Experimental investigation of the effect of pipe inclination on the hydrodynamic behaviour of slug flow using electrical capacitance tomography

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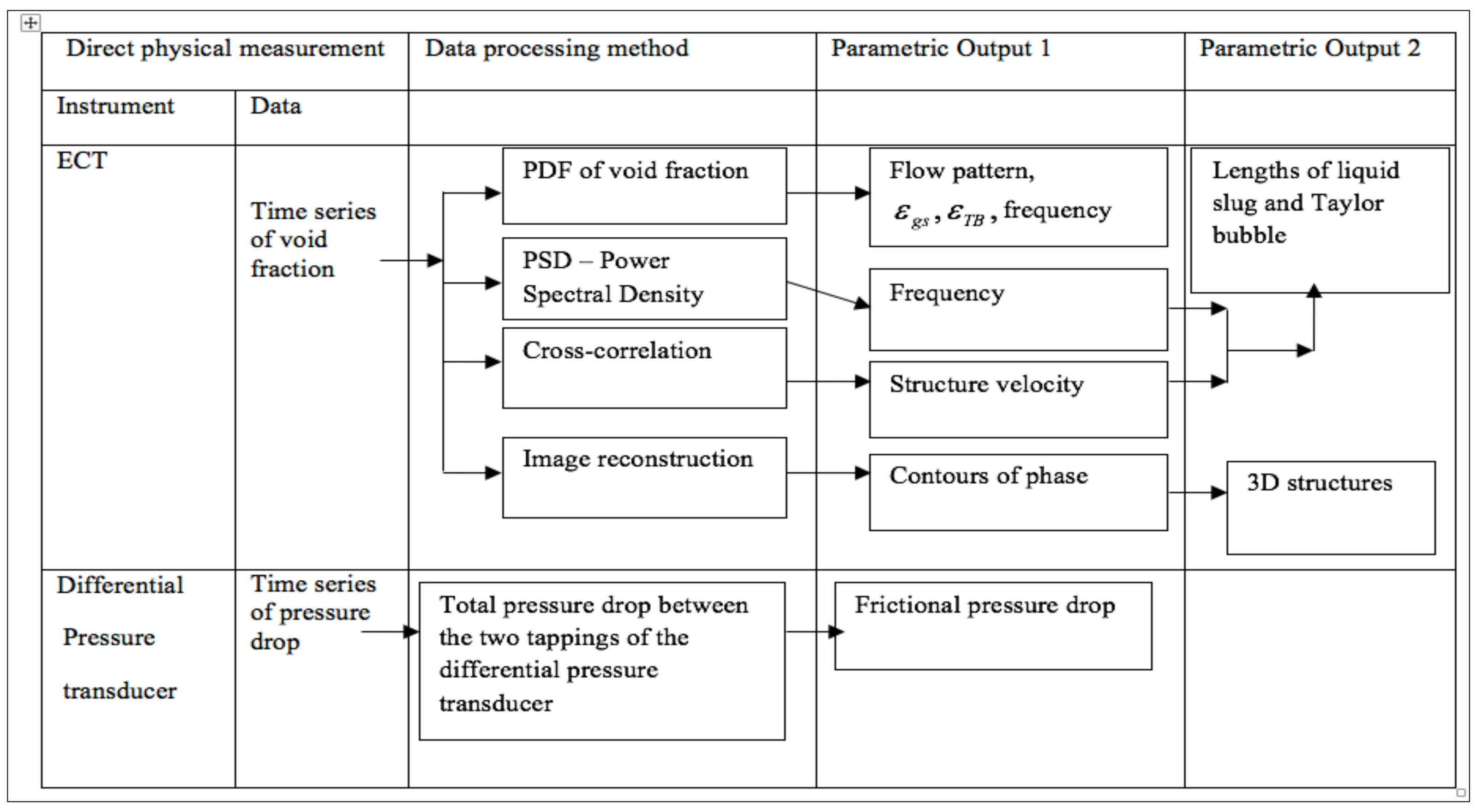
Introduction

Two-phase gas–liquid slug flow in inclined pipes is important in oil/gas transportation. Due to the fact that slug flow can change characteristics from one well to another, it is important to investigate the response of the characteristics of a two-phase slug flow as a result of a change in the pipe inclination angle. This study investigated the effect of pipe inclination on the hydrodynamics of slug flow in a 67-mm internal diameter inclinable pipe. The slug flow regime was generated using air–silicone oil mixture over a range of gas ($0.288 \leq U_{SG} \leq 1.35$m/s) and ($0.205 \leq U_{SG} \leq 0.52$m/s) superficial velocities. The 3D structures are particularly difficult to visualise using conventional optical techniques because even if the pipe wall is transparent near−wall bubbles would mask the flow deep inside the pipe. An advanced wire mesh sensors (WMS) was used and the two-phase mixtures employed was air–silicone oil. Electrical Capacitance Tomography (ECT) was used to determine: the velocities of the Taylor bubbles and liquid slugs, the slug frequencies, the lengths of Taylor bubbles and the liquid slugs, the void fractions in the Taylor bubbles and liquid slugs. A differential pressure transducer was used to measure the pressure drops along the length of the pipe.

Flowchart for experimental measurement



Picture of the experimental rig

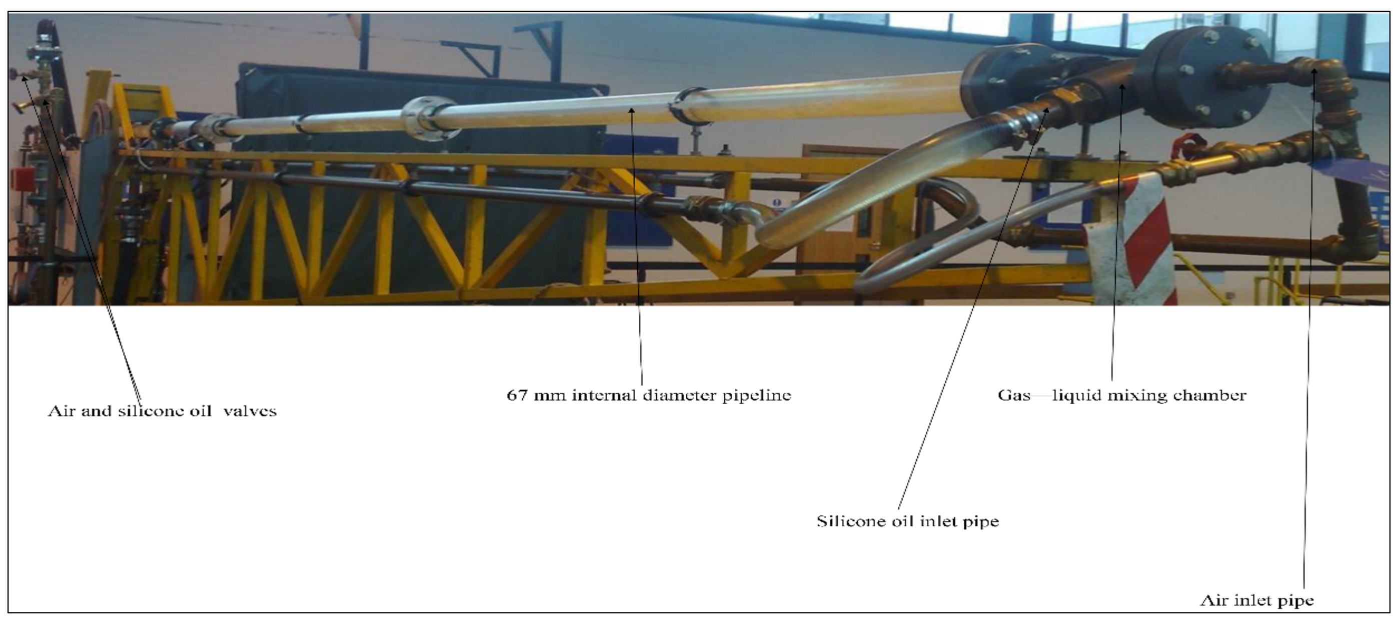


Figure 1: Picture of the experimental rig in this study

- In the design of the physical experimental rig, the flow stability was achieved by using a purpose built mixing device

- The silicone oil enters the mixing chamber from one side and flows around a perforated cylinder through which the air is introduced through a large number of 3 mm diameter orifices

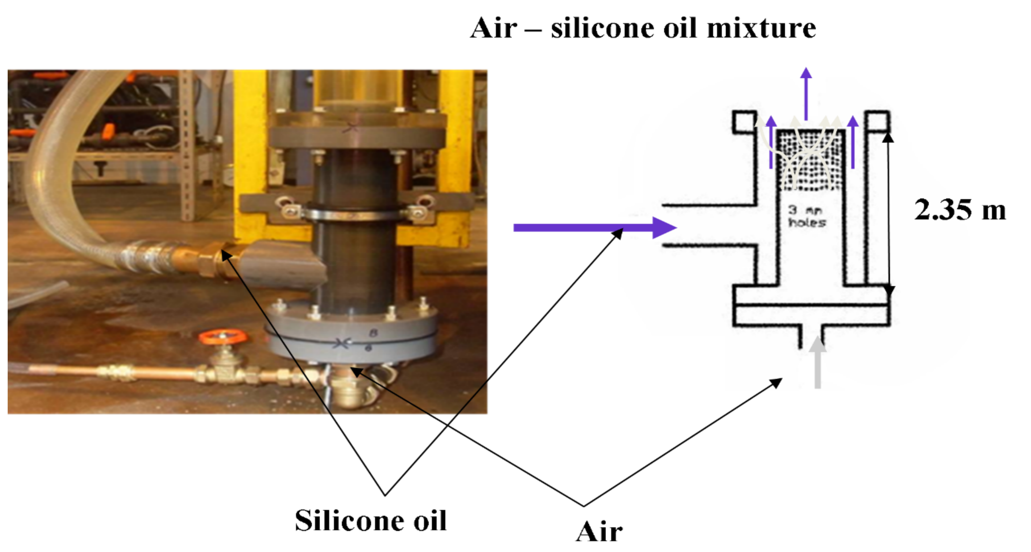


Figure 2: Air-silicone oil mixing section

Figure 3: ECT Sensor

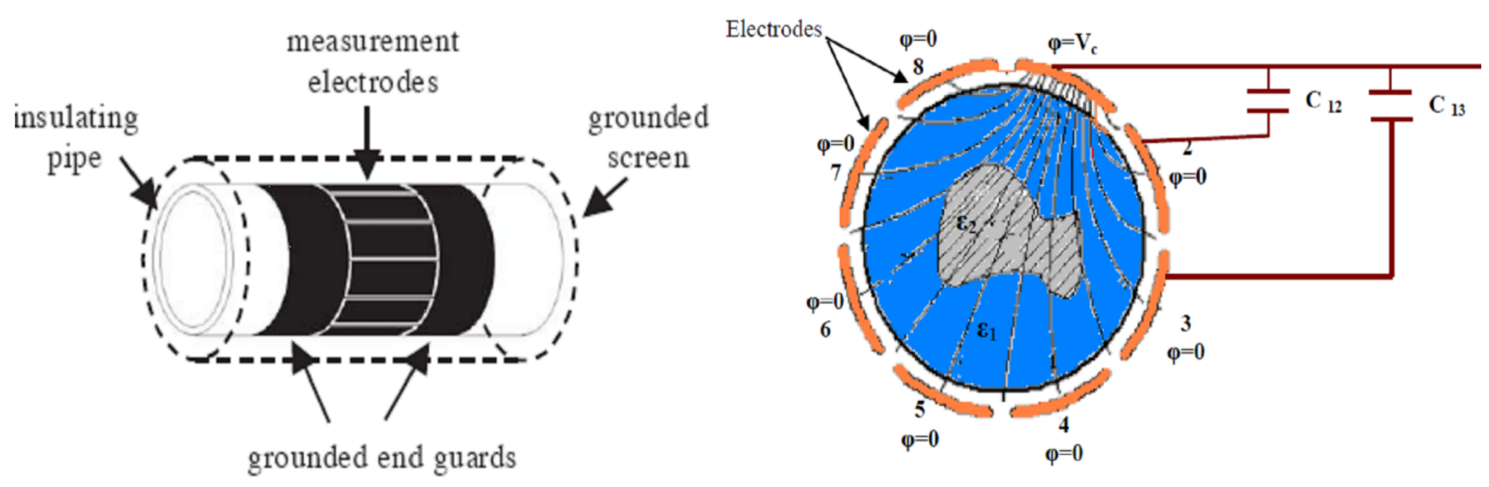


Figure 4: The electrical capacitance tomography (ECT) sensor

- An image reconstruction algorithm then translates the measurement data into the cross-sectional data into the cross-sectional concentration map
- The ECT uses capacitance data measured between any two of a multiple set of electrodes mounted at the periphery of the pipe of a two-component flow to be imaged

Experimental Results

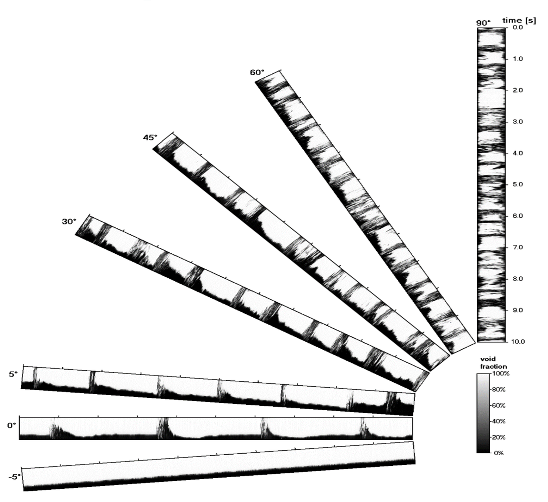


Figure 5: Effect of pipe inclination angle on the flow pattern

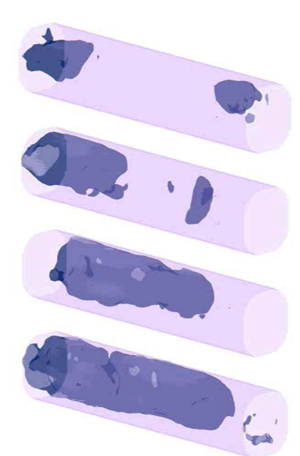


Figure 6: 3D structures at 60 degree pipe inclination angle and different gas superficial velocities

- Black and white colours represent liquid and gas phases, respectively
- As observed, due to the wide range of pipe inclination angles, different flow structures occur at different flow conditions.
- This Intermittent behaviour can be characterized by the structure frequency obtained from Power Spectrum Density method (PSD)

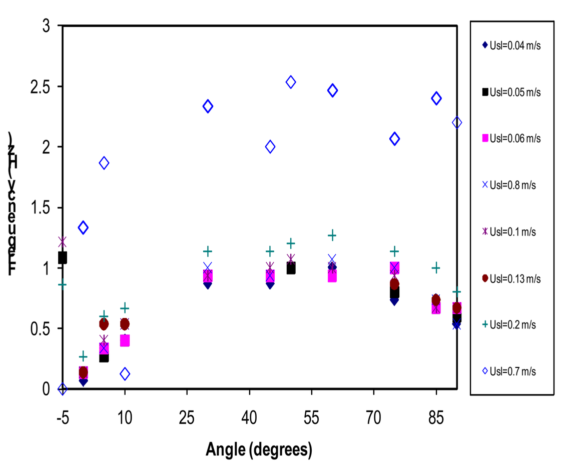


Figure 7: Structure frequency as a function of the pipe inclination angle Gas superficial velocity is 0.9 m/s and different liquid superficial velocities

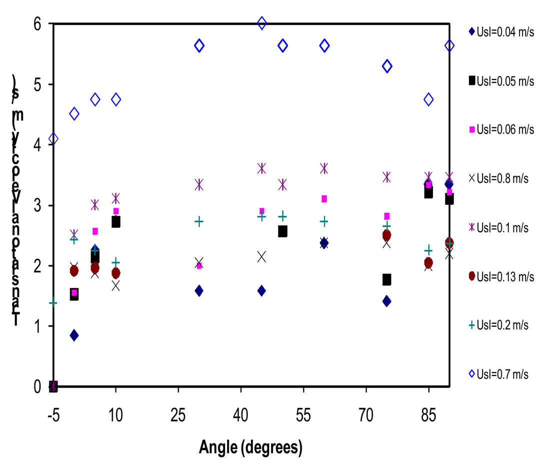


Figure 8: Structure velocity as a function of the pipe inclination angle. gas superficial velocity 0.9 m/s and different liquid superficial velocities

- The structure frequency (Fig 7) is highly dependent on the pipe inclination angle as deduced by Hernandez-Perez (2010).
- Maximum frequency occurs at an inclination angle around 60 degrees.
- The structure velocity (Fig 8) increase as a linear function of the mixture velocity
- Structure velocity is responsive to the inclination angle as agrees with conclusions of Van Hout et al. (2003).

Conclusion

- A study of the sensitivity of the structure of two-phase flow to the change of pipe inclination angle and liquid physical properties has been performed.
- It can be concluded that the effect of the liquid flow properties has been observed to be higher at vertical inclination, particularly for the bubbly flow pattern.
- A higher structure frequency can be detected as a result of an increase in the Morton number, which corresponds to the silicone-oil mixture.
- Structure frequency and velocity are highly affected by the pipe inclination angle, with the highest values achieved at inclination angles around 60 degrees.
- Bubble size distribution has also been found to be affected by the inclination angle.

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