow identification by Y. Mi and associates was a fuzzy-neural hybrid system of processing and interpreting impedance-based measurements. They used the software consisting of a neural and a fuzzy block. The neural block consists of a feedforward neural network with channels. The output of the neural network flows into the fuzzy rule base. The impedance measurements through this method proved its perfect flow regime identification abilities. The output of the system is a number that gives the centroid of a given flow’s membership function. They even observed that the system correctly identifies all the flow categories.\textsuperscript{9}

An instrument system based on flow-imaging technique was developed for measuring flow patterns. By using the fuzzy identification method, the flow pattern was identified on-line. Measuring the pressure drop and conductance of flow in the pipe recognized the flow pattern. They evaluated the void fraction and noticed an error lesser than 10%. They obtained images of the flow patterns on the CRT; they were similar to the photographs obtained by high-speed camera.\textsuperscript{10}

In conclusion, its noticeable that the use of these flow pattern recognition techniques not only allowed us to study the flow patterns, but also let us compare the different flow patterns obtained through different methods. This research not only compares the results obtained from the experimental work carried out in the same time and space, but also proves the concomitancy between the pressure and resistive systems used to detect the flow patterns.

Experimental Setup

The experimental setup consists of a transparent vertical channel measuring a diameter of 35mm. The whole apparatus supports closed-loop water and open-loop airflows. The systematic representation of the experimental set up used is shown in figure 1.

![Experimental apparatus diagram]

1. Tanks
2. Rotameters
3. Pressure gauge
4. Vertical channel
5. Pressure sensor
6. Resistive sensor
7. Capacitive sensor
8. Optical sensor
9. Laser
10. Signal Conditioner
11. CADAS (Computer Aided Data Acquisition System)

Figure 1: Experimental apparatus.

A mixing chamber is positioned at the bottom of the channel, which allows the mixture flow to enter the channel. The electrodes are attached on the two opposite sides of the channel in a non-intrusive way. There are four different sensors for the four different flow pattern measurement systems. The signals from each sensor were conditioned to a proportional voltage signal that was then converted to a digital input to a computer-aided data acquisition system.
The capacitance system consists of the two electrodes placed on the opposite sides on the inside of the flow channel. A correlation between this capacitance and the in-situ spatial concentration is described by equation (1).

The storage of the signals from the four different systems is collected using a multi-channel interface simultaneously. It measures the capacitance of the mixture within the capacitive sensor with a 1MHz operating frequency. The captured signals are transferred to a proportionate voltage signal, which is then interfaced into a computer-aided data acquisition system using VEE Pro and GPIB software. The different parameters obtained from the measurements would be used to generate different flow patterns.

The resistive method measures the in-situ concentration based on the difference between the resistivities of both air and water in the channel. The signals obtained from the resistance meter are studied using statistical tools in the same time and space. The resulting resistivity of the mixture is given by the following equation.

\[ \rho_m = \rho_w c_v + \rho_a (1-c_v) \]  

(2)

The sensor resistance correlation with the mixture parameters is described by the following equation:

\[ R = [\rho_w c_v + \rho_a (1-c_v)] \frac{L}{A} \]  

(3)

The pressure system consists of a pressure sensor, which measures the static gauge pressure in the channel. The physical conditions inside the channel tend the fluctuation in the pressure. The average and fluctuating components of pressure were utilized in the study of the flow patterns. The pressure can be described by equation (4).

\[ p = h \rho_m g \]  

(4)

Where \( \rho_m \) is the specific density of mixture.

In the optical method, the laser is placed in front of the optical sensor. The intensity of the light passing the mixture is the measured parameter. The output voltage of the resistance meter is dependent on it. The variation of the intensity is due to the interfacial phenomena. Due to the scattering of the light by interfacial phenomena, output voltage of this system is corresponding to the flow patterns.
Results

As illustrated in the background, the four different methods were employed, capacitive, optical, pressure and resistive to determine signal related to the flow patterns in the multi-phase flow and data was collected simultaneously in the same space and time. The choosing of these eight patterns was done on the basis of visual observations of the differences in flow regimes.

Figure 2. Signals in the time domain (in seconds) from the four systems (capacitive, resistive, pressure and optical) at flow patterns 1, 4 and 8.

The pictorial representation of signals from all four systems used at flow patterns 1, 4 and 8 in the time domain is shown in the figure 2. The capacitive system in the top row followed by resistive, pressure and optical systems.

From the signals obtained from the different systems, it can be clearly seen that there are similarities between the capacitive and resistive signals. We can even notice a significant difference between the capacitive and resistive signals when compared with pressure and optical signals.
The RMS value is the first parameter, which may be used in this study of flow patterns. It depends on the amplitude of the fluctuations. The average magnitude of the signal is represented by the use of the RMS value and is given by:

\[
\text{RMS}_i = \sqrt{\frac{\sum (\bar{V} - V)^2}{\text{number of samples}}}
\]

(6)

In figure 3, the RMS values vs. in-situ spatial concentration for all four measurement systems employed in which the RMS values are plotted against the average concentration for each flow condition.

One way to compare the ability of the individual method is by comparing the sensitivity to the change of flow pattern. The absolute value of the RMS and the slope of the curve directly define the sensitivity over a particular range. The steeper the curve, the better is the capability to determine the flow pattern. In figure 3, one can easily observe that the curve of the optical system has at least three local maxima, as opposed to only one in other three systems. From the absolute values of RMS, both capacitive and resistive systems are the next most sensitive system. The pressure system is more sensitive than the optical method at flows with lower average concentration but least sensitive for flows with high average concentration. The RMS curve of both resistive and pressure systems have shown concomitancy with each other.

![RMS vs. Concentration](image.png)

**Figure 3.** RMS values vs. in-situ spatial concentration for the four measurement systems.
Conclusions

In this preliminary study of the flow patterns in multi-phase flow, four different measurement methods to determine concentration or parameters related to concentration and flow patterns were applied in the same space and time. This also allowed for the comparison for the capabilities of the four different methods to determine its sensitivity to the flow patterns in vertical channel.

During the experiment, eight different flow regimes visually recognized, were analyzed in the time domain in order to determine the sensitivity of the four different methods to flow patterns. Each method indicated different impact of flow patterns on the RMS values.

All the methods used demonstrated sensitivity to flow pattern in reference to the relative RMS values however the sensitivity for each method was a unique function of flow patterns. Only pressure and resistance signals indicated full concomitancy in the range of flow patterns, however. The RMS characteristic for a capacitive system is demonstrating a similar characteristic like pressure and resistance signals. Otherwise the optical signal demonstrated a different characteristic by having three local maxima.

References


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MADHUSUDHAN KOLAR.

Madhusudhan Kolar is a master’s student of Mechanical Engineering Dept. in University of Louisiana at Lafayette. He is Mechanical graduate from Karnataka University, India. He is interested in dynamics of real fluids in microchannels. He is planning to graduate in Fall 2002.

JERRY K. KESKA

Dr. Keska, a mechanical engineer, currently serves as an Associate Professor of Fluid Power and Mechanical Systems in the Industrial Technology Department at the University of Louisiana at Lafayette. His research interests are in the areas of Microelectromechanical Systems (MEMS), fluid dynamics of complex heterogeneous mixtures (multiphase, slurries), tribology, microheatexchangers, computer-aided measurement systems and instrumentation, electromagnetic sensors, turbulence and flow pattern phenomena in mixtures, and deterministic and random signal analysis including validation process.