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# Measurement of oil volume fraction and velocity distributions in vertical oil-in-water flows using ERT and a local probe*

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**Abstract:** This paper presents the use of a high performance dual-plane electrical resistance tomography (ERT) system and a local dual-sensor conductance probe to measure the vertical upward oil-in-water pipe flows in which the mean oil volume fraction is up to 23.1%. A sensitivity coefficient back-projection (SBP) algorithm was adopted to reconstruct the flow distributions and a cross correlation method was applied to obtain the oil velocity distributions. The oil volume fraction and velocity distributions obtained from both measurement techniques were compared and good agreement was found, which indicates that the ERT technique can be used to measure the low fraction oil-water flows. Finally, the factors affecting measurement precision were discussed.

**Key words:** Volume fraction and velocity distributions, Oil-in-water flow, Electrical resistance tomography (ERT), Local probe
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## INTRODUCTION

The need for metering multiphase flow in the petroleum industry has been evident for many years. Considerable research has been conducted into this field for developing a suitable flowmeter which can be used in industrial environments. Various technologies have been employed, and among which the tomographic techniques are increasingly being used.

Process tomography is an emerging measurement technology with applications in a broad range of industries. It is non-invasive and can yield detailed local flow information such as phase and velocity distributions, which can help us to understand flow processes better and is helpful for process monitoring and flow metering.

This work is aimed at developing a laboratory prototype based on ERT system for metering two-phase vertical pipe flows in which the continuous component is electrically conductive. The local volume fraction distributions obtained using ERT can be erroneous to a certain level, because they are highly sensitive to such factors as the accuracy of the electrical measurements made at the system boundary and the image reconstruction algorithm used (Dickin *et al*., 1993). Reference measurement error of 1% could lead to conductivity error of up to 10% depending on the magnitude of the conductivity charge (Wang *et al*., 1999). It is important that reference measurements use an independent technique so that the ERT data can be validated and the capability of ERT system can be improved. Using a local intrusive conductance probe is a simple and effective way.

## EXPERIMENTAL SETUP

The experiments were carried out in a flow loop built at the University of Huddersfield, UK. The flow loop has a 2.5 m long, 80 mm internal diameter,

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transparent, vertical working section. Water and oil were pumped into the base of the working section via different branches with turbine meters respectively, which enabled the water volumetric flow rate $Q_w$ and the oil volumetric flow rate $Q_o$ to be measured.

Tests were carried out at water flow rate of 7.5 $m^3$/h and oil flow rates of 0.75, 1.5 and 2.25 $m^3$/h.

## ERT SYSTEM AND DUAL-PLANE SENSOR

A new ERT system for online measurement of two-phase flows has been developed at Leeds University, UK. The ERT system's axial velocity can be up to 10 m/s, with 5% velocity measurement resolution (Ma *et al*., 2003).

The distance between the dual planes of the ERT sensor with 16 electrodes per sensing plane was 30 mm. The setup of the ERT system and dual-plane sensor in the test loop are shown in Fig.1.

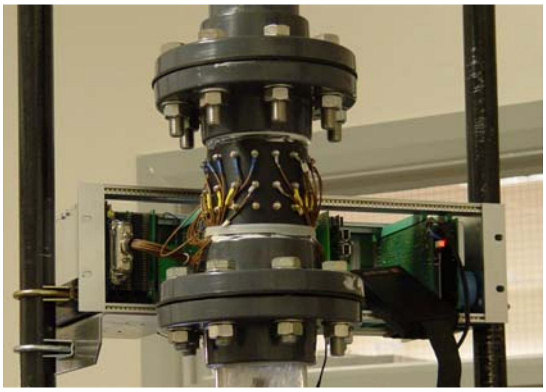

**Fig.1 The setup of the ERT system and the dual-plane sensor**

A total of 8190 dual-frames of voltage measurements were acquired for each flow condition. The voltage measurements took 8.96 s at a speed of 914.3 dual-frames per second (dfps). A sensitivity coefficient back-projection (SBP) algorithm was adopted to reconstruct the high speed flow images.

### Data analysis

With conductivity distributions acquired from ERT, the oil concentration distributions (expressed as oil volume fraction, $\alpha_c$) can be determined by applying the Maxwell equation (Maxwell, 1881):

$$\alpha_c = \frac{2\sigma_1 - 2\sigma_{mc}}{2\sigma_1 + \sigma_{mc}} \quad (1)$$

where $\sigma_1$ is the conductivity of water, and $\sigma_{mc}$ is the local mixture conductivity.

The axial flow velocity distributions can be estimated by a direct cross-correlation method, as given in Eq.(2):

$$R_{12}^{(k)}(n) = \sum_{m=1}^{k} f_1(m) f_2(m+n) \quad (2)$$

where $k$ is the sample length, $n$ is the offset number and $f_1(m)$ and $f_2(m)$ are the $m$th up-flow and down-flow images respectively. Eq.(2) can be simply implemented online by updating the $R_{12}^{(k)}(n)$ with the new ($k$+1)th images, as described in Eq.(3):

$$R_{12}^{(k+1)}(n) = R_{12}^{(k)}(n) + f_1(k+1) f_2(k+1+n) \quad (3)$$

This implementation can save calculation time and greatly reduce memory size.

## LOCAL DUAL SENSOR PROBE

A number of dual sensor probes were constructed at the University of Huddersfield, UK. Each probe was manufactured from two stainless steel acupuncture needles which were 0.3 mm in diameter and were mounted inside a stainless steel tube with outer diameter of 4 mm as shown in Fig.2 (Lucas *et al*., 2004). Each acupuncture needle was coated with waterproof paint and insulating varnish except the very tip of the needle.

The dual sensor conductance probe was mounted in a fully automated, two-axis traversing mechanism

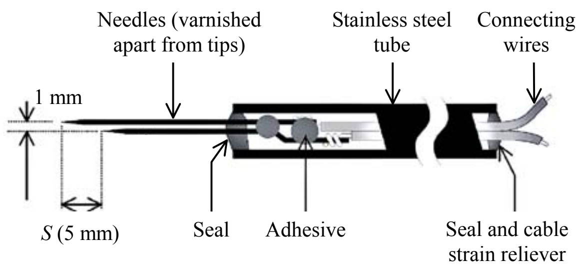


**Fig.2 Geometry of the dual sensor conductance probe**

which enabled the probe to be moved to any spatial location in a plane at the working section. In the experiments, the probe was traversed across four equispaced diameters with 15 equispaced locations on each diameter giving a total of 57 distinct measurement locations respectively. At each measurement location, and for each flow condition, data were acquired from the dual sensor probe for a period of 30 s.

## EXPERIMENTAL RESULTS

According to (Beck and Plaskowski, 1987), the minimum acquisition time, $\delta$, can be taken as twice the product of the minimum transit time of the fluid, $\tau$, and the fractional velocity discrimination, $\kappa$ given below:

$$\kappa=\delta/2\tau \quad (4)$$

The discrimination resolution calculated from Eq.(4) in this study is about 1%, which is a big advance compared with previous works (Wu *et al*., 2005). Good correlation is reflected by the smoothness and continuity of the cross correlation curves.

The oil concentration and velocity distributions obtained from both techniques are shown in Figs.3 and 4.

## CONCLUSION AND DISCUSSION

The oil volume fraction and velocity distributions in vertical oil-in-water flows have been measured by a dual-plane ERT system and a local intrusive conductance probe. The mean oil volume fractions were 9.1%, 16.7% and 23.1% in this study, good agreement between the results obtained using the two techniques has been achieved in these cases. If the oil volume fraction is so high that big oil bubbles or slugs begin to form and some electrodes lose contact with water, measurements from these electrodes may be erroneous. The conductive ring technique can be used to address this problem (Wang *et al*., 2002).

The difference between the results of the two techniques may be caused mainly by:

1. The measurement time required by the probe and ERT is quite different, the former need about 30 min to measure one flow status, the latter needs only about 9 s. If the flow status is not stable enough, a big difference will occur.

2. The ERT sensor noise level increased since

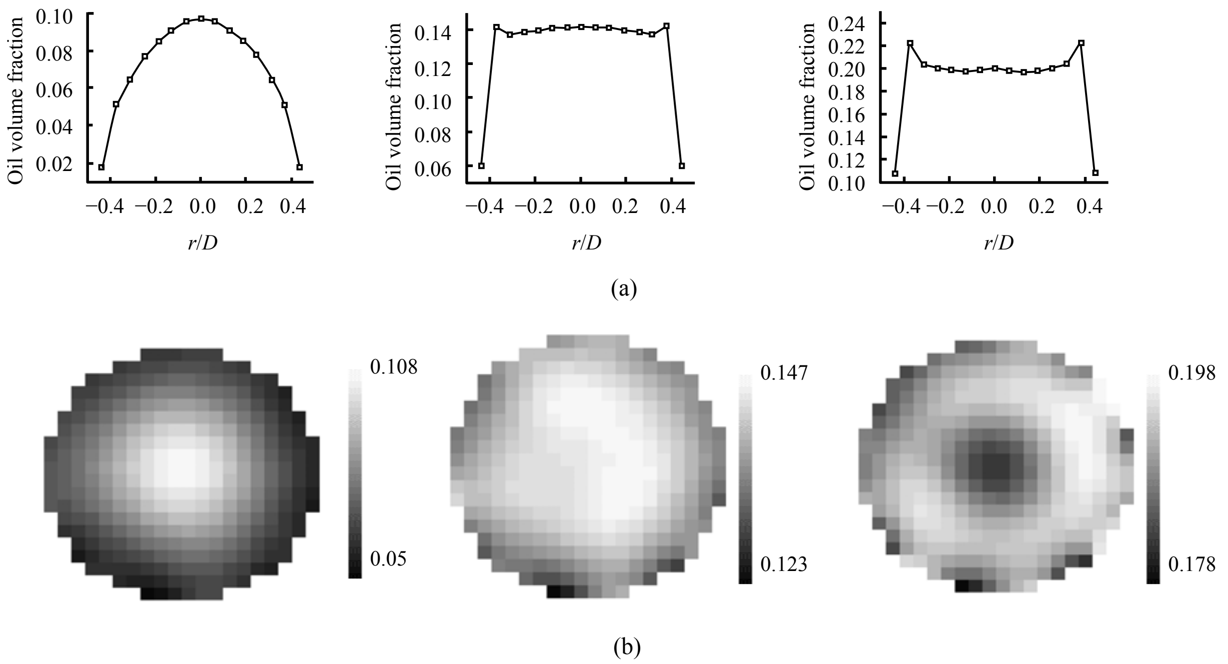


**Fig.3 Local oil volume fraction distributions obtained using the local dual-sensor conductance probe (a) and using the ERT system (b) at $Q_w$=7.5 m$^3$/h and $Q_o$=0.75, 1.5, 2.25 m$^3$/h from left to right**

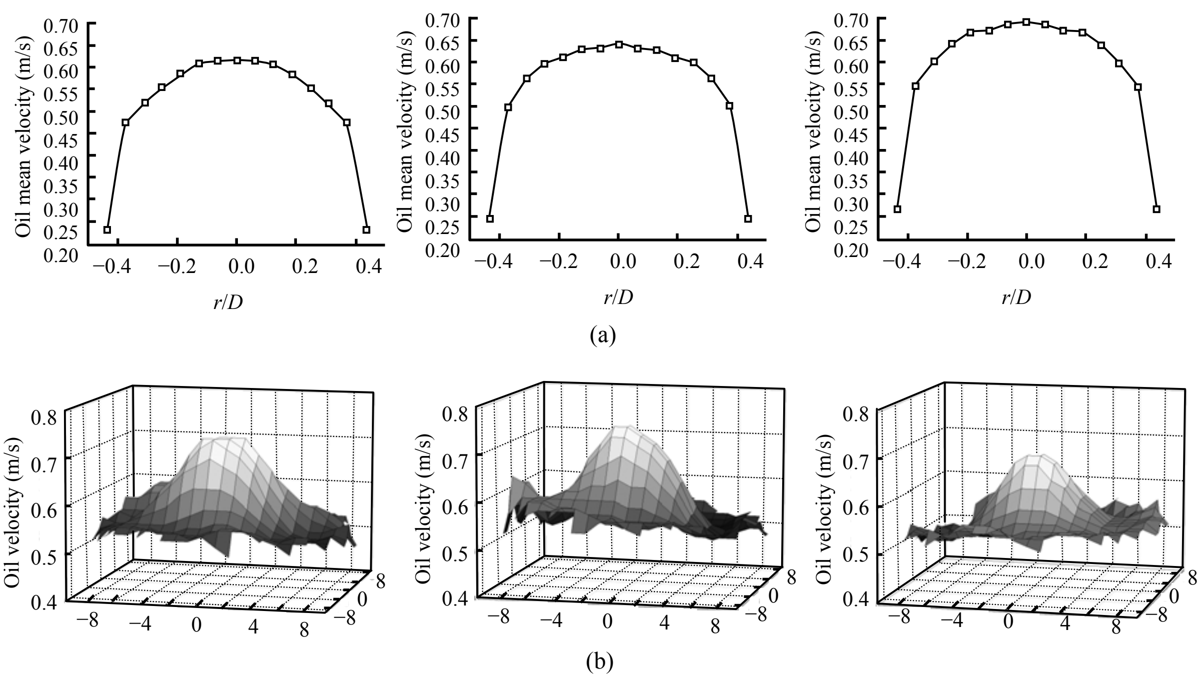


**Fig.4 Local oil velocity distributions obtained using the local dual-sensor conductance probe (a) and using the ERT system (b) at $Q_w$=7.5 m$^3$/h and $Q_o$=0.75, 1.5, 2.25 m$^3$/h from left to right**

the system worked under a higher frequency, which caused the volume fraction and velocity distributions to be a little noisy at the edge.

3. The precision of the ERT reconstruction algorithm.

4. The probe's intrusiveness can disturb the flow condition.

To get quantitative results of these factors affecting the measurement precision, a large number of experiments based on an in depth and systematic analysis of the ERT hardware and software are needed. The new ERT system has provided a good method to measure the oil-water pipe flows. Further study is in progress to optimize the system.

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