
MEASUREMENT OF LIQUID FILM HEIGHT IN GAS-LIQUID TWO-PHASE FLOWS USING TWIN-WIRE CONDUCTANCE PROBES

Mohammed Kabir Abdullahi^{1,*}

¹Nuhu Bamalli Polytechnic Zaria

Email: m.abdullahi07@alumni.imperial.ac.uk*

*Corresponding author: Mohammed Kabir Abdullahi

DOI: <https://doi.org/10.67203/sp.ICESID.2026>

ABSTRACT

Accurate measurement of liquid film thickness is important in process equipment because it supports heat- and mass-transfer calculations. In gas-liquid two-phase flow, film thickness is also required for estimating liquid film holdup. Twin-wire conductance probes have been shown to provide reliable measurements of liquid film height in air-water two-phase flows. In this work, probes were fabricated from 0.5 mm platinum wire of 99.95% purity in the student workshop at Imperial College London using standard machining procedures. The probes were mounted on a 32 mm pipe to measure liquid film height in air-water stratified and slug flows. The resulting measurements were accurate, instantaneous, and suitable for tracking changes in liquid film thickness. This paper falls within the sub-theme of sustainable engineering processes. The data and the correlations in this paper can be found useful in the prediction of slug flows for pipeline safety in Nigeria's oil and gas pipelines.

Keywords: Liquid film holdup; twin-wire conductance probes; liquid film thickness

1.0 INTRODUCTION

Flows containing more than one phase, commonly referred to as *multiphase flows*, are encountered in many chemical engineering applications. Examples include separation units, chemical reactors, nuclear reactors, tube-bundle heat exchangers, pipeline systems, and several other items of process equipment. Gas-liquid or vapour-liquid flows occur in oil and gas pipelines, condensers, evaporators, distillation columns, absorbers, and combustion systems. Liquid-liquid systems are found in processes such as liquid-liquid extraction and emulsification, while solid-liquid mixtures are frequently transported as slurries through pipelines. Improved understanding of multiphase flow is essential for the effective design and operation of such systems. This paper focuses specifically on measuring liquid film height in gas-liquid flow through horizontal pipes.

When two closely spaced, vertical, parallel wires are immersed in a conducting liquid, the length of wire in contact with the liquid can be inferred from the measured resistance between the wires. This arrangement provides an instantaneous measurement because of the rapid transmission of electrical signals. The method was particularly suitable for the present experiments because rapid response was required to capture fast-moving slug fronts, and because water provides sufficient electrical conductivity.

This work confirms that accurate, time-resolved measurement of liquid film thickness and holdup remains central to the analysis of gas-liquid two-phase flow. Modern studies have extended earlier conductance-probe approaches through interdigital and multielectrode conductance sensors for non-uniform film distributions, while wire-mesh sensors are increasingly used to obtain spatially resolved phase-fraction and flow-pattern information in industrial and laboratory pipe flows (Tompkins, C et al, 2018). Recent slug-flow modelling studies (Ehinmowo, et al (2025), Miao L, et al (2026), have also shown that reliable predictions of pressure gradient, translational velocity, slug liquid holdup, and film-region behaviour depend strongly on high-quality experimental measurements for validation. These developments demonstrate that conductance-based techniques, although well established, remain relevant because they provide fast local measurements that can support both experimental characterisation and the validation of contemporary mechanistic and numerical models of horizontal gas-liquid flow.

In the experiments reported here, conducted by MK Abdullahi (2013), twin-wire conductance probes were used to measure instantaneous liquid height at several positions along the test section. The probes were designed, fabricated, and installed on the Long Tube System (LOTUS), whose general layout is shown in Figure 1. Figure 2 shows the schematics of the probes mounted on the LOTUS test section, while Figure 3 presents a photograph of the twin wires inserted into a pipe section. Because the conductance between the two wires changes with liquid height, recording this conductance provides an instantaneous measure of the local film height. The conductance-time traces can also be used to determine the film height ahead of a slug and, when two probes are placed a known distance apart, to estimate the slug-front velocity. Twin-wire conductance probes therefore offer a convenient method for measuring local liquid film height when the liquid has sufficiently high electrical conductivity (Miya, 1970; Brown et al., 1978; Davies, 1992; Strand, 1993; Srichai, 1994; Manolis, 1995). The LOTUS facility used probes made from 0.5 mm diameter platinum wire of 99.95% purity. This work is within the sub-theme of sustainable engineering processes of this conference.

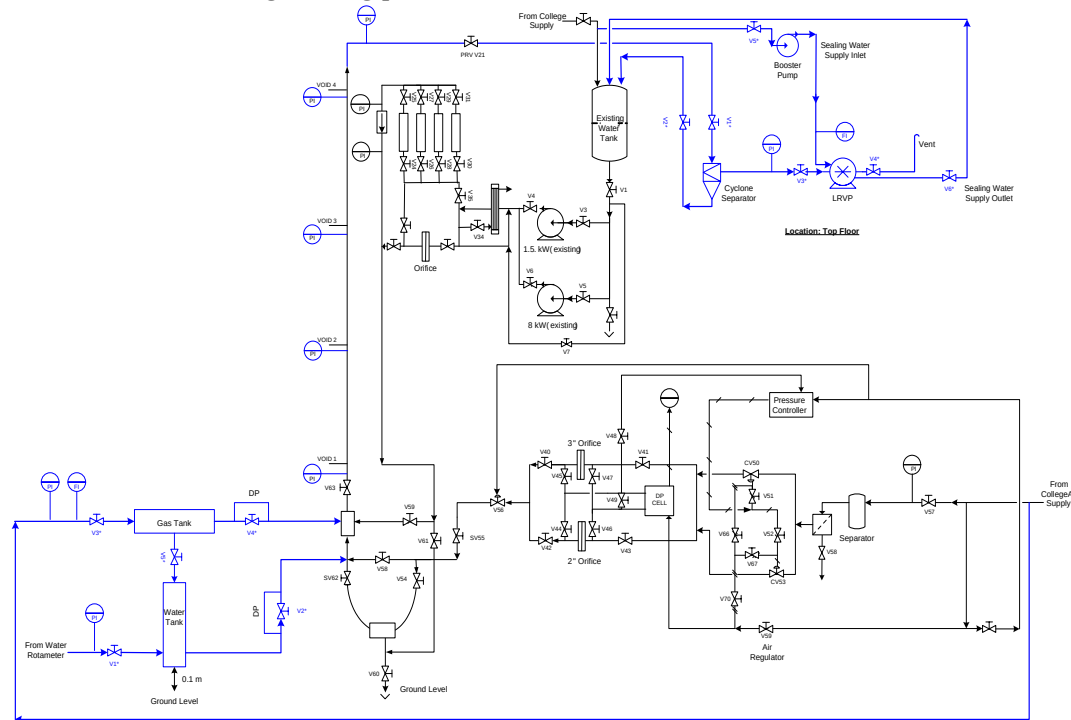


Figure 1: General schematic of the LOTUS Rig

2.0 CONSTRUCTION OF TWIN-WIRE CONDUCTANCE PROBES.

The conductance probes were constructed on pipe sections with an internal diameter of 32.8 mm. Figure 2 shows a schematic of the probe arrangement, with the twin wires positioned 2 mm apart. Four probes were manufactured in the student workshop at Imperial College London and subsequently mounted on the LOTUS test section. Selecting an appropriate wire diameter is important: the wire must be large enough to keep its electrical resistance low relative to that of the liquid, but small enough to avoid disturbing the flow. Two fluid-dynamic considerations govern this choice. First, the wire diameter must be sufficiently small that any wake generated by the wires is negligible. Second, interfacial effects around the wires must also remain insignificant (KOSKIE et al., 1989).

A saddle was attached to the outer surface of each probe assembly, and the wires were screwed to it to keep them straight and correctly positioned.

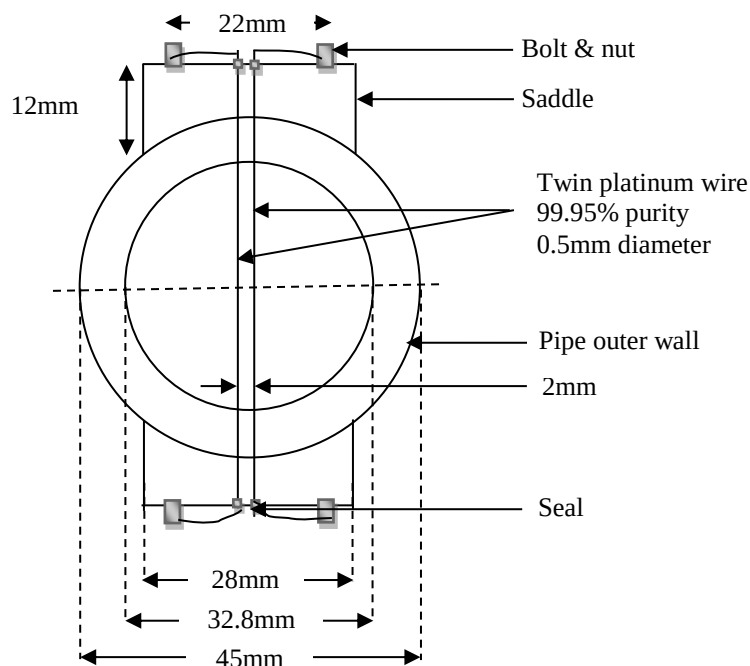


Figure 2: Schematic representation of the twin-wire conductivity probe as used on the LOTUS facility

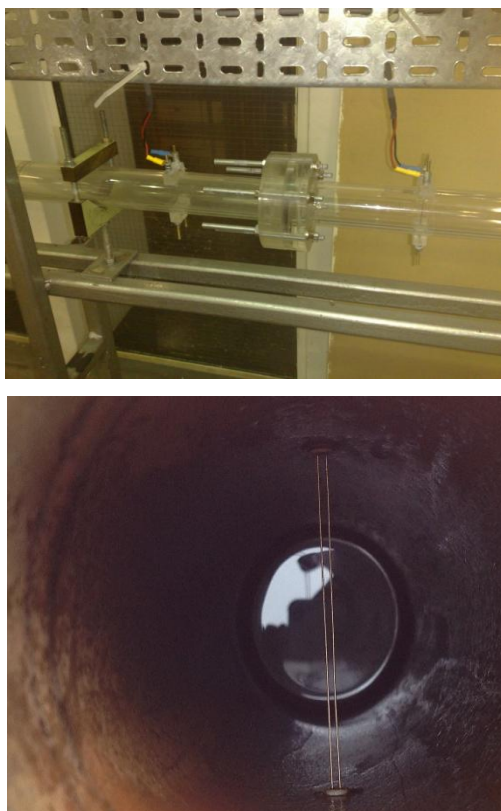


Figure 3: RHS - Photograph of mounted twin-platinum-wire probes on the 32.8 mm LOTUS rig showing probes 2 and 3; LHS - Internal view of twin-wire probes on WASP test section

An equilibrium condition is established when two electrodes are placed in an aqueous medium. This condition results either in a zero net rate of charge transfer between similar metal electrodes or in a potential difference between dissimilar electrodes. When current passes between the electrodes, charge transfer occurs at the interface between the aqueous solution, or water film, and the metal electrodes. This transfer takes place through the movement of protons across the electrical double layers

of ions formed on the anode and cathode surfaces. The process requires activation energy, which is supplied by the potential difference maintained across the system (Glasstone, 1942). In most cases, the current through the double layer increases exponentially with over-voltage, defined as the additional potential difference across the double layer beyond that present when no net current flows. When an external potential is applied between electrodes immersed in an aqueous medium, the over-voltage does not change instantaneously; instead, it increases in a manner similar to the charging of a capacitor through a resistor (Coney, 1972). The double layer can therefore be represented as a capacitance in series with the resistance of the bulk solution.

When alternating current is applied, the influence of double-layer capacitance decreases as the AC frequency increases (Coney, 1972), so the total impedance approaches that of the bulk solution. A very high applied frequency is not necessarily required for the impedance to depend mainly on the bulk solution resistance, particularly when electrodes with high double-layer capacitance, such as platinum, are used.

3 CALIBRATION OF TWIN-WIRE CONDUCTANCE PROBES

Offline calibration was performed for all four probes. Two 1.0 m long pipe sections with an internal diameter of 32.8 mm were used: one fitted with probes CPR1 and CPR2, and the other with CPR3 and CPR4.

An offset run was first conducted with the pipe dry, and the corresponding data were recorded to establish the voltage at zero liquid film height. The pipe sections were then filled with water and sealed using a flange at one end and a cock at the other to retain the water. With the pipe positioned horizontally, the data acquisition system was operated to record the full-pipe reading, corresponding to the 32.8 mm pipe diameter. The liquid level was then reduced in stages, the pipe was kept horizontal, and further readings were taken to obtain voltages corresponding to different liquid levels.

Calibration data relating probe output to liquid height were therefore essential. Such data were obtained for the twin-wire probes used in the LOTUS experiments, as shown in Figure 4.

Figure 4 indicates that an approximately *linear* relationship is expected between probe conductance and liquid height. Early attempts to relate conductance directly to the liquid level observed from the side of the pipe showed deviations from linearity at low and high liquid heights. These deviations resulted from distortion of the interface image caused by the curvature of the pipe wall, which introduced error in locating the true interface position. A correction procedure was therefore developed to relate the apparent side-view level to the true level. Known volumes of water were introduced into a length of acrylic resin tube, which was then sealed and placed horizontally. The true water level was calculated from the known volume added and compared with the apparent level observed from the side of the tube. This comparison enabled correction of the apparent levels. After correction, plots of relative liquid height, defined as liquid height divided by pipe diameter, against data logger reading became close to linear for the four probes used in the LOTUS and LOWPRESS experiments. Some deviation remained at low film heights, probably because of uncertainty in identifying the interface position. It was therefore reasonable to assume a linear relationship when converting data logger output to liquid height. This assumption is convenient because film height can be obtained by linear interpolation between the empty-pipe and full-pipe conductance values, which were measured daily during testing.

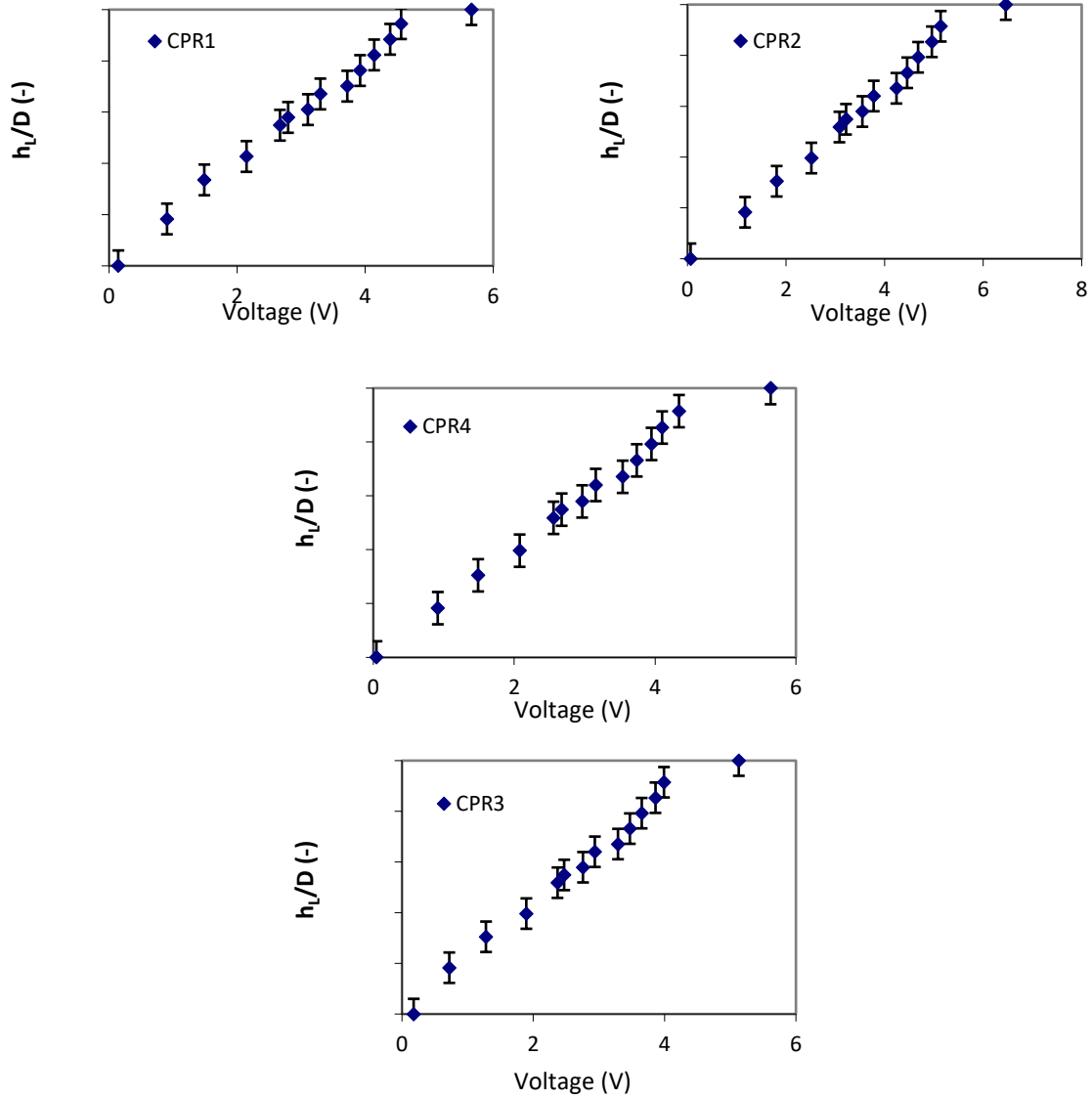


Figure 4: Variation of data logger reading (proportional to conductance) with non-dimensional liquid height for the four twin wire probes used in the LOTUS experiments

From these data, a correlation was derived for the measurement error. This took the form:

$$\varepsilon = -0.1836 \left(\frac{h_L^M}{D} \right)^2 + 0.4165 \left(\frac{h_L^M}{D} \right) - 0.1607 \left(\frac{h_L^M}{D} \right) \quad (1)$$

It was then possible to correct the measured film heights by subtracting the error:

$$\frac{h_L}{D} = \frac{h_L^M}{D} - \varepsilon \quad (2)$$

The results of this correction process are shown in Figure 5. The data now follow the diagonal line to within their error bars (assumed to be ± 1.5 mm).

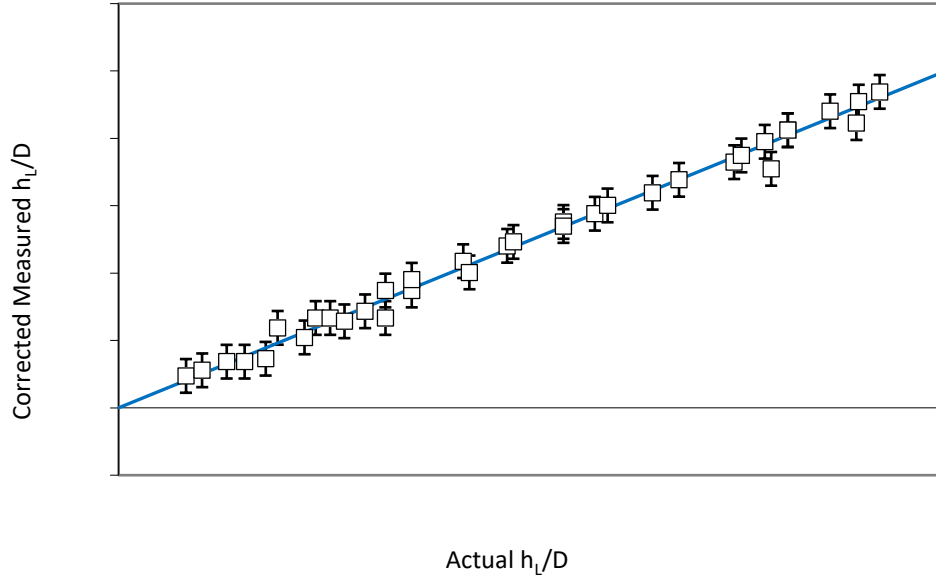


Figure 5: Corrected side-on h_L/D versus actual h_L/D

Each of these probes was constructed as shown in Figure 2. This design has the advantage that the two sets of probes are always at a known, fixed distance apart and so this test section has often been used for measuring slug translational velocities.

The liquid film holdup ϵ_{LF} can also be determined from the conductance probe measurements of $\frac{h_{LF}}{D}$ and computed using Eqn. (3).

$$\epsilon_{LF} = \frac{1}{\pi} \left\{ \pi - \cos^{-1} \left(2 \frac{h_L}{D} - 1 \right) + \left(2 \frac{h_L}{D} - 1 \right) \sqrt{1 - \left(2 \frac{h_L}{D} - 1 \right)^2} \right\} \quad (3)$$

4 Experiments

A typical experiment began by establishing stratified flow in the 32.8 mm horizontal tube. The air and water streams used to create the stratified flow were supplied by the LOTUS rig and passed through a three-way ball valve, as shown in Figure 6. The third connection to this valve was linked to a water-filled vessel pressurised by air from the rig. In the LOTUS experiments, this vessel was a vertical 3 m long stainless-steel tube with an internal diameter of 76.2 mm. When the three-way valve was operated, water from the pressurised vessel entered the test section rapidly, and the rate of water ingress was measured using the venturi meter. The injected water travelled over the existing stratified layer as a pushed-in slug. At the same time, the feed supplying the initial stratified flow was shut off.

The fundamental principle of the experiments is illustrated in Figure 6 and 7 for the stratified flow case and push-in liquid slug respectively. In the case illustrated, the experiment starts with the setting up of a stratified flow in the pipe with the 3-way valve set for through flow as shown. The liquid flow rate in the stratified flow is $\dot{V}_{LF}$ and the liquid fraction in the stratified flow is ϵ_{LF} . In the experiments, the liquid height in the preceding film region h_{LF} is measured using the twin wire conductance probe system. Assuming that the interface is flat ϵ_{LF} is related to h_{LF} by the expression in Eqn. (3):

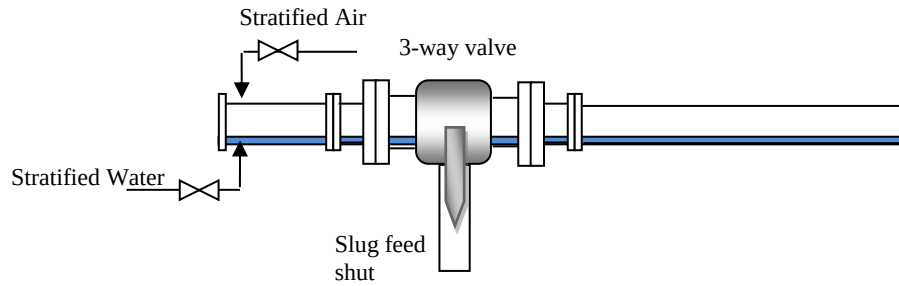


Figure 6: Stratified flow in horizontal test section

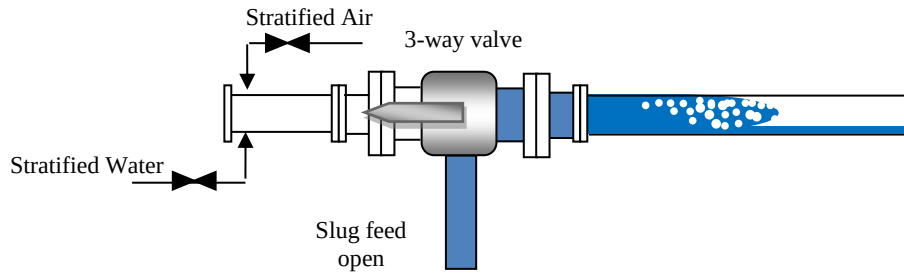


Figure 7: Slug flowing over stratified flow in horizontal test section

Figure 6 illustrates a typical arrangement for measuring liquid height with twin-wire probes positioned upstream of the three-way valve. With the stratified air and water valves open, stratified air-water flow was established in the test section. In the situation shown in Figure 7, the air and water feeds for the stratified stream were closed, and the pushed-in liquid slug moved over the existing stratified layer ahead of it.

5 Data acquisition and processing on LOTUS rig

Air flow rate was monitored continuously. Pressure transducers measured both the absolute pressure at the upstream tapping of the orifice plate, and the pressure drop across it. The upstream tapping was connected to a 0–10 barg absolute pressure transducer, which had been verified against a previously calibrated transducer and found to be accurate within ± 4 mbar. The pressure-drop across the orifice plate was measured using a 0–1 bar differential pressure cell. A water-filled manometer was also connected in parallel to allow periodic accuracy checks.

Output signals from these transducers, together with the signal from the transducer mounted on the test line, were converted to digital form and stored on an Amstrad PC1512 (8088) personal computer. Analogue-to-digital conversion was performed using a Scientific Solutions Inc. Lab Master data acquisition unit, which can process up to 16 channels and can be configured for signal ranges of either -10 to $+10$ V or 0 to 10 V. In the experiments described here, the 0 to 10 V range was selected to match the transducer outputs. A Quick BASIC program written by Manolis (1995) controlled the conversion process and recorded the digitised data. To avoid reducing acquisition speed, only output voltage signals were stored during each run; these were later converted into pressures and air flow rates after completion of the test. For all LOTUS rig experiments, this system operated at a data acquisition frequency of 10 Hz.

For more detailed pressure profiles and for recording conductivity-probe output signals, a faster data acquisition system could be connected in parallel. This system used an Amplicon-Liveline PC30AT analogue-to-digital conversion card installed in the expansion slot of a NAGA 80486 DX-33 personal computer. It enabled rapid acquisition from up to 16 channels. A Quick BASIC program controlled the conversion process and recorded the digitised data, allowing sampling frequencies between 0 and 1000 Hz to be selected.

In this experiment, a sampling frequency of 500 Hz was generally used as a compromise between the need for high sampling rates and the practical difficulty of handling very large data files. According to the sampling theorem (Lynn, 1982), the maximum frequency that can be adequately

represented by a sampled continuous signal depends on the sampling interval. For adequate representation of this frequency:

$$\vartheta_{\text{sample}} = \frac{1}{2t_{\text{dur}}} \quad (4)$$

Where $\vartheta_{\text{sample}}$ is the frequency of the sampled continuous signal and t_{dur} is the time duration between samples. A sampling rate of 500 Hz ($t_{\text{dur}} = 0.002$ s) corresponds to $\vartheta_{\text{sample}} = 250$ Hz which should be sufficient for representing major system changes. Figure 8 is a block diagram of the data acquisition for the probe signals obtained in the LOTUS and LOWPRESS tests.

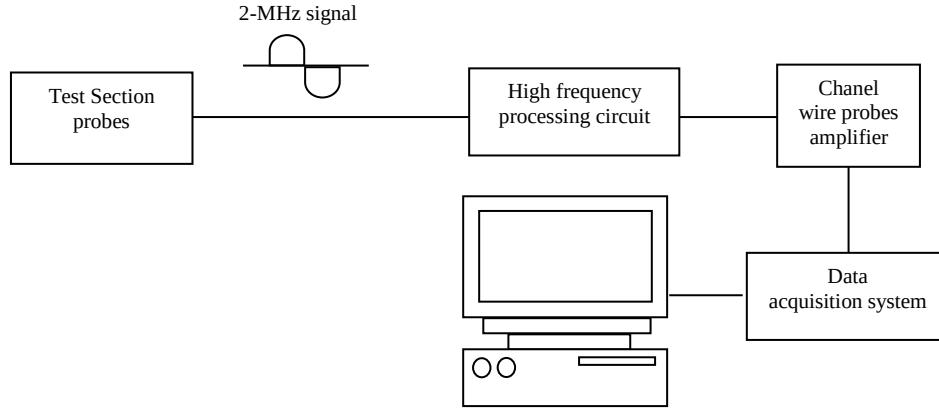
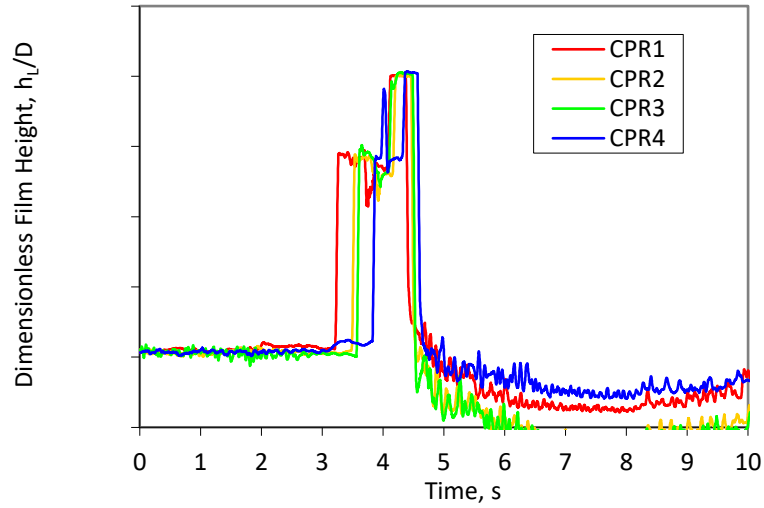


Figure 8: Block diagram of high-frequency probes signal processing system

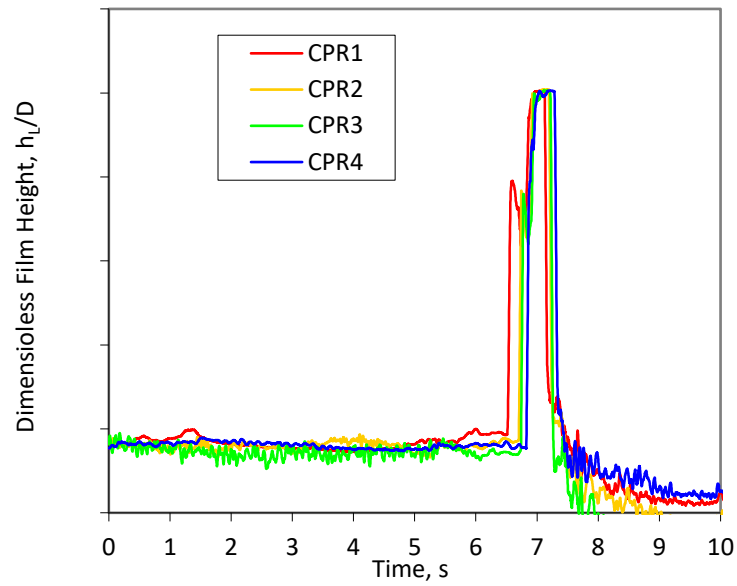
6 Results and Discussions

As will be seen from the time-traces in Figure 9 (a), for superficial gas velocity (measured using an orifice plate), $u_{SG} = 3.058$ m/s; and liquid superficial velocity (measured with a rotameter), $u_{LF} = 0.0156$ m/s the dimensionless liquid film height, $\frac{h_{LF}}{D}$ from the probes between $t = 0$ to about $t = 3.0$ s was averagely 0.22. It can be seen that the gas-liquid interface resembles that of laminar flow in single phase flow, and it is therefore referred to a stratified smooth flow. The stratified flow has been established within the test section up to $t = 3.0$ s.

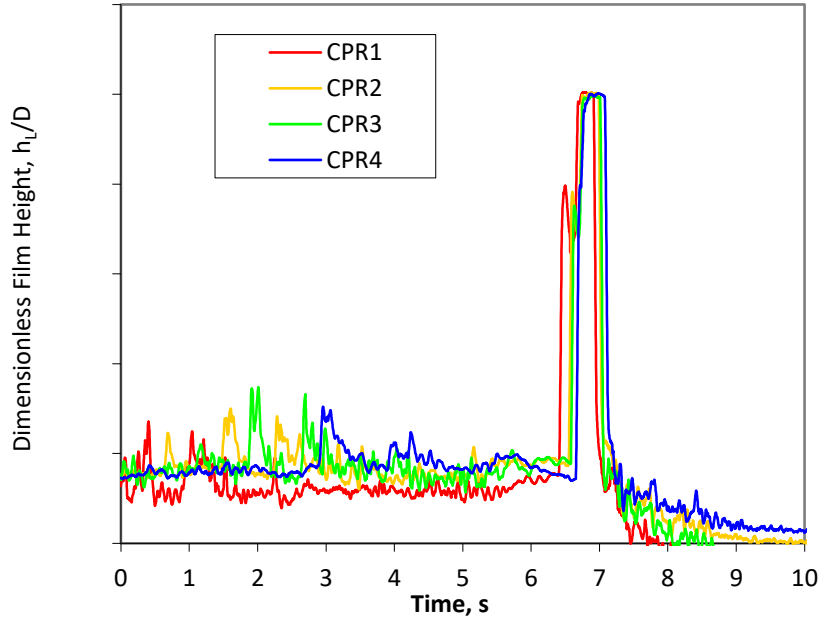
When the 3-way valve was open, a liquid slug from a pressurised pipe at a velocity (measured using a venturi meter), $U_{LS} = 2.45$ m/s arrived at the first probe at about $t = 3.2$ s, it is clear there was a rapid rise of the liquid height up to the last probe showing that the probes responded instantaneously to change in liquid film height. The liquid film height downstream of the slug front values is typically in the range of 0.6 – 0.8. Therefore, the average film height across the pipeline through the four probes can be determined and the instantaneous localised film height can also be determined for a given gas-liquid flow. Eventually, the gassy zone passes, and a nearly pure liquid zone is seen which has arisen from the injection system and which has not been penetrated by the entrained gas, $\frac{h_{LF}}{D} = 1.0$. Then, the holdup decreases rapidly indicating that the liquid in the slug injection system has been exhausted and the pressurised drive gas is entering through the three-way valve. During the time of the slug front passage between the probes, the water flow rate is being recorded from the output of the venturi meter (and remains constant until the water is exhausted), see slug feed time traces in Figure 9 (b).



(a) Superficial gas velocity, $u_{SG} = 3.058$ m/s; Superficial liquid velocity, $u_{LF} = 0.0156$ m/s and Liquid slug velocity, $U_{LS} = 1.951$ m/s = 2.422 m/s



(b) $u_{SG} = 5.083$ m/s, $u_{LF} = 0.0156$ m/s and $U_{LS} = 1.951$ m/s



(c) $u_{SG} = 6.211$ m/s, $u_{LF} = 0.0257$ m/s and $U_{LS} = 2.081$ m/s

Figure 9: Time traces - (a - c) Dimensionless liquid film height as a function of time for probes placed at 4.4 m (CPR1) from the 3-way valve, 5.4m (CPR2) from the 3-way valve, 5.6m (CPR3) from the 3-way valve and 6.6 m (CPR4) from the 3-way valve

Similar explanations on the measurement of liquid film height can be applied to Figure 9 (b) and (c). in (b) the gas velocity was increased while the liquid velocity remained unchanged. However, it can be seen that the time-traces showed a liquid film height lower than in (a). This is because the high gas velocity has changed the flow from stratified smooth to stratified wavy.

As can also be seen in (c), the gas and liquid velocities were further increased resulting in a highly wavy interface close to slugging. The film height fluctuates between about 0.1 to 0.3. averaging the film height data will give the average film height but if a localised film height is required at any pipe location is desirable, that can be determined too.

7 CONCLUSION

The LOTUS facility, which has a pipe diameter of 32.8 mm and a length of 6.3 m, was used to measure liquid film height with twin-wire conductance probes. It was clear from the data in the time-traces that slug flows can be predicted at high gas-liquid flows. Slugging leads to pipeline damage and can cause serious safety concern in oil-gas fields. Because water is electrically conductive, the probes provided reliable measurements of film height during the experiments. The results showed that changes in water level produced proportional changes in probe response, confirming that the probes could measure liquid film height accurately and rapidly. These measurements are important because they enable calculation of liquid holdup using Equation (3), and the resulting holdup values can then be used to determine the actual velocities of the gas and liquid phases. The data generated, the graphical representation in Figure 5 as well as the time-traces in Figure 9 can be utilised in the validation of models for liquid film height predictions in stratified and slug flows even in 2026 and beyond. Slug flows is associated with high pressure, leading to pipe vibration and bursting. However, this work provided an insight to the flow ranges within which slug flow regime is encountered. This knowledge can help present pipeline breakdown in Nigeria's oil gas fields,; proper slug flows mitigations are employed. Therefore, this work adequately fits the sustainable engineering processes sub-theme.

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