

Visualisation of Two-phase |Gas-Liquid Pipe Flows using Electrical Capacitance Tomography

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Electrical Capacitance Tomography (ECT) can be used to measure concentration distributions in two-phase flows. We have extended the technique to measure the velocity distribution through correlating axially separated zones in two image planes. ECT is non-intrusive, and the reconstruction of the concentration and velocity distribution can be undertaken in real time and over an arbitrary number of zones in the flow cross-section.

ECT measurements are made by placing rings of electrodes around the circumference of the pipe or vessel of interest, measuring the electrical capacitance between each independent pairing of electrodes and using image reconstruction techniques to show the permittivity distribution within the sensor. In our experiments we have used a Tomoflow R100 ECT Flow Analysis System with a twin-plane 8 segment guarded array of electrodes, where the electrode axial length was 30mm. The planes are separated by 100mm axially and the acquisition rate was 200 frames per second on both planes.

The experiments were carried out at SINTEF in Trondheim, Norway, in a 0.068m diameter horizontal pipeline. Oil and air flows were used with superficial gas velocities of between 0.2 and 12m/s and superficial oil velocities of 0.05 to 1.0m/s. Gas concentrations (void fraction) ranged from 6% to 55%. Flow conditions varied from stratified flow where the two phases flow smoothly in separate parts of the pipe, through slug flow with long coherent fluid slugs to highly turbulent periodic passage of frothy flow structures (known to the Norwegians colloquially as ‘ghosts’).

Reference measurements include the individual flowrates before the two streams were mixed at entry to the flow loop, a single-beam gamma-ray densitometer placed adjacent to the ECT sensor, and video recording of the flow patterns through the transparent pipe wall. The great advantage of ECT imaging is that measurements can be made internally in all parts of the cross-section simultaneously whereas the reference gamma-ray densitometer measures a line-average across the flow. We define a ‘virtual instrument’ from the image maps which average along a line across the flow to mimic the sensitivity

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of the gamma-ray meter. Comparison of this virtual sensor with the gamma-ray measurements show good agreement in stratified and slug flows. The gamma-ray has a much longer averaging time (0.5s cf. 0.005s for ECT) and differences between the measurements appear to be in the favour of ECT in fast highly structured flows.

It is apparent from the images that many of the 'slug' structures have an air-core passing through the centre. By plotting 3-dimensional pictures based on the images as time slices separated by the local transit time we can show concentration contours that clearly show the internal structure of the flows. In particular with the 'ghosts', which appear visually from outside the pipe as bubbly slugs, it is clear that they are in fact bubbly waves which have extended 'wings' up and around the pipe.

We present a variety of 2-D cross-sectional images, time series velocity and concentration graphs and 3-D contour plots. The good temporal and spatial resolution of ECT throws an extensive new light on these otherwise difficult to measure dynamic flow structures.