Chapter

Electrical Resistance Tomography Applied to Slurry Flows

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Abstract

Electrical resistance tomography (ERT) is used to investigate a variety of slurry flow applications including pipe flow, mixing tanks, and thickener feed wells. Transparent liquids such as Carbopol polymer solutions and water are often used to allow for visualization of slurry flows, but ERT can provide data about solids behavior when the liquid phase is transparent or when it is opaque. The state of suspension of solids using ERT is often useful even when the technique is not a primary requirement of a test. The chapter introduces ERT from the point of view of a user in a research environment, but with flow scenarios relevant to industrial applications in mineral processing. Relevant literature concerning slurry flow applications of ERT is reviewed. The basic theory of ERT will be presented together with a discussion of the image reconstruction problem which is a topic of research activity in the slurry transport community. An overview of ERT applications in slurry pipe flow and mixing tanks will be presented. Examples of the application of ERT to pipe flow and tanks will be discussed in detail, including practical experiences with integrating ERT into slurry pipe and tank rigs.

Keywords: electrical resistance tomography, slurry flow, pipe flow, visualization

1. Introduction

Electrical resistance tomography (ERT) is a well-established technique for obtaining the cross-sectional distributions of solids in slurry pipe flows and tanks, among other uses. Basic details of the ERT technique are given in [1] and many other publications. ERT for process applications was discussed in [2]. Previously, ERT had been extensively used in geophysical applications as well as being explored for use in biomedical imaging. The basics of design and implementation of ERT technology suitable for process applications are presented in the paper. The authors specifically mention mixing scale-up as an application for ERT and introduced the 1.5-m diameter tank at UMIST (University of Manchester Institute of Science and Technology), which was equipped with a full set of ERT electrodes covering most of the tank wall. A recent book describing many forms of tomography for industrial applications, including ERT, is [3].

The present contribution describes the basic principle of ERT as applied to slurries focusing on pipe flow and mixing tanks as conducted by the Fluids Engineering Team at CSIRO.

2. Basic principle of ERT

The principle of operation of electrical resistance tomography (ERT) is to inject a known electrical current into a pair of the (usually) 16 electrodes in a plane equispaced around a vessel or pipe wall and measure the voltages present on the remaining electrodes. The process is cycled through the remaining possible pairs of injection current locations (15 pairs) to give an extensive data set for the measurement plane. The complete set of measured voltages is then used to reconstruct an image of the conductivity in the vessel's cross section from which the solids concentration or gas fraction can be obtained in principle, if the liquid- and solid-phase conductivities are known (gas and most solids in slurries would have zero conductivity). A basic schematic of the measurement and reconstruction process is shown in **Figure 1**.

ERT requires an inverse problem algorithm to calculate the conductivity distribution from the voltage measurements. If the conductivity distribution is known from such a calculation, the volume concentration of the nonconductive solids or gas can be calculated from the measured conductivity via the reduced Maxwell equation:

$$\phi = \frac{2(\sigma_1 - \sigma_{mc})}{\sigma_{mc} + 2\sigma_1} \tag{1}$$

where.

σ_1 = continuous phase or background conductivity (typically water or another homogenous supernatant such as a carrier fluid or fine particle slurry).

σ_{mc} = measured reconstructed conductivity.

ϕ = volume fraction of the nonconductive phase.

Note that the aforementioned equation is applicable for zero conductivity solids only with a more complex version applicable if the solids exhibit some level of conductivity. The equation is also applicable for a gas phase which can also be considered having zero conductivity. The volume fraction may be readily converted to other measures of concentration if the solids and liquids densities are known.

Areas of an image with a lower conductivity indicate the presence of solids to be higher as the particles present in many slurries are nonconductive. The data acquisition process is repeated across multiple planes in the vessel or pipe; however,

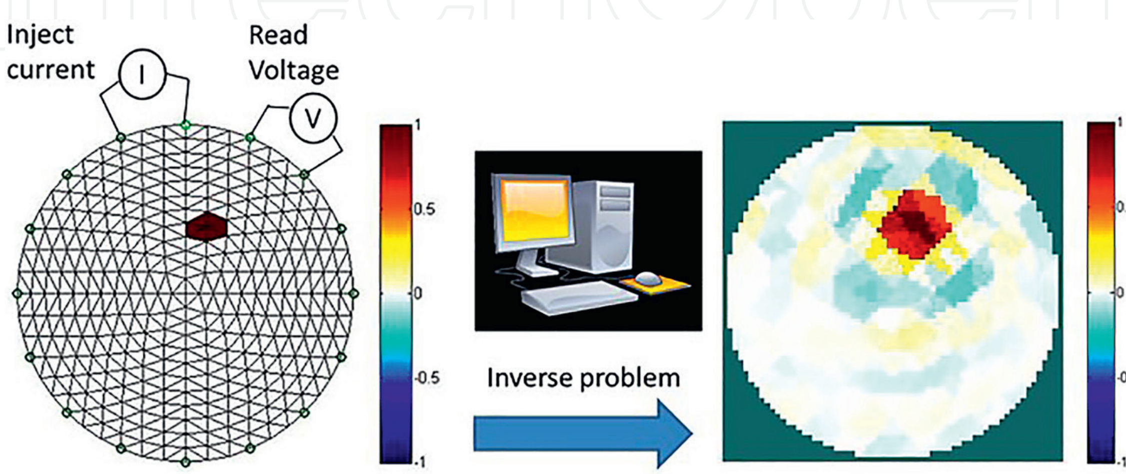

Figure 1.
Basic operation principle of ERT. Differential reconstruction assumed.

usually only one plane can be measured at any one time with most commercial hardware and software.

3. Slurry ERT literature review

Improving the accuracy and utility of ERT for slurry applications has been the subject of many articles over the years, and a selection of these is reviewed here. A recent comprehensive overall review of slurry applications of ERT is given in [4].

Ref. [5] has presented a general iterative algorithm to improve the quantitative accuracy of ERT. This used a 2D model for the forward problem and was shown to be superior to the linear backprojection (LBP) algorithm used for rapid image reconstruction.

A further paper from the same group demonstrated ERT in use to understand the differing flow regimes in pipe flows [6]. They used slurry concentrations up to 20% by volume in a pipe loop with diameter 3 inches. The ERT was shown to readily visualize the flow regimes from homogenous flow to stratified flow. The transitions between these flow regimes could also be readily detected.

Ref. [7] examined the solids distribution in suspension flows with ERT. They used both neutrally buoyant, low- and high-density particles. Their algorithm used a 2D inverse problem and a 3D forward problem called a "pseudo three-dimensional algorithm." They attempted to model the observed particle distributions with limited success.

Ref. [8] examined bidispersed suspensions of negatively buoyant particles in a low Reynolds number pressure-driven pipe flow. A nonlinear ERT reconstruction algorithm was used. They used PMMA particles and silver particles. Due to the conductivity of the silver particles, the two types of particles were able to be imaged separately. These data were used for comparison with a suspension model, and another interesting result was the observation of the hindering of particle settling of one phase by the other phase.

Ref. [9] used a high-speed ERT system to measure concentration and velocity profiles in pipe flow. An 80-mm diameter pipe rig was used for all the tests. Two electrode planes of 100 mm apart were used for a cross-correlation technique to measure velocities. Kaolin carrier fluids and silica sand coarse particles were used to make the slurries.

Ref. [10] described one of the earliest ERT results for pipe flow. They used 60-mm and 100-mm diameter pipe loops with slurries made from water and sand or glass particles. Solids concentrations ranged from 6.8 to 13.7% by weight. Among other results, they were able to demonstrate ERT detection of a dispersed suspension compared with a saltating suspension. They proposed that a deposition velocity could be determined from the ERT image.

A recent example of ERT in conjunction with CFD applied to slurry tank flows is [11] where the mixing performance of a coaxial system comprises a wall scraper and a pitch blade central impeller. It was found that the coaxial mixer system provided better particle suspension than a single-impeller system.

A combination of ERT and magnetic flow meter has recently become commercially available as discussed in [12, 13]. The device was trialed in a dredging application. A significant advantage of the new device is that it eliminates the safety concerns of nuclear sources on board dredging vessels. The ERT is integrated into a single spool together with the magnetic flow meter.

Ref. [13] also describes other industrial applications of ERT in slurry flows, including mineral processing, tunneling, and deep-sea mining. Again, the motivation for much of this work is replacement of nuclear density gauges.

4. CSIRO slurry research facilities

CSIRO Mineral Resources has a 100-mm diameter pipe rig in several versions which has been equipped with ERT since 2002. The rig also is equipped with conventional instrumentation including a magnetic flow meter and pressure transducers as shown in the schematic diagram in **Figure 2**. This rig can also be inclined if required as shown in **Figure 3**. Transparent sections allowed for visualization. The sampling point shown allows for carrier fluid/slurry to be taken off the top of the flow in

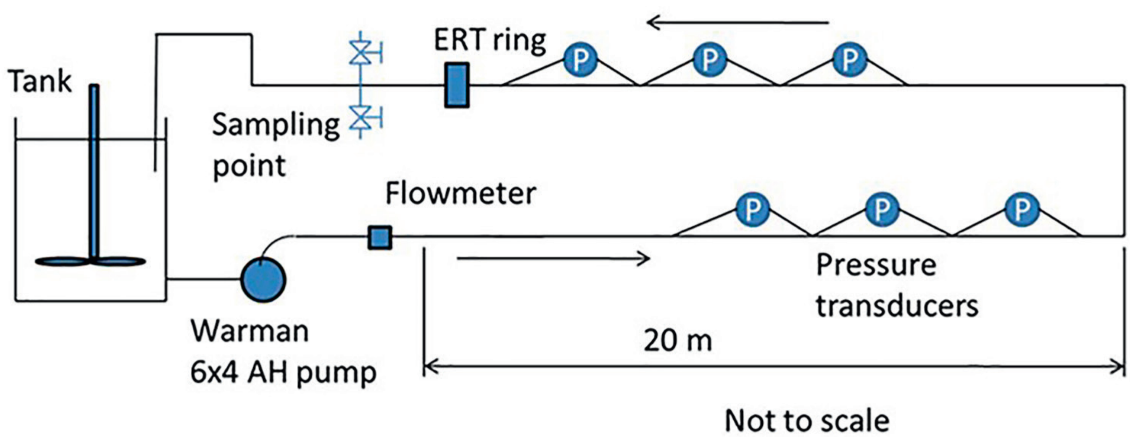

Figure 2.
Schematic diagram of CSIRO mineral resources pipe rig.

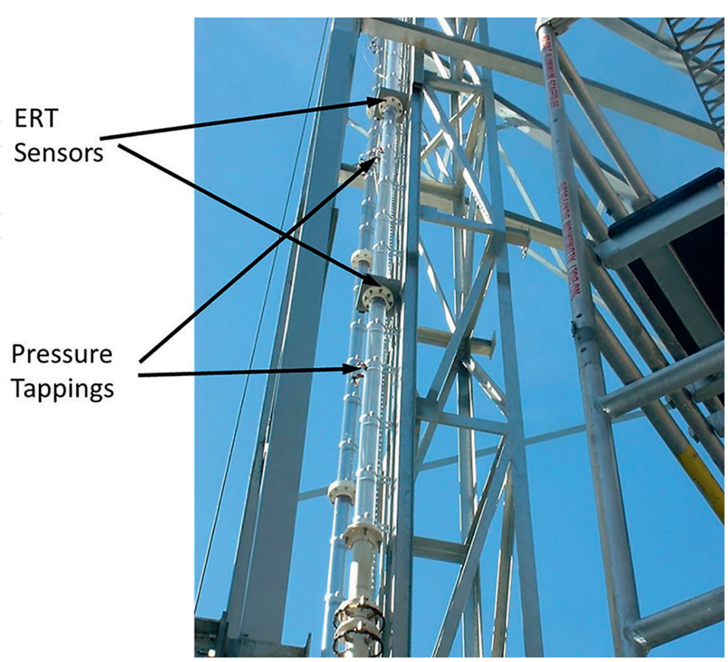

Figure 3.
View of ERT sensors on pipe rig when pipe is in the vertical orientation.

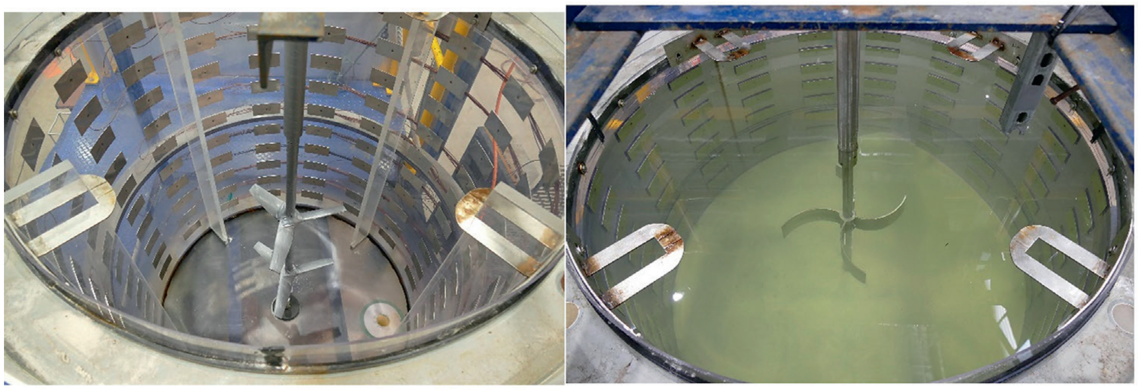

Figure 4.
Photographs of a 1-m diameter tank equipped with ERT electrodes. Two different impeller configurations shown: Baffled and unbaffled.

laminar flow to allow for rheology measurements as well as conductivity measurements without having to fully screen the complete slurry samples. Further rig details are given in [14].

The slurry mixing tanks at CSIRO typically include impeller torque and speed measurement capability and are made from transparent acrylic to allow for flow visualization, particularly in order to examine particle suspension behavior. Selected tanks have recently been equipped with ERT electrode sets to allow for imaging of concentration distributions and particularly to explore solids concentration variations within the tank which cannot be discerned from video recordings or other means. **Figure 4** shows photographs of two tank configurations used at CSIRO for slurry research.

CSIRO Mineral Resources primarily uses ITS ERT equipment including 2x ITS P2000 and 1x p2+ instruments together with the data acquisition and reconstruction software provided with these instruments. The P2000 was the primary instrument for the pipe rig and was placed in a remote weatherproof box on the rig to minimize the analog signal cable lengths. Similarly, the ERT electrode rings and cables were weather-proofed.

5. Image reconstruction for slurry applications

5.1 Background

Image reconstruction is one of the major challenges in ERT applications as it is an ill-posed problem, as noted in [15], and is still an active research area. An in-depth analysis of research work in the area of image reconstruction will not be discussed here; however, relevant points for slurry applications will be illustrated.

An overall principle of ERT is that image reconstruction is an inverse problem; it is required to calculate the conductivity distribution in a defined space based on boundary measurements. The calculation of the measurements based on a known conductivity distribution within the space and electrode injection current is relatively straightforward and is referred to as the "forward problem."

Early reconstruction methods were based around a backprojection algorithm as described in [16]. Algorithms based on this concept are still in use at the time of writing as the usual reconstruction technique supplied with commercial ERT systems.

Typically, this is a linear backprojection (LBP) algorithm. It has the advantage of speed, allowing for near real-time imaging and relative simplicity. The backprojection has the disadvantage of being qualitative and also suffers from blurring in instances where high-conductivity gradients are present as noted by [17]. However, in many circumstances, it is sufficient for investigating slurry flows and is widely used. Usually, the ERT process begins with collecting a homogenous reference data set in the vessel of interest. A data set is then obtained with the solids or gas added to the vessel and the reconstruction performed using a differential approach relative to the reference.

Alternative algorithms are available to overcome some of the shortcomings of the LBP in situations where there would be a benefit such as sharp concentration gradients and rapid images are not required. These algorithms have grown in popularity, especially as computational power has increased, thus allowing more complex computational processing in a reasonable time.

Ref. [18] presented a sensitivity conjugate gradient (SCG) method for ERT which was also an early commercial offering. This technique was shown to decrease the blurring or smearing inherent in the LBP for sharp discontinuities and thereby provide improved contrast recognition than the backprojection algorithm tested on synthesized data. Examples using real data were also presented including imaging a human hand. The real data results showed that the SCG was able to provide much more detail than other contemporary alternatives.

Ref. [19] describes a MATLAB toolkit, EIDORS, which provides a framework for developing and testing tomography reconstruction algorithms. Simulations of ERT measurements can be made in the toolkit and various reconstruction approaches tested. Experimental data can also be processed in EIDORS using a wider variety of algorithms. Further details of EIDORS are given in [20].

The commercial ERT suppliers are also continuing to develop their offerings for postprocessing of ERT data. An example of this is described in [21]. A variety of algorithms were presented which were stated to be suitable for various scenarios in ERT. A recent state of the art is described in [12].

Most ERT data acquisition and reconstruction are performed assuming two-dimensional behavior of the electric fields. This is a simplification as noted by [22] as the actual electric fields are three-dimensional. The effects can be mitigated in some circumstances by using a 2.5D approach as described in [23]. While the 2.5D approach was successfully used for slurry pipe imaging by [24], it is more difficult to apply the concept to a mixing tank as the invariance of the slurry condition along the axis of the vessel is not necessarily present, unlike for the case for pipe flow. Judicious choice of the injection current for the ERT test and the spacing between electrode rings may reduce the 3D effects. A full 3D data acquisition and reconstruction is also possible in principle to avoid these issues but is not available in the presently available commercial hardware, since the planes are usually measured separately in sequence. However, if the flow timescales are long relative to the data acquisition time, the data from the separate planes can be combined to provide three-dimensional information. This approach can be useful for tanks or gas/liquid systems and for the cross-correlation velocity measurements. High-speed versions (500 frames per second or more) of the commercial ERT systems are available for these applications.

5.2 Comparison with other imaging techniques

Other imaging techniques have been applied for slurry flows. An example is gamma-ray tomography which is an extension of the industrially used gamma-ray density instrument. This technique relies on the attenuation of the gamma-ray varying as varying density slurry flows through the measurement section as described in [25]. Tomography applications require multiple sources and detectors or a single source and detector that can be rotated or translated across the measurement section. More details of the technique are given in [26]. Disadvantages of the method were the time taken to acquire the data (tens of minutes using a single source/detector) and an increase in errors near the pipe wall. The acquisition time can be a concern given that laboratory slurry tests are usually carried out in recirculating rigs, thus leading to potential change of the properties of the slurry due to particle attrition and temperature rise. A multiple source/detector system was described in [27] based on a system described in [28] and the errors of the system evaluated for water/clay/sand slurries in a 100-mm pipe up to 20% v/v of sand. Further work by the SRC group is given in [29], where they use the gamma-ray technique to assist with correcting ERT for conductivity changes in the carrier fluid. The device used was capable of rapid imaging (up to 100 Hz) unlike single source/detector systems.

The present author and his colleagues have used MRI imaging to investigate slurry flows, prior to using ERT. Ref. [30] describes the basic principles of NMR/MRI together with its application to flows. A useful property of NMR is that there is a velocity sensitivity inherent in the physics, which is manifested in the phase image. While it was possible to obtain velocity and concentration data from MRI for synthetic polymer solution-based slurries, the rapid decay of the NMR signal due to the short T2 relaxation time prevented application to industrial slurries in larger pipes where rapid gradient switching is difficult, although smaller systems such as the rheological application discussed in [31] are possible. A further update of MRI possibilities for rheology and fluid dynamic applications is given in [32]. Another consideration is that the MRI equipment is often larger and more expensive than ERT, although permanent magnet systems are available which are more economical than cryogenic systems, whereas ERT is more usable industrially as described in [13]. It is possible to obtain velocity information from ERT data via a cross-correlation technique using two electrode planes. This technique was used by [9] with a high-speed ERT data acquisition system to obtain velocity data in slurry pipe flow.

Figure 5 from [33] shows a comparison between a photograph, MRI and ERT from the CSIRO pipe rig where a bed of solids was present in the pipe flow. The ERT data includes LBP as well as a more advanced SCG processing [18] of the same data. This algorithm was one of the early postprocessing options available commercially, and the results are in better qualitative agreement with the MRI and photograph than the LBP. Slurry velocity images obtained by MRI over a range of velocities are shown in **Figure 6**. These flows were all in the laminar regime. Unfortunately, the MRI system was not usable with industrial slurries or the later development of the pipe rig which had a steel structure.

5.3 ERT image reconstruction for pipe flow

The commercial ERT systems (ITS P2000 and p2+) used at CSIRO for slurry flow research were supplied with the LBP reconstruction as the default option. In practice, when operating the pipe rig and mixing tanks, the real-time LBP images are very useful in monitoring the state of suspension in the flow and adequate for determining the effect of pipe velocity or impeller speed on particle suspension.

An early comparison between LBP and a more advanced algorithm (SCG) for a settled bed of solids was given previously in **Figure 5**.

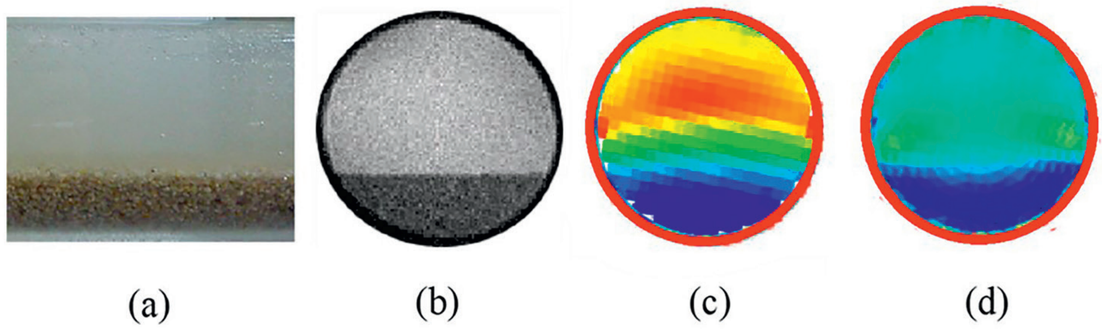

Figure 5.
Comparison between (a) photograph, (b) MRI and ERT algorithms, (c) LBP, and (d) SCG ([18]). As originally published and presented at the BHR 15th International conference on Hydrotransport, Banff, Canada, 3rd-5th, June 2002, [33].

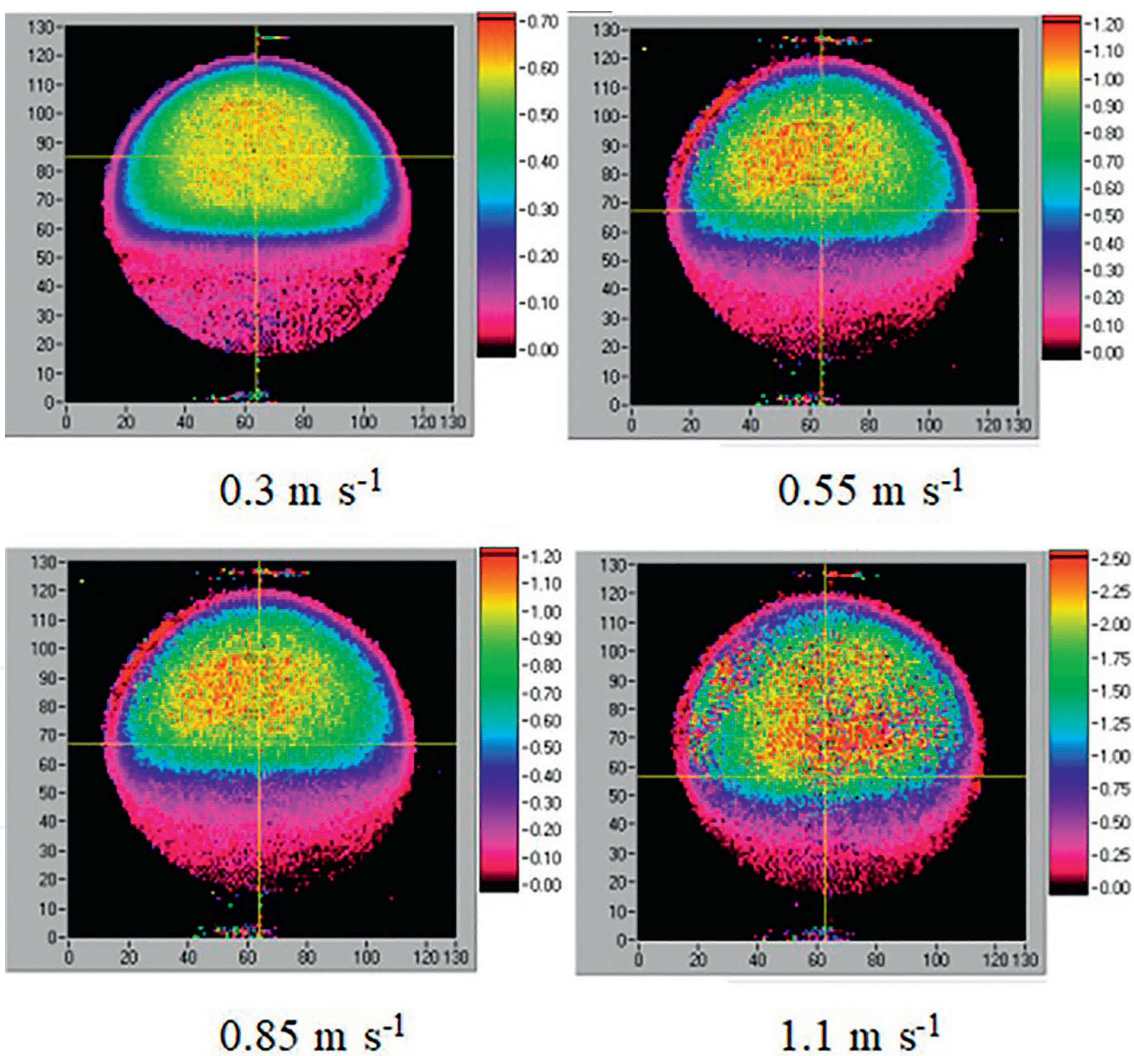

Figure 6.
MRI velocity images (5% v/v solids in Ultrez 10 (Carbopol polymer solution)) at superficial velocities from 0.3 to 1.1 m s^{-1}. The distortion in the velocity images is due to the bed of solids.

The author and his colleagues also use a 2.5D approach as described in more detail in [24] which describes the application of an absolute image reconstruction approach which does not require a reference image other than for data acquisition. The essential

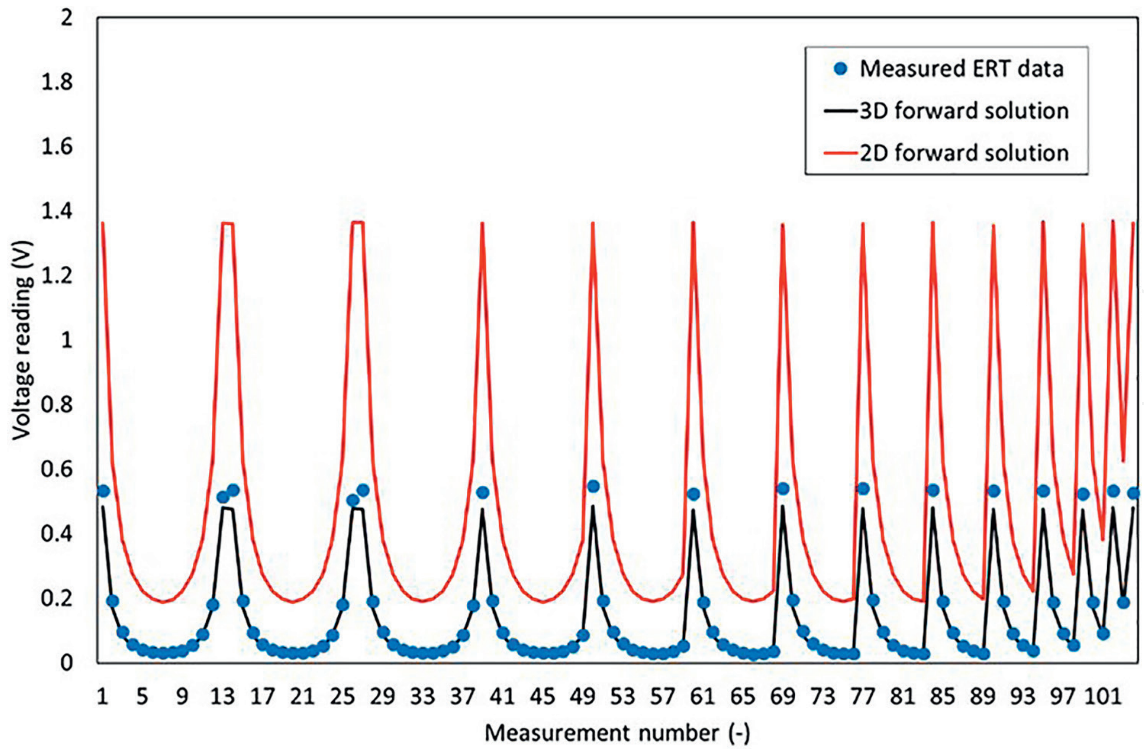

Figure 7.
ERT voltages from experiment and simulation of a homogenous fluid in a pipe asssuming 2D and 3D behavior. As originally published and presented at the BHR 20th International conference on Hydrotransport, Melbourne, Australia, 3rd–5th may 2017, [24].

feature of this approach is to conduct the forward problem in 3D (assuming that the pipe flow is invariant along the pipe axis) and the inverse problem as a 2D slice through the center of the electrodes. The significance of the 3D forward problem is shown in **Figure 7** where measured ERT from a pipe with a homogenous fluid is shown compared with 2D and 3D forward solutions. It is clear the 3D forward problem is the most appropriate.

The results from conventional LBP differential processing and 2.5D absolute processing are shown in **Figures 8** and **9**, respectively, for a high-conductivity tailings sample in a 100-mm pipe. In this case, the reference data were taken from a homogenized sample of the slurry. It should be noted that both approaches adequately detect the stratification of the flow, but the absolute processing allows for the case where obtaining a suitable carrier fluid reference image is difficult. The author's colleagues are continuing research into image reconstruction approaches for pipe flow at the time of writing.

6. Slurry pipe applications and challenges

This section discusses application examples of ERT in slurry pipe flow over a variety of slurries ranging from synthetic laboratory slurries to industrial tailings samples.

Figure 10 shows LBP images from a CSIRO test in a 50-mm NB pipe rig examining the transition from horizontal to vertical flow for a polymer solution/crushed glass-based suspension based on data presented in [34]. The sample results here showed that the stratification could be maintained, change side, or be destroyed in the pipe depending on flow conditions which, in the case of constant carrier fluid rheology,

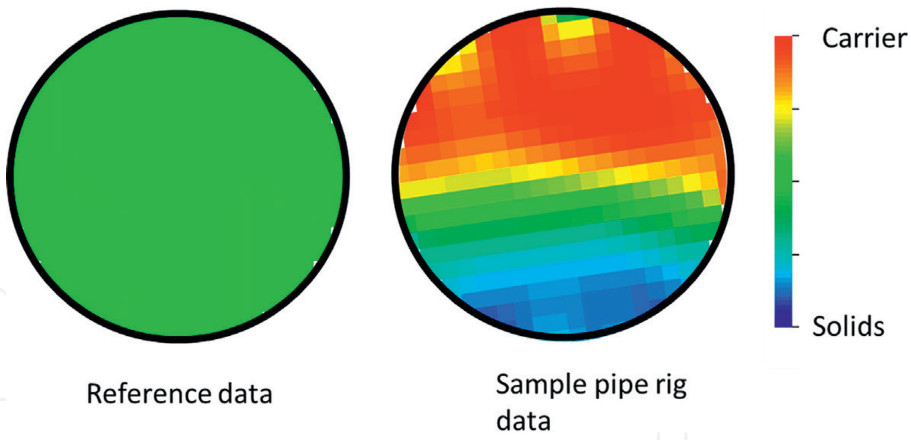

Figure 8.
Comparison between reference data and sample pipe rig data for high-conductivity tailings. Conventional differential 2D LBP processing. Both images are at the same (arbitrary) scale. As originally published and presented at the BHR 20th International conference on Hydrotransport, Melbourne, Australia, 3rd–5th may 2017, [24].

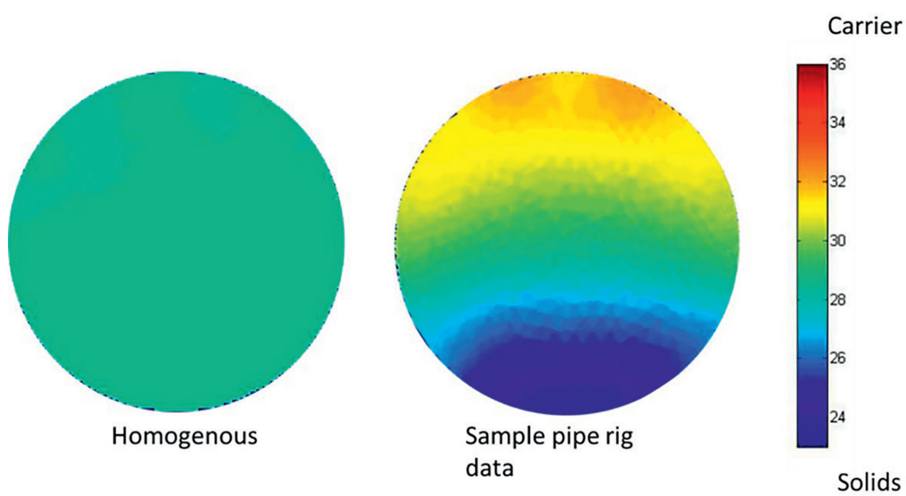

Figure 9.
Comparison between homogenous and stratified ERT images using absolute 2.5D processing on the same data as **Figure 8***. Conductivity images shown. As originally published and presented at the BHR 20th International conference on Hydrotransport, Melbourne, Australia, 3rd–5th may 2017, [24].*

could be superficial velocity. Further results from [34] showed that the distribution of solids in the vertical pipe was a function of the rheology of the carrier fluid and the pipe velocity for a fixed 4x diameter bend as the transition element from horizontal to vertical, with some conditions leading to the stratification being maintained in the vertical pipe. It should be noted that the yield stress of the carrier fluid could statically support the dispersed coarse particles in the vertical pipe, but not a bed of solid particles thus leading to particle settling on shutdown. Hence, the design of a system to vertically convey coarse solids would need to take account of the observed behavior and ideally guarantee particle dispersion.

Figure 11 shows LPB images taken from a pipe test with a synthetic clay/sand/gravel slurry during a pipe test for evaluating rheology additives [14]. The effect of the pipe velocity on the degree of suspension is clear from the ERT images.

An industrial slurry was supplied to CSIRO for pipe tests as a complete slurry; thus, it was not possible to obtain a separate reference from a homogenous carrier fluid. Thus, a reference had to be obtained from a homogenous mix of the slurry as

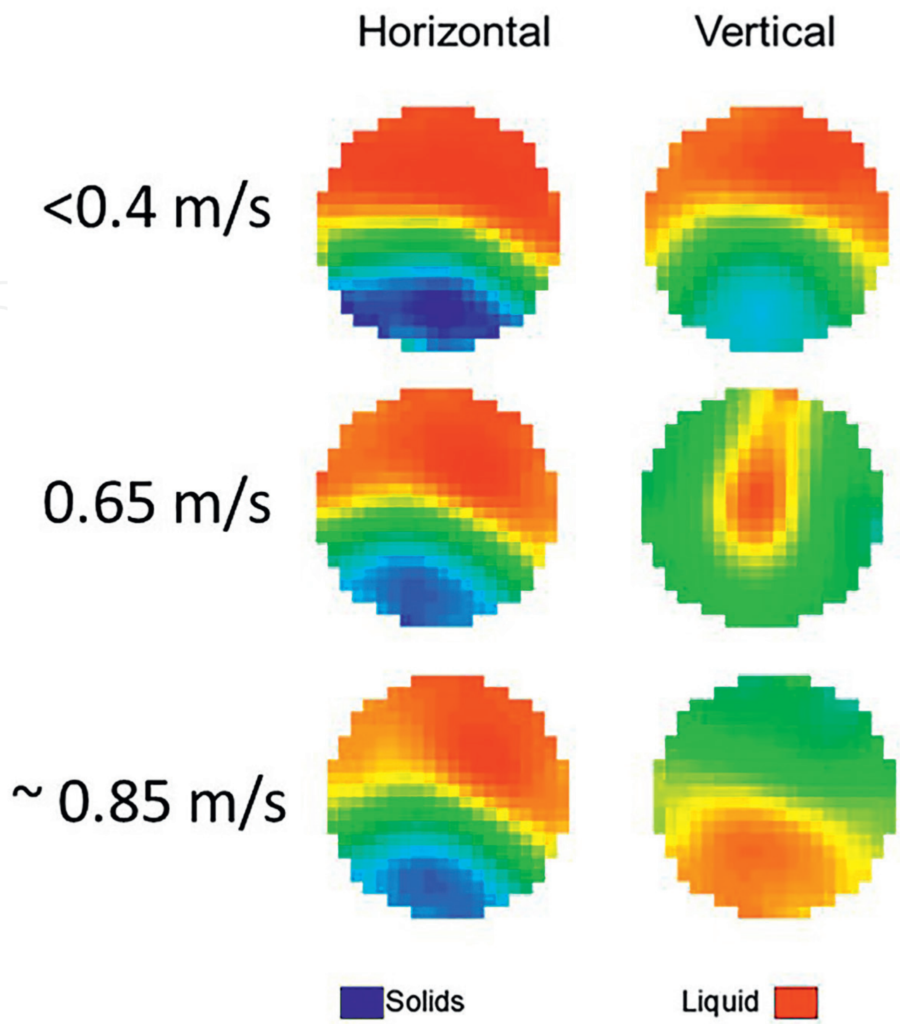

Figure 10.
ERT images for flow around a vertical pipe bend. Adapted from data presented in [34].

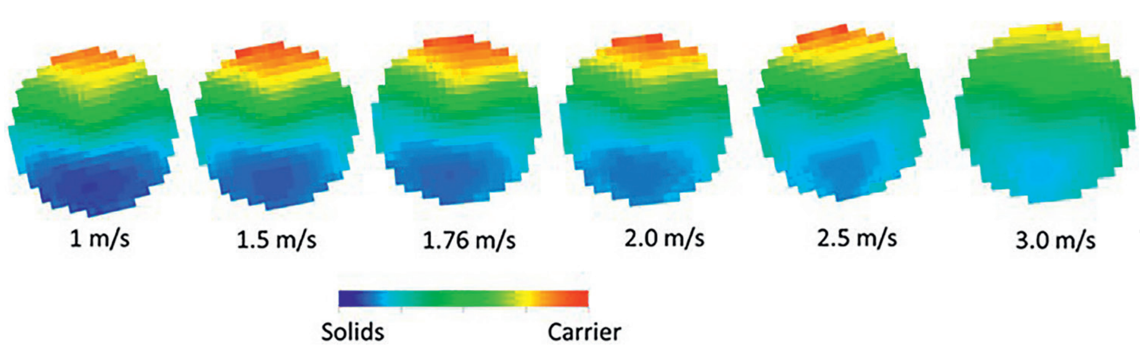

Figure 11.
Synthetic clay/sand/gravel slurry at 80% w/w solids.

supplied in order for the data acquisition to occur. It was known that there were coarse particles in the slurry, but the slurry overall had the appearance of a high-yield-stress-based suspension. A view of the slurry slump test together with ERT results obtained from the 2.5D absolute imaging approach as described in Section 5.3 are shown in **Figure 12**, showing stratified behavior, even with a high yield stress carrier fluid.

A data set for very high-conductivity tailings is shown in **Figure 13** which shows ERT images plotted on the flow curve for two concentrations of the tailings from [24].

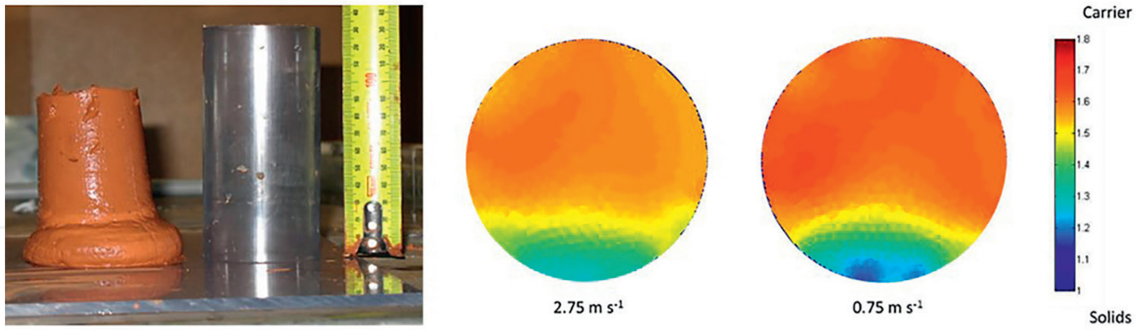

Figure 12.
High yield stress slurry conductivity images showing stratification. As originally published and presented at the BHR 20th International conference on Hydrotransport, Melbourne, Australia, 3rd–5th may 2017, [24].

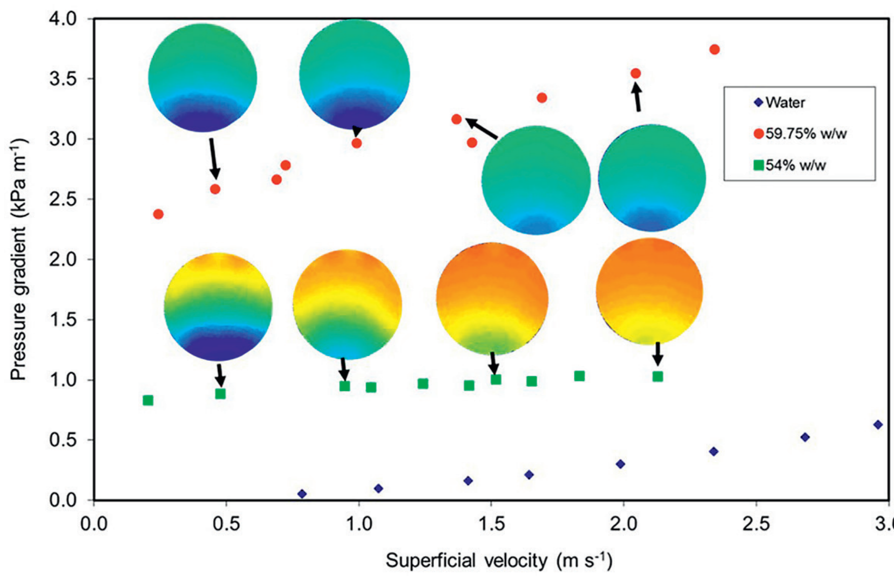

Figure 13.
Flow curve and ERT for high-conductivity tailings at two concentrations in a 100-NB pipe. Color represents conductivity. As originally published and presented at the BHR 20th International conference on Hydrotransport, Melbourne, Australia, 3rd–5th may 2017, [24].

The ERT data shown were processed using the absolute 2.5D ERT approach. The ERT system had to be operated at its highest possible current setting (75 mA) to obtain usable data in the 100-mm diameter pipe rig.

The slurries tested in **Figures 12** and **13** were supplied as complete slurries; thus, there was no possibility to separately obtain a reference image from a homogenous carrier fluid. The procedure was then to use a dummy section of pipe with an ERT sensor to obtain a reference from a homogenized sample of the slurry as shown in **Figure 14**. It is conceded that this approach involves a compromise; however, it was possible to obtain data sufficient to demonstrate that the slurry flows were stratified under shear in the pipe which was the primary objective of the tests. The significance of the stratified flow is that predictive models are required to take this behavior into account for correct predictions of industrially sized pipe flows as discussed in [35] and subsequent publications up to [36].

While many of the results described earlier are in the laminar flow regime, the CSIRO group has also investigated the turbulent pipe flow regime using ERT as described recently in [37]. For this work, ERT was used to obtain solids concentration

Figure 14.
Dummy pipe section for obtaining ERT references of homogenous slurries.

data for comparison with a DNS-DEM model for weakly turbulent coarse-particle non-Newtonian suspensions.

Other practical challenges relevant to the use of ERT in pipe flow were as follows:

- The ERT required short cables (3 m or less), especially when high-conductivity slurries were used. This restricted the number of ERT rings that could be used on the pipe rig to one installed adjacent to the ERT electronics rather than distributed along the pipe rig. For lower-conductivity carrier fluids, (<0.5 ms/cm) 10-m cables provided satisfactory results, thus allowing the electrode sets to be distributed along the pipe rig.

- Since the rig was outside, care was taken to enclose the electrodes in a waterproof box and the cables in a waterproof covering with a military specification connector. The electronics was located in a weatherproof box approximately halfway along the pipe rig in order to minimize the maximum cable length needed to cover the entire rig.

- The carrier fluid conductivity needed to be monitored and any changes taken into account if accurate concentration values are required.

- The choice of injection current required some consideration as the bulk resistivity increased as the solids were introduced into the slurry. The resistivity increase could lead to clipping of the ERT signals when polymer solution carrier fluids were used (e.g. ~0.3 ms/cm conductivity). It was found that reducing the injection current overcame this issue with a typical satisfactory value of 6 mA used for the 100-mm pipe rig. Higher injection currents (30–75 mA) were used with industrial slurries of higher conductivity to obtain usable data. In practice, it was found to be useful to obtain reference data at several different injection currents before introducing coarse solids. This procedure allowed choice of a suitable current for the majority of the test campaign, once initial slurry measurements had been made.

- Any air in the fluid/slurry must be eliminated as much as practicable. Air bubbles cause difficulties with obtaining satisfactory reference data as they pass by electrodes and can also lead to incorrect concentration data at the top of the pipe. References were normally taken with the pipe flow running in order to avoid the case where an air bubble was trapped against an electrode. The author and his colleagues also preferred to operate pipe tests with the return pipe to the holding tank submerged in the carrier liquid or slurry to minimize air entrainment due to the plunging jet effect. They also filled the pipe system with water and eliminated air from the rig before adding polymer powder or clay whenever possible, since air bubbles were difficult to remove from slurries with high yield stress carrier fluids.

- Adjustment of carrier fluid conductivities was usually not possible as addition of salt, etc., ran the risk of significantly changing the carrier fluid rheology which was fundamental to the flow behavior.

- The solids conductivity was not always known, especially for minerals or tailings slurries from sites. In these cases, a relative stratification may be the only obtainable data from ERT which is used in conjunction with rheology, flow curves, etc., to interpret the flow behavior.

7. Slurry tank applications

CSIRO has a long history of mixing tank research as shown in [38] and has recently started to apply ERT to this area of slurry flow dynamics. ERT allows for a deeper exploration of concentration inhomogeneities as a function of the agitation type. These inhomogeneities have been observed in unbaffled tanks under certain agitation conditions and have recently started to be investigated by ERT by [39] using a 1-m diameter tank at CSIRO and water/sand slurry.

A time series of ERT images from a single plane of the 1-m diameter tank are shown in **Figure 15**, and stills from a video are shown in **Figure 16**. A low concentration region is evident, traveling around the tank near the slurry surface. These concentration transients can then be correlated with other aspects of tank performance such as impeller torque and particle suspension. This research activity is continuing at CSIRO at the time of writing.

Further recent ERT work has commenced at CSIRO in a smaller (390 mm diameter) tank which is unbaffled. A photograph of the tank with the impeller turned off and particles settled is shown in **Figure 17**. This tank is used for fundamental research into impeller suspension performance before scaling up to the larger 1-m diameter tanks.

The object of the initial work with the tank was to investigate the performance of the various options for ERT processing using the ITS Reconstruction Tool Suite [21]

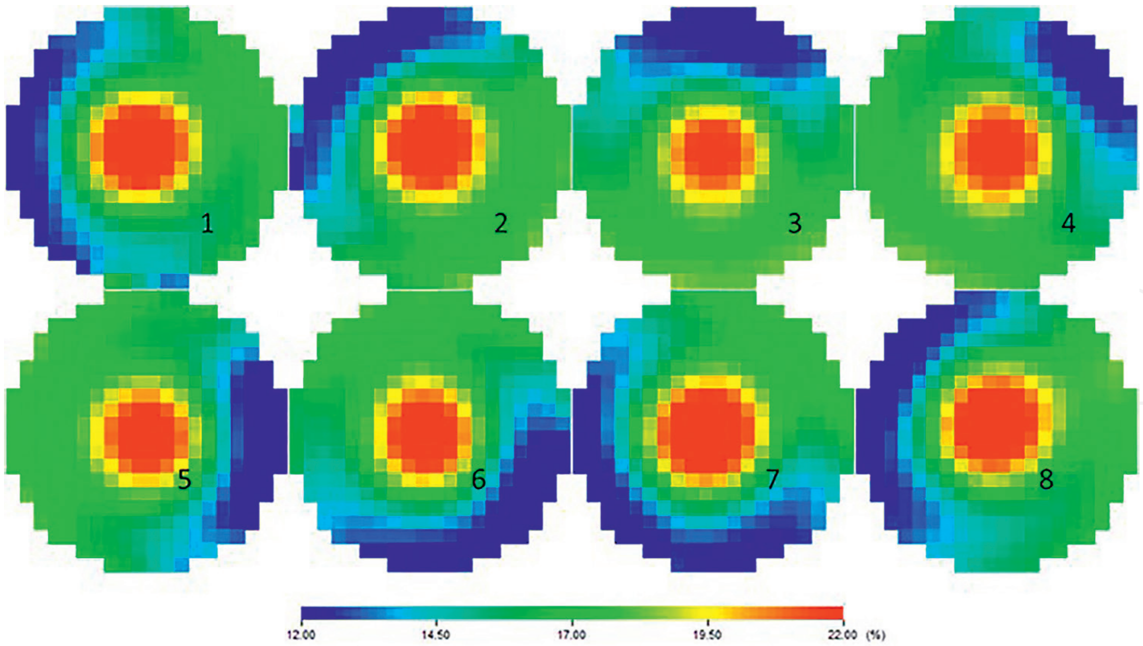

Figure 15.
Time-dependent concentration in unbaffled tank. Electrode plane near the top of the tank.

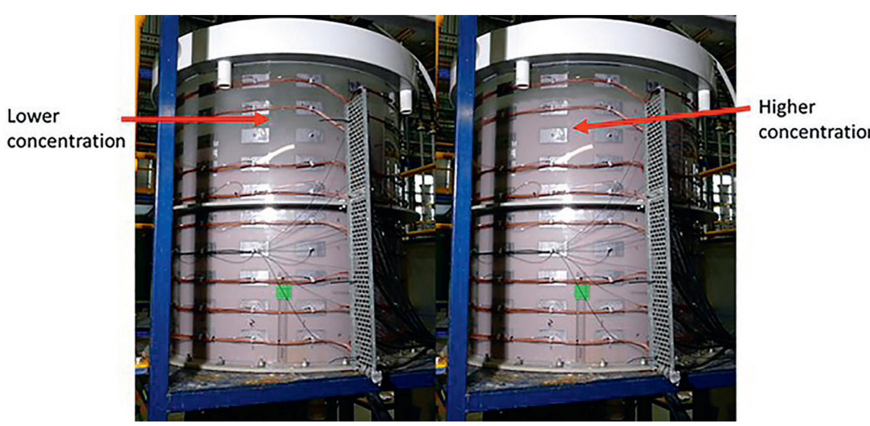

Figure 16.
*Stills from video taken at the same time as **Figure 15**.*

for tank applications, especially when settled solids were present. **Figure 18** shows a comparison between the LBP and the Laplace option where it is seen that the Laplace option performs significantly better in capturing the settled solids without the artifacts in the center of the images from the LBP. Work is ongoing at the time of writing to further optimize the imaging of the suspension in the tank as well as obtain data on the effect of different impellers, etc.

8. Conclusions

ERT has been a part of CSIRO's research into slurry pipe flows for nearly 20 years and is now being extended to mixing tanks.

The insight that ERT offers into the state of suspension of the flow is difficult to obtain by other means, especially given the opaque nature of industrial slurries.

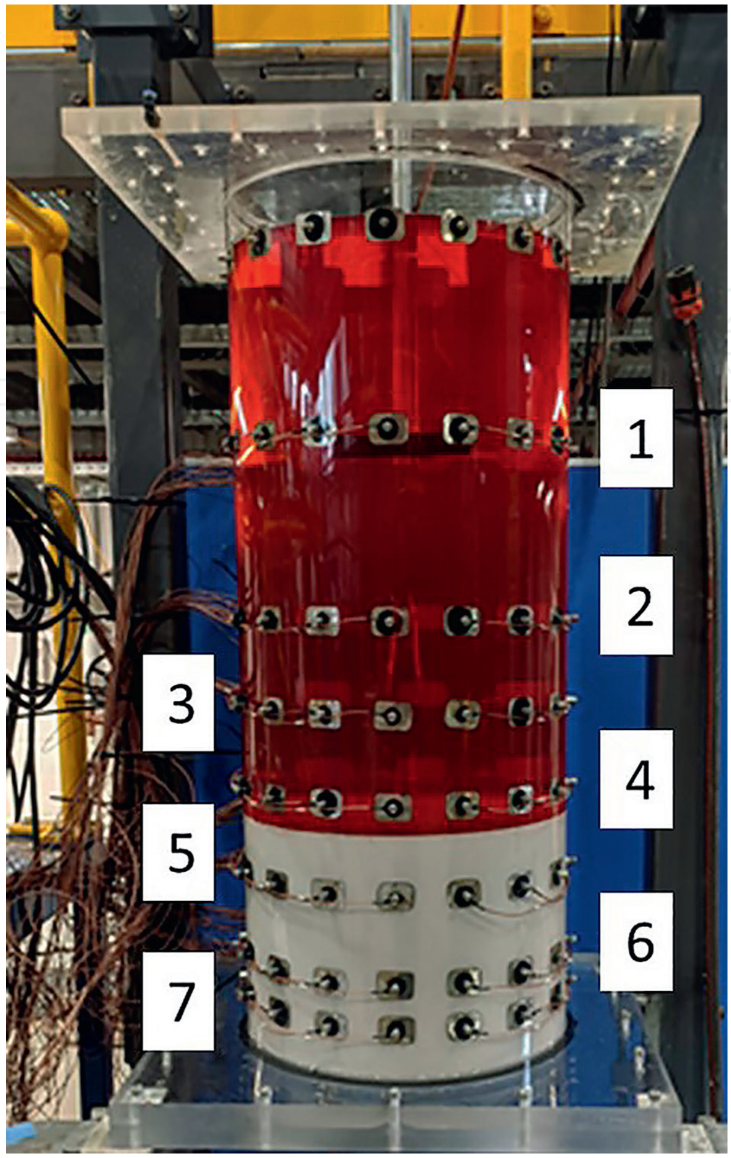

Figure 17.
Photograph of tank with settled solids. Plane 7 is the lower-most electrode ring, with plane 1 at approximately the impeller height.

A variety of image processing options are available for ERT, both commercial and open source, and both approaches are useful in a slurry flow research environment.

At CSIRO the preferred approaches are currently:

- linear backprojection for online live imaging using the ITS data acquisition software;
- absolute 2.5D for pipe flow postprocessing using EIDORS [20], especially where the conductivities of the constituents are unknown;
- the ITS Reconstruction Tool Suite for further off-line data analysis.

There are continuing developments in reconstruction algorithms both in the literature and commercially available which are aimed at improving the quantitative accuracy of ERT for slurry applications.

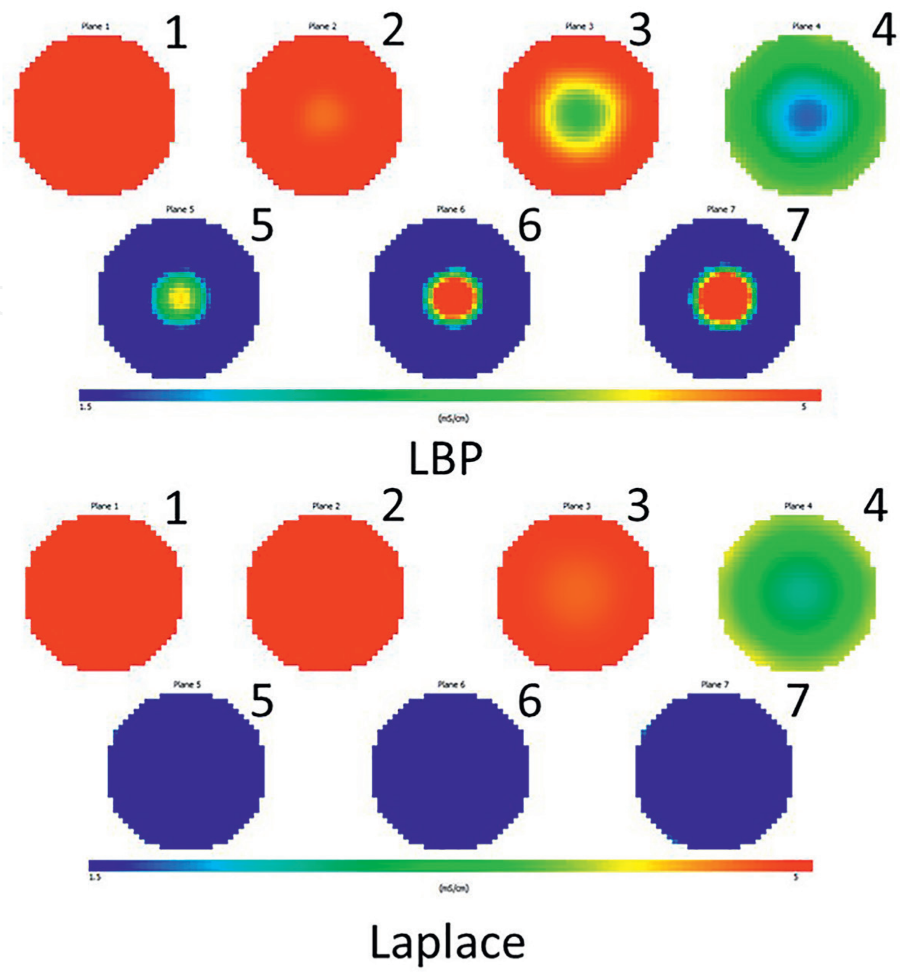

Figure 18.
Images from seven planes of the 390-mm tank with settled solids lower image set processed with the ITS reconstruction tool suite, Laplace algorithm. 50-mA injection current, 9600 Hz. Threshold set to 1.5–5.0 ms/cm. Liquid conductivity of 4.99 ms/cm. Photograph and ERT images courtesy of Michael Hurley, CSIRO mineral resources.

The significance of ERT (and previously MRI) for CSIRO was that the data demonstrated the regimes of flow in cases where visual observation or other diagnostic instruments were not usable. These results were then used to feed back into development of slurry pipe flow prediction models which were based on correct flow mechanisms rather than purely empirical methods. The demonstration of stratification of high yield stress carrier fluid-based slurries in laminar pipe flow was of particular significance in gaining acceptance of stratified flow models for that flow regime.

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