Modelling and Analysis of In-Situ Validation Technique for Multiphase Flowmeters

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Abstract— Multiphase flows are increasingly found in many parts of the petroleum industry, from reservoir to downstream processing plant. Multiphase flows such as oil-gas, oil-water, gas-water and oil-water-gas are commonly encountered. The accuracy of most multiphase flowmeter highly depended on the flow regime of the mixture being metered. Flow regimes in multiphase flow are often unpredictable which makes the calibration of most multiphase flowmeters is flow regime dependent. As the capabilities of multiphase flowmeters increases, the problems of how to validate the performance of such instruments increases. This paper investigate and optimise a sensing technique that can be used for in-situ validation of multiphase flow measurement. To date, several flow measurement techniques were available with different feature and for different applications. Capacitance sensor relatively has fast response, low cost and easy to construct, which explain its wide use in industrial applications. Ways in which number of parameters effects the sensitivity of the capacitance sensor were investigated. This includes capacitance sensor geometry (electrode length and electrode separation), pipe material and thickness. The effect of fluid conductivity and guard electrodes on sensor performance was also investigated. ANSYS finite element software package was used to model a three-phase flow regime with capacitance electrodes and its sensitivity for carrier and phase detection in multiphase flow. Results obtained by the finite element simulation compared favourably with experimental results.

I. INTRODUCTION

Flowmeters are used in nearly every sector of industry, from utilities such as water and gas through to manufacturing and production. The total world flowmeter market is today worth over $3000 million and is expected to continue growing steadily in the future [Thorn 2001]. However, alongside the increased demand for single phase metering, there is a growing demand in areas such as the petroleum and food industries to be able to measure multiphase flows. The overall uncertainty of the flowrate measurement would therefore depend on the accuracy with which these three independent measurements can be made. The velocity of the liquid and gas phases cannot be assumed to be the same, and the way the gas is distributed in the liquid (the flow regime) will change depending on factors such as gas content, individual phase velocity and pressure.

To date, there are many types of flowmeters utilising a range of different sensing techniques [Yeung *et al* 1998] [Yang *et al,* 2003][Hang *et al*, 2003]. Different type of sensors may give different types of information depending on the strength of the signal. For a given application the accuracy and functionality of theses techniques are flow profile dependent, which includes flow regime type, component fraction and material type. The obtained information can be used to describe different feature of the fluid flow behaviour in multiphase flow measurement. Therefore, the selection of the sensor type is important in order to be able to acquire the right information for the right flow measurement condition. Capacitance sensing method is becoming widely used as a rapid and robust tool to provide data for the analysis of various multiphase flow systems (William *et al* 1999). However, the technique is flow regime dependence, where a correction factor usually required to compensate this effect. Also the conductivity of the fluid mixture reduces the sensor sensitivity. A new technique has to be considered in order to reduce the effects of the conductivity and the flow regime dependency of the capacitance sensor with a reasonable sensing sensitivity, such as localising the sensing field of the capacitance sensor.

II. NUMERICAL MODEL AND VARIABLES

It has been found that the simplest way to model a capacitance sensor in a uniform fluid flow is to use an electric lossy capacitor, which integrates a loss-free capacitor component and a resistor component connected in parallel. Figure 1a depicts the equivalent circuit of the capacitance sensor in a non-intrusive measurement system. Where, C and R are the capacitance and resistance components of the mixture respectively, C_{p1} and C_{p2} are the capacitance components between the electrodes and the mixture in the pipe. However in real measurements only the overall equivalent capacitance/resistance components are measurable. To take this into account, the equivalent circuit, figure 1a, is further modified to that of figure 1b. So that comparison can be made between the simulated and measured values. Where C_T and R_T represent the total equivalent capacitance and resistance components of the fluid flow respectively. The mathematical functions describing the measured capacitance and resistance in this model have been given by the following equations (Hammer *et al,* 1998).

$$R_T = \frac{1+\omega^2 R^2 (C + C_1)^2}{\omega^2 R C_1^2} \qquad (1)$$

$$C_T = \frac{C_1(1+\omega^2 R^2 C(C+C_1))}{1+\omega^2 R^2 (C+C_1)^2} \quad (2)$$

Where $\omega = 2\pi f$, and $C_1 = C_{p1}C_{p2} / (C_{p1}+C_{p2})$

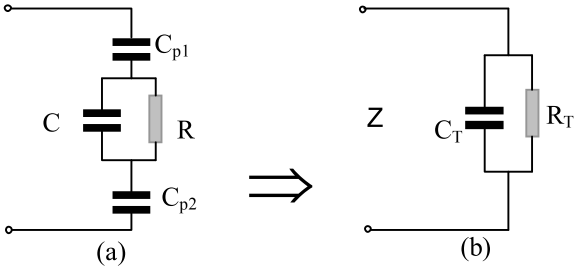


Figure 1-Equivalent circuits of the capacitance sensor

III. MODELLING PROCESS FOR CAPACITANCE SENSOR

Finite element simulation using ANSYS software package has been used to study the effect of the sensor geometry on the sensitivity of the capacitance sensor for carrier and phases detection in multiphase flow (water, oil and gas) at different types of flow regimes. A capacitance sensor model was built as shown in figure2, which shows a cross-section view of the designed capacitance sensor model in multiphase flow.

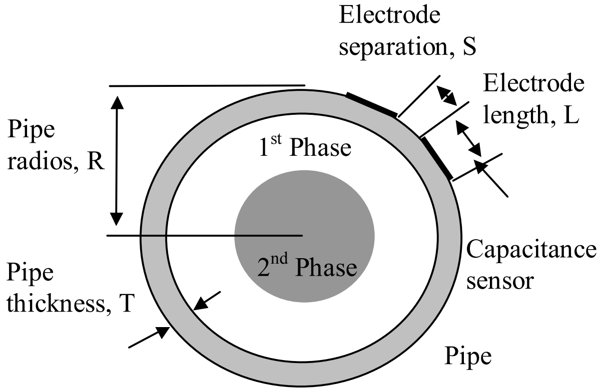


Figure 2-Schamatic drawing for the capacitance sensor model in multiphase flow

The parameters considered in this simulation were electrode length (L), electrode separation (S), pipe wall thickness (T), and guard electrode separation. These geometric parameters can be varied by a fraction of a millimetre, thereby building a detailed picture of the capacitance-sensing field. Also physical parameters such as pipe and fluid flow permittivity were also considered. In this model, the carrier phase thickness was modelled by inserting a small circle of the first phase (the dispersed phase) into the middle of a second phase (the carrier phase) in the pipe. In order to be able to simulate the thickness of the carrier phase, the diameter of the dispersed phase was gradually increased (thereby reducing the thickness of the carrier phase) bringing the fluid interface closer to the sensor which is located at the outer surface of the pipe wall. Six different combinations of fluid phases were used water-oil, water-gas, oil-water, oil-gas, gas-oil and gas-water then the capacitance changes was measured at different carrier phase thickness for each combination.

Different types of meshing elements are available in the finite element package, each types may specify different inputs and output parameters. Element type "Plane 67" was used in this model

IV. SIMULATION

To optimise the electrode geometry, finite element simulation provide a predicted electrical filed distribution and the stored energy which can be used to calculate the capacitance change at different carrier phase thickness, and at different values of electrode length and electrode separation. Figure 3 showed the equipotential distribution of the given capacitance model for input parameters in table1. It can clearly be seen the possibility to identify the overall capacitor sensitivity pattern from the electric field distribution between the capacitor electrodes.

Fluid relative permittivity	Water = 80 Oil = 2.0 Gas = 1
Pipe relative permittivity	2.5
Pipe thickness, T	1, 2, 3, 5, 7 &10 (mm
Electrode Length, L	0.726 to 5.08 (mm
Electrode Separation, S	0.36 to 5.44 (mm

Table 1-Input parameter for the capacitance sensor model

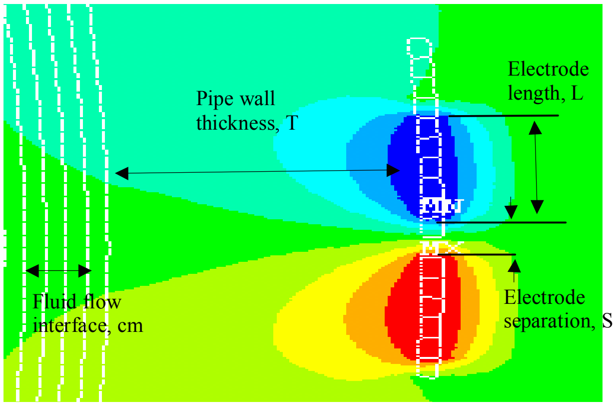


Figure 3- Equipotential field distribution for a capacitance sensor

The total capacitance value has been calculated from the energy stored in the capacitance sensor as follows,

$$W_e = \frac{C(V_1 - V_0)^2}{2} \qquad (3)$$

$$\Rightarrow \quad C = 2\frac{W_e}{(V_1 - V_0)^2} \qquad (4)$$

Where, W_e is the total stored energy in the system when the capacitance electrodes excited at a potential difference of (V_1-V_0) and C is the capacitance value. The source electrode has been set at potential of 5V.

Six different combinations of fluid flow including water-oil, water-gas, oil-water, oil-gas, gas-oil and gas water were used at different electrodes geometry. Then the capacitance was measured at different carrier phase thickness for each combination of fluid phase, as shown in figure 4. It can be seen that the sensor respond is nonlinear in nature and have three measurement ranges, water carrier range, oil carrier range and gas carrier range. These ranges can be used to identify the carrier phase in the fluid flow. There are always two main ambiguity points, where the sensor output beyond them becomes uncertain. These ambiguity points occur at the intersection of the gas-water and oil-gas, and water-gas and oil-water curves, and represented by M on the plots, as shown in figure 4. This ambiguity point defines the uncertainty range of the capacitance sensor in identifying the carrier phase. Also it can clearly be noted that the worst ambiguity point occurs between the gas-water and oil-gas combination, which is at about 0.7cm carrier phase thickness. This would mean that the capacitance change has a unique output response for each of the three phases (oil-water and gas) presented in the fluid flow as long as the carrier phase thickness is higher than 0.7cm.

Sensor resolution is another factor which has also been considered in this study. It has been defined as the minimum change in the sensor output (response) in order to be able to differentiate clearly between the three phases oil-water-gas present in the fluid flow. It has been calculated as follow,

$$\zeta = \frac{(C_g - C_o)}{2} \qquad (5)$$

Where, ζ is the minimum measured resolution, C_g is the capacitance value for gas phase and C_o is the capacitance

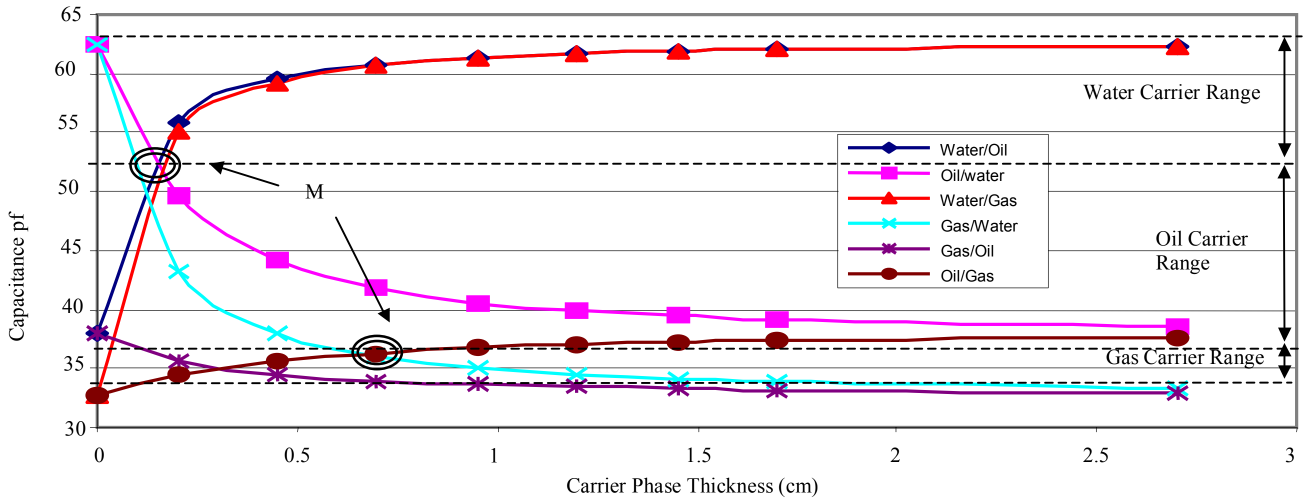


Figure 4- Capacitance change for six different combination of fluid flow in oil-water-gas.

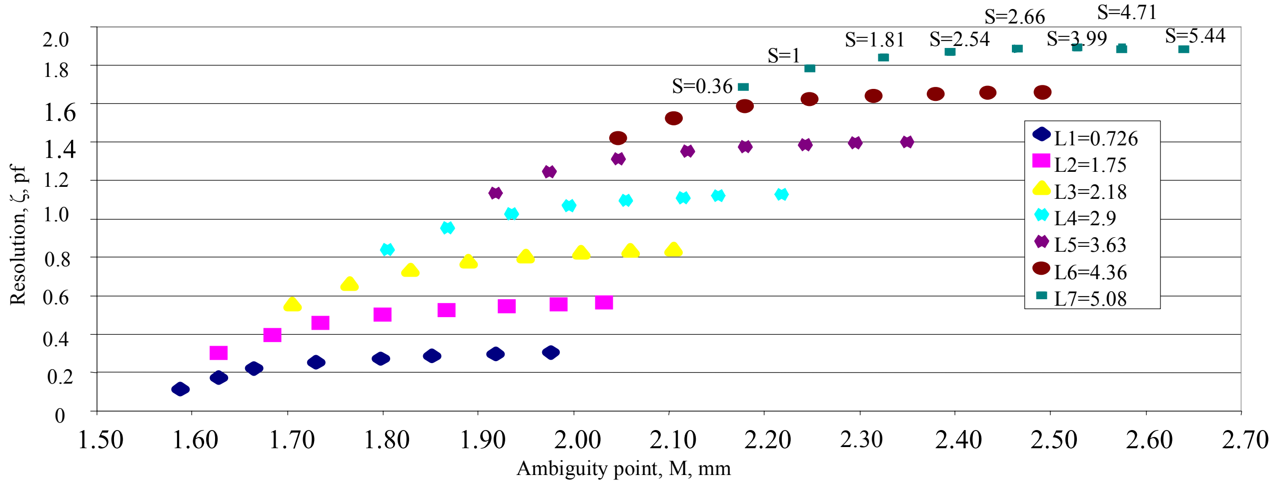
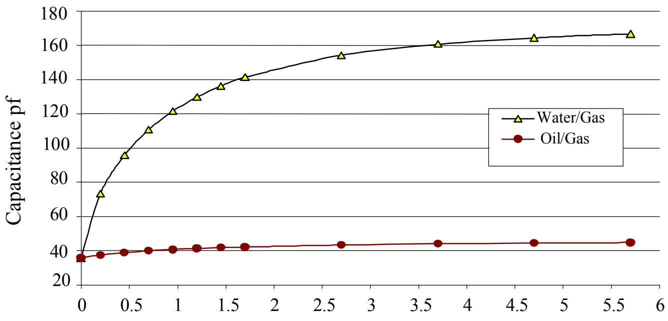


Figure 5-Resolution Vs ambiguity point at different values of L and S (T=2mm)

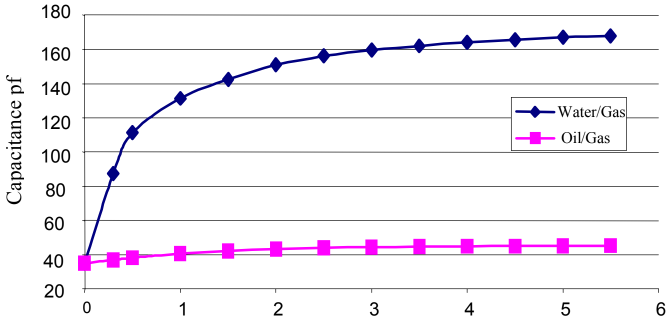
value for oil phase. To simplify the effect of each considered parameter, a plot combines all the results of the simulations have been created as shown in figure 5. The resolution ζ and ambiguity points have been given for different electrode length (L) and separation (S). Given a required minimum ambiguity point and a required minimum resolution, it can be used to obtain a unique optimum electrode area and electrode separation value for these requirements. It can clearly be seen that by choosing minimum resolution value, which reflects the minimum required measurement system, and by selecting the minimum ambiguity point, this will make a unique point on the plot which represents the predicted best selection of electrode area A and separation S in this condition.

V. EXPERIMENTAL RESULTS

Laboratory scaled experimental investigation has been conducted to compare finite element simulation results with an experimental investigation. A series of experimental works have been carried out using two-plate capacitance sensor with electrodes area A= 4.9cm, electrodes separation S= 0.2cm, and wall thickness T=3cm. Two set of experiments are conducted by this model, the first experiments using distilled water to simulate very low conductive fluid flow. The obtained results compared with a finite simulation results at same geometry and physical parameter of the experimental simulation, both results were given in the following figure 5, which shows well matching in water-oil two-phase flow.



a) Carrier phase thickness (cm)



b) Carrier phase thickness (cm)

Figure 5-Capacitance changes in water-oil two-phase flow, a) simulation results (ANSYS), b) experimental results

VI. CONCLUSION

Validation techniques based on using capacitance sensor for flow regimes, carrier and phase detection has been addressed. Finite element simulations have been used to model a fully reliable capacitance sensor for three-phase oil-water-gas flow application. From the simulation results, the following conclusion drawn:

1) By reducing the size of the electrode length and separation of the capacitance sensor the effective sensing field becomes much narrower, therefore a better ambiguity point can be achieved.

2) The smaller the electrode length L and separation S the better the sensor resolution.

3) The usage of earthen guard electrode could introduce a strong sink to the electrical field of the capacitance sensor, and then the sensor resolution will be reduced.

4) Capacitance sensor can be used in full fraction range of oil-water-gas phase for flow regimes, carrier and phases detection, and hence be a cheap and non-intrusive measurement alternative.

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