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# Visualisation and metering of two phase counter-gravity slurry flow using ERT

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**Abstract**

Two-phase slurry flow is encountered in many industries such as petroleum, mining and related industries. The abrasiveness of slurry and interaction of solid particles with the carrier liquid make slurry flow measurement one of the most challenging applications in multi-phase flow metering. This paper presents a new method of solid-liquid flow metering, in which the Electrical Resistance Tomography (ERT) is used in combination with a commercial Electromagnetic Flow Meter (EMF) to measure the volumetric flow rate of each phase. A set of experiments were carried out using a mixture of sand particles and tap water as slurry. Two different sand types (coarse and medium), with a particle size range of 53-2330 µm, were pumped through a 50 mm inner-diameter pipeline. The range of throughput solids concentration used in the experiments was 5%-10% and operated the transport velocity was 2-5 m/s. The effect of solids concentration and solids velocity on the measurement scheme is discussed. The measurement results are compared to that of Coriolis mass flow meter and discharge flow measurement system (flow diversion system). The accuracy of the measurement results is assessed and the performance of the applicability of the proposed method is highlighted.

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## 1. Introduction

Counter gravity slurry flow is a common occurrence in many industrial sectors, these being drilling of oil wells, mining, dredging and in the nuclear industry. The process of metering and visualising of counter gravity slurry flow requires significant attention and importance as the process is very complicated in nature. The intention is to optimise and enhance solid liquid flow by the use of ERT and EMF instrumentation which are used in combination to visualise the internal characteristics of slurry flow. The flow of two phase fluids is observed in many different pipeline orientations and consequently the different phases experience slippage and separation, therefore leading to different flow regime configurations, however the effect is minimal in vertical slurry flow as reported in the literature [1].

The monitoring and control of complex two phase processes is vital for safe and efficient production, transportation and exploration of the slurry flow systems. Visualisation and metering of the internal structure of such slurry flow systems provide detail imaging and distribution of the constituent phases. In the past there have been a number of techniques to measure the parameters of solids volume fraction and solids velocity distribution, however due to the limitations, the techniques have not been fully established and therefore are still under research. Such examples include conductivity probes, positive displacement meters and ultrasonic meters; however these instruments provide intrusive measurements which are undesirable as it affects the internal flow of the system [2].

Considerable research has been conducted in developing flow meters that are suitable and applicable to be utilised in the industrial field. The use of ERT technology has been employed considerably and therefore the potential and advantages of tomographic technique are great. Process tomography has advanced over the years and is the preferred measurement technology and therefore it is used widely in a broad range of industries and applications, as it offers non-invasive forms of measurement which can yield detailed local flow information such as velocity and phase distribution, which can be useful in understanding of process monitoring and flow metering [3]. Reference measurements are made by the Coriolis mass flow meter which allows for independent measurement to validate against ERT system. Electrical resistance tomography (ERT) is utilised in combination with the electromagnetic flow meters (EMF) to provide for the measurement of the dispersed phase concentration/velocity distribution as well as the mean phase volume fraction and the resulting volumetric flow rates of the constituent phases [4].

The test section of the flow loop system consists of the ERT, EMF and CMF instrumentation and the experimental procedure was performed on a vertical counter gravity test section of the slurry flow loop. The validity of the results obtained by the ERT and EMF are scrutinised and compared against the CMF and the flow diversion system. Analysis of error and the results obtained from experimentation are illustrated both quantitatively and qualitatively.

## 2. Experimental set up and procedure

### *2.1. Methodology-slurry flow loop*

Appropriate procedures and practices are employed, so as to fulfil the objectives and to generate the required results for analysis and evaluation of the ERT system. The counter-gravity vertical section of the slurry flow consisting of water and either course or medium sand, is to be visualised and measured using the ERT system as well as the flow loop system which will enable for a comprehensive set of experimental results to be obtained. The ERT system measures the dispersed phase of the slurry flow, i.e. mean solids concentration and solids velocity, while the electromagnetic flow meter (EMF) will measure the continuous phase of the system. Concentration, velocity and type of sand are the important parameters that will be varied and the resulting change in the process conditions will be observed using the voltage system. The voltage system will be utilised throughout the duration of experimentation and the purpose is to provide rapid continuous stream of information during operation of the flow loop system and the development of the flow regimes and flow characteristics within the pipeline.

### *2.2. Set up of slurry flow loop system*

Fig. 1 seen below illustrates the slurry flow loop system; the schematic diagram illustrates a horizontal and vertical pipeline section of 7 and 5 meters respectively. The inner diameter of the pipe cross section is 50 mm. The slurry is transported and circulated through the system using a centrifugal pump. The mixture of sand and water is homogenously mixed using the mixing tank which is directly connected to a digi-drive frequency converter. The complex measuring equipment including pressure and temperature sensors ERT, EMF, CMF and a handheld conductivity meter as well as thermocouples are all equipped and installed onto the flow loop system, Fig. 1 (b) represents the vertical test section and the order on instrumentation. The Labview software records, processes and displays the generated data from the CMF and the EMF. The ERT system is then used to acquire the mean solids volume fraction, mean solids axial velocity and mean liquid volume fraction. The EMF is also utilised however the only measurement recorded from the instrument is mean liquid axial velocity of the continuous phase. The generated data from the ERT and EMF are then subsequently used to determine the mean solids volumetric flow rate and mean liquid flow rate. The design of the system is such that it rests on a table with a steel frame structure, in which the pipeline is supported on. The two sections of the system are connected together using a pivot point. A lifting mechanism which consists of an electric winch is used to bring the horizontal section of the pipeline to a vertical upright position [1, 6].

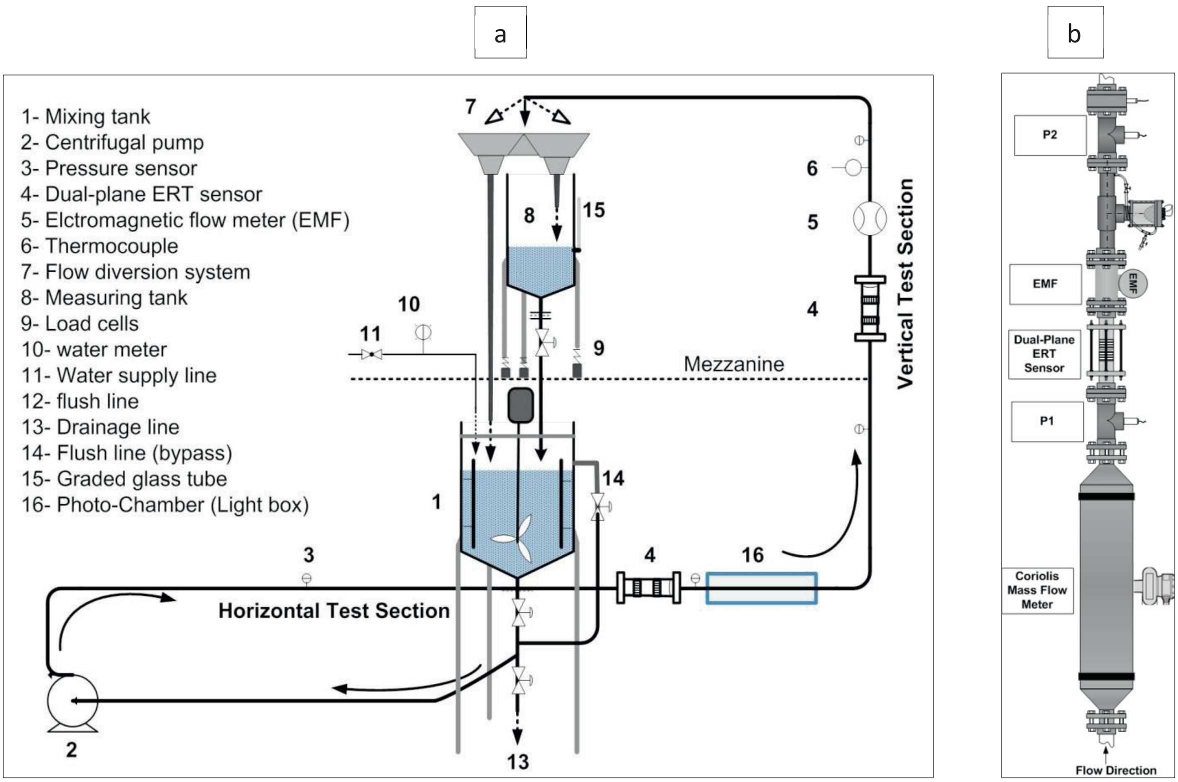


Fig. 1. (a) Slurry flow loop system; (b) Vertical test section of slurry [1].

The flow loop is prepared in which the mixing tank is homogenously mixed with the correct type of sand and the desired concentration is achieved. As a rule of thumb, to operate efficiently the system is operated at 5% concentration and is increased up to 10%. The digi-drive frequency convertor is utilized to increase the frequency of the pump in order to achieve a velocity of 5 m/s for the slurry system. As the desired velocity is reached the conductivity of the water is measured by the handheld conductivity meter. The conductivity is continuously monitored throughout the experimentation period; the purpose is to acquire further reference measurements. The voltage system concurrently provides data from the ERT and EMF system, furthermore temperature and pressure is also measured by the voltage system. Subsequent readings are taken from the Coriolis mass flow meter (CMF) and are compared with that of the voltage system for validation. The pressure of the system is continuously monitored by the Labview software, this continuous observation allows the stability of the system to be monitored, hence results can then be recorded, and furthermore the pressure sensor readings provide in advance indication of any possible blockages. Stability is achieved indicated by minimum fluctuation of pressure, the results are then recorded and the next set of conditions is implemented, and so the velocity of the continuous phase is reduced to 2 (m/s) in intervals of 0.5 (m/s). The concentration of sand is then increased up to 10% and the procedure is then repeated as above. In addition the conductivity of brine in the mixing tank is measured manually for every test condition as well as the temperature since energy from the pump is dissipated into the continuous phase therefore affecting the process conditions.

## 3. Results and Discussion

### 3.1 *ERT solids volume fraction distribution*

Figs. 2 (a) and (b) illustrate the distribution of solids volume fraction for both medium and coarse sand types across the cross section of the pipeline.

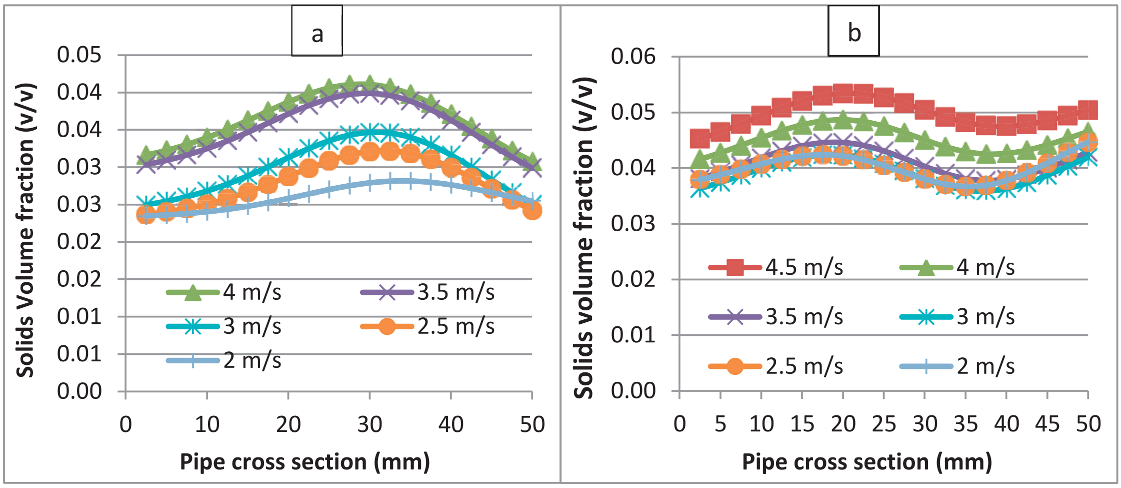


Fig. 2. (a) 5% medium sand; (b) 5% coarse sand.

Fig. 2 (a) represents the visualisation of solids volume fraction for 5% medium sand. The results illustrate a parabolic curve, in which at the centre of the pipe cross section the highest degree of sand concentration is observed. Studies conducted by [1, 5], have resulted in similar findings. The reason for that is the flow of slurry is most developed at the centre of the pipeline and the flow away from the centre encounters greater friction therefore a greater degree of solids build-up near the walls of the pipe. In Fig. 2 (b) for 5% coarse sand the profile is such that at the centre of the pipe, a peak in sand concentration is observed and on the right of the centre line there is large noticeable dip; however to the right the degree of dip is lower, this could be due to the greater concentration of sand in the system flowing faster along the flow loop. For 5% medium sand the flow pattern follows a fast moving stream of slurry at the centre of the pipe cross section as indicated by the consecutive peaks from the different transport velocities. Further observations of the Fig. 2 a and b show that as the transport velocity of the slurry is increased the solids volume fraction measured by the ERT system reaches a closer value of 5% solids volume fraction. The highest solids volume fraction detected and recorded by the ERT system at the centre of the pipe is approximately 4% and that is observed at a transport velocity of 4 m/s while the lowest solids volume fraction observed at the centre of the pipe is approximately 2.75% and that is at 2 m/s, the same phenomena is noticed with 5% coarse sand. It can be deduced that at higher sand volume fractions the degree of sand concentration detected by the ERT system, is lower than at lower sand volume fractions, the justification for that could be due to a higher volume of sand being accumulated along the horizontal sections of the pipeline and that the velocity is incapable of fully transporting the sand around the flow loop. The effect of increase in the rate of mixing allows for more accurate measurement of the solids volume fraction of the sand by the ERT system.

*3.2 ERT solids axial velocity distribution*

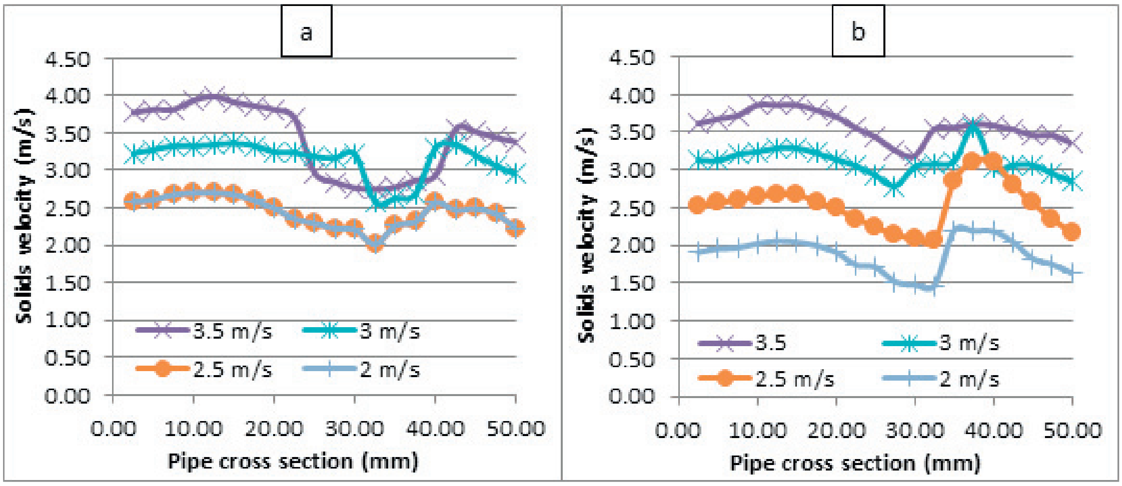


Fig. 3. (a) 5% coarse sand; (b) 10% coarse sand.

The dispersed velocity profiles of 5% and 10% coarse sand are illustrated by Fig. 3 (a) and (b). Across the pipe cross section, the velocity of the dispersed phase fluctuates in both 5% and 10% coarse sand. Observations of both Fig. 3 (a) and (b) show that from 0 to 25 mm across the pipe cross section, the degree of fluctuation is minimal almost steady, however from 25 to 50 mm, there is a large degree of turbulence and unsteadiness in the dispersed phase velocity profiles. With the coarse sand there is no large drop in velocity however fluctuation is still present from the centre of the pipe to 25 mm. There could be many reasons to explain such observations, one possibility could be that, across one half of the cross section of the pipe the flow of dispersed phase could be smooth and there is minimal collision between the coarse sand particles therefore the velocity is steady. On the other half section of the pipe the flow of coarse sand could be unsteady due to random collision between the particles leading to loss in velocity. Other errors could be systematic such as vibrations in the flow loop; or, that within the coarse sand there are large particles sizes present which could affect the flow regime. The trend however is seen on more than one occasion therefore it could be systematic i.e. issue with the ERT system. Issues with the pump were encountered repeatedly during operation, a surge in pump frequency could destabilise the flow, and although the stability was monitored using the pressure sensors, enough time was not allowed to reach appropriate flow conditions. Multiple reference measurements had to be taken due to the increase in temperature of the slurry and subsequently the change in conductivity of the system. The disruptions caused by taking references, could be another possible cause for error.

*3.3 ERT solids axial velocity distribution (error analysis)*

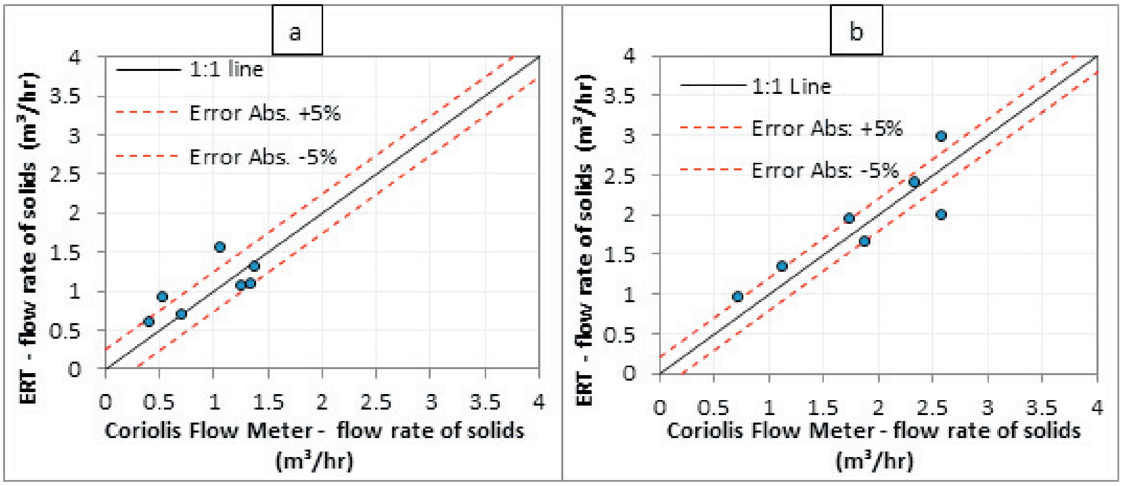


Fig. 4. (a) 5% coarse sand; (b) 10% coarse sand.

Fig. 4 (a) and (b) illustrate the error analysis performed on both 5% and 10% coarse sand. The y axis consists of ERT measurements while the x axis is the reference measurement obtained from the CMF. It can be seen from Fig. 4 (a) that two points lay outside the ±5% region and therefore it can be treated as an anomaly, however for the rest of the points sensible results are obtained since the points lay within the ±5% region. The range of CMF is from 0 to 4 $m^3$/hr. and likewise for ERT. For fig. 4b, there is only one point that is outside of the error ±5% region, and furthermore the points are distributed across the range of data on the y and x axis.

## 4. Conclusions

In conclusion, the combination of (ERT & EMF) for process measurements is developed for two phase flow and the results obtained illustrate the success of the new technique. The validation of ERT with that of the CMF, presented sensible outcomes in which matching results were obtained from the instruments on the flow loop system. The ERT system presents accurate slurry flow measurements for the distribution of solids volume fraction & solids axial velocity. In the visualisation of both the coarse and medium sand, for the different conditions of 5% and 10%, robust data were generated from the ERT system, therefore the author can say with confidence that the ERT system is adequate in performing Visualisation and generation of concentration profiles within the pipe cross section. The validation of the novel meter against Coriolis mass flow meter suggests ±5% abs. error. The visualisation & measurement system can well be used for monitoring and measuring vertical slurry flow.

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