

Industrial Monitoring of Hydrocyclone Operation using Electrical Resistance Tomography

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Abstract – *The development and application of electrical resistance tomography for on-line auditing of an industrial hydrocyclone separation is reported. The work demonstrates the retrofitting of electrodes into a commercially available separator and their use in laboratory, pilot plant and plant scale investigations of clay refining. A number of new and significant applications are described including: the development of methodologies to allow observation of the occurrence of faults in underflow discharge (spraying, roping, blockage); accurate measurement of the air core size for different operational conditions; direct calculation of solid concentration profiles based on parametric reconstruction of conductivity data in three dimensions.*

Keywords: *centrifugal separation, ERT, hydrocyclones,*

1. INTRODUCTION

Elucidation of the mechanisms of separation and detailed models of fluid flow within hydrocyclone separators has yet to be achieved [1,2]. The main reasons for these shortcomings are:

- the complexity of solving Navier-Stokes equations for non-Newtonian anisotropic fluids that contain high concentrations of interacting particles,
- the complex high swirl and varying turbulence conditions prevailing in the separator
- the presence of an interface (the air core) inside the separator,
- the lack of on-line measurement methods to provide reliable experimental data for model development under credible process conditions.

Some earlier work [3-5] on the application of electrical resistance tomography (ERT) to gravity mineral separators provided a promising indication that ERT could deliver results that

would assist in addressing some of the constraints indicated in the above list. In this paper we report on a major advance in using and extending these concepts into industrial practice.

The particular goals of the work reported here arose from an industrially sponsored initiative (the Technology Foresight Challenge) to demonstrate the benefits of applying various process tomographic techniques in industrial environments. Our primary objectives driving the research reported here included investigations of:

- the ease of retrofitting electrodes into standard commercially available separators,
- use of simultaneous multi-modality sensing on hydrocyclones,
- operability of tomographic sensor systems in real industrial environments,
- ability of the sensing methods to deliver information on fault detection, performance auditing, automated spigot wear detection,
- on-line measurement and control,

- quantification of benefits arising from applications of the technology.

This short paper describes the implementation of ERT for on-line measurement and process diagnosis. Some other aspects of the work are reported elsewhere [6,7].

2. SENSOR INSTALLATION

Experimental measurements were performed on 50 mm diameter hydrocyclones. There are many hundreds of such units in use at English China Clays (ECC) refineries. Often individual units are arranged together in a spider-type array sharing a common feed stream (Figure 1). The units treat fine slurries containing up to 15 wt. % solids and may have a cut size in the region of 7 microns. The operational performance is determined by the cyclone body geometry and the relative size of the apex spigot and overflow diameters.



Figure 1: Unit containing multiple 50 mm diameter hydrocyclone separators treating china clay

In our work ERT sensors were fabricated first in a resin mould of the industrially-used hydrocyclone and then retrofitted into a conventional commercial unit (Svedala Ltd). Figure 2 shows the appearance of the resin moulded unit which contained 8 planes of 16 electrodes. The electrodes were disc-shaped and engineered to be flush with the inner wall. The electrodes were approximately 8 mm in diameter. The ERT system was based on the 'Prototype 1000' (Industrial Tomography Systems Ltd).

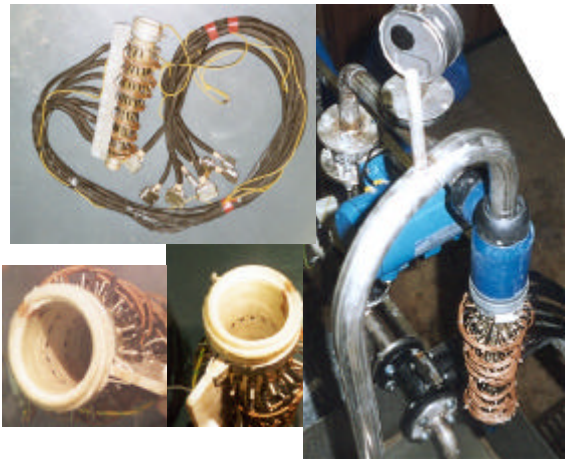


Figure 2: Examples of photographs illustrating the installation of multiple electrodes into a 50 mm hydrocyclone used in laboratory evaluations

Tests were performed in progressively more demanding environments starting from the laboratory (Figure 2) through a pilot scale plant and then on to an operating plant (Figure 3).



Figure 3: Outside industrial implementation at a refinery

3. APPLICATION EXAMPLES

3.1 Discharge fault detection

Tests on treating clay samples removed from an industrial flow circuit in a pilot plant facility at ECC have indicated the possibility of identifying different (real) fault conditions based on analysis of reconstructed images and from analysis of the raw data sets from a limited number of projections.

Considering the former, Figure 4 shows reconstructed images for the top and bottom electrode rings installed in the 50 mm unit (similar to Figure 2). The top plane is located just below the vortex finder and the bottom plane is just above the spigot cap.

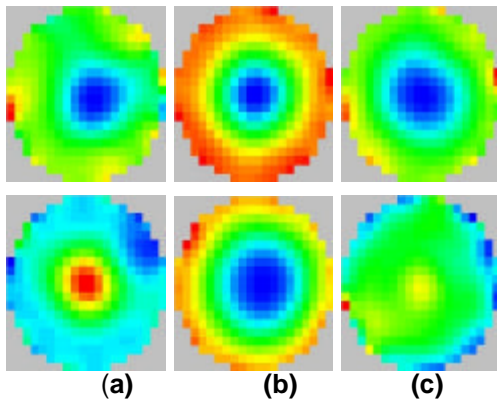


Figure 4: Instantaneous conductivity images for top and bottom electrode planes for three observed fault conditions (a) roping discharge (b) spigot detachment, and (c) underflow blockage,

The different colours shown in the figure relate to different relative conductivities – from which it appears that the three fault conditions shown here can be identified. The left-hand pair (a) shows the situation when the underflow is roping (high viscous solids concentration, poor cut size). The air core (characterised here by a blue colour) is clearly evident in the top plane of each pair of images. (b) shows the effect of the spigot experiencing gross wear or detachment of the spigot completely – a large air core is seen to develop. (c) shows the detection of blockage of the spigot. No *a priori* knowledge has been assumed in reconstructing the images shown here, other than the assumption inherent in the linear back projection reconstruction scheme. Using these methods it is postulated that fault states in a given hydrocyclone could be diagnosed.

3.2 Auditing of operational state

Pilot plant trials have demonstrated how the relatively crude images can reveal subtle changes in the size of the air core and apparent concentration of solids in cross-sections through the separator. For example, Figure 5 shows the effect of increasing the feed rate (expressed here in the conventional way in terms of a pressure drop (bar) at the feed inlet to the hydrocyclone). The different colours again correspond to different conductivities. The human eye can discern changes in the air core size as the pressure drop is increased. In addition there are evident differences between a hydrocyclone fitted with smaller (5 mm diameter) underflow spigot (bottom row of images) compared to an 8 mm diameter spigot (top row). In addition subtle

changes also occur as the spigot becomes worn – this wear is often not uniform around the spigot resulting in asymmetries occurring in the conductivity maps.

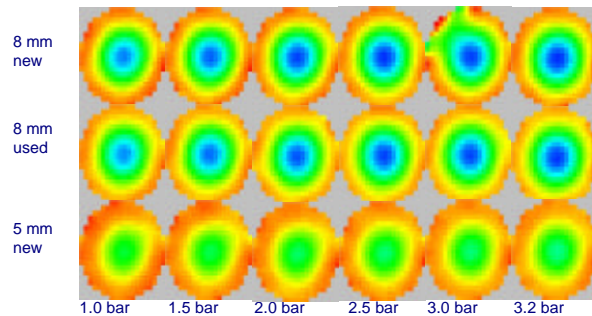


Figure 5: Effect of feed pressure drop (flow rate) on image obtained near apex for different spigot diameter (top: 8 mm new, middle: 8 mm used; bottom 5 mm new)

If the user's knowledge of the process phenomena is used to develop a reconstruction algorithm that is based on a process based model, significant enhancements can be achieved. For example, if the reconstruction seeks to fit the location and diameter of the air core itself then these parameters can be predicted with accuracy and at known confidence levels.

To provide an example of this, Figure 6 shows the operation of the system in an industrial setting (top left) and sample results. The image (top right) shows the information that needs to be interpreted if a linear projection is applied to a pixel-based reconstruction. If a parametric approach is used (as described elsewhere in this volume [6]) quantitative sizing of the air core can be achieved, as demonstrated in the lower graph in Figure 6 for two different spigots, again as a function of pressure drop. The accuracy is very good and sufficient to allow the method to be considered as a mean of wear detection for the spigot itself (since air core size can be related to spigot size).

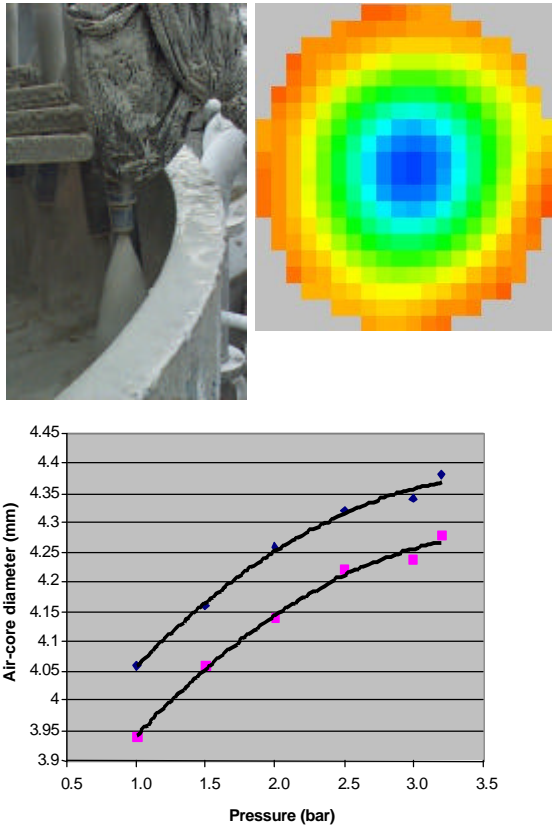


Figure 6: Industrial ERT measurements (top left) and typical resistivity image in the apex region (top right) and derived air core size measurement (bottom) using a parametric reconstruction for two different spigot types as a function of pressure drop data

3.3 Quantification of radial concentration profiles

The approach to image reconstruction illustrated in Figure 6, can be extended to include fitting the measurements to other system properties. For instance, to deduce the conductivity profiles from which the solid concentration can be inferred. The problem can be expressed in terms of 'fitting parameters' that describe the essential features of the property being sought [6]. For the hydrocyclone this involves estimating the size and location of the air core, and the form of the curve defining the radial solids concentration profile normal to specified positions along the axis of the cyclone. If the air core size is centrally located, then the problem may reduce to solution of 3 or 4 parameters.

Figure 7 shows an example for the china clay separator. High conductivity is associated with lower solids concentration – but we have not attempted here to replot the data in terms of solid concentration (this could be achieved using a calibration equation for the functional dependence of conductivity on solid volume

fraction - subject to further assumptions regarding absence of particle anisotropy effects).

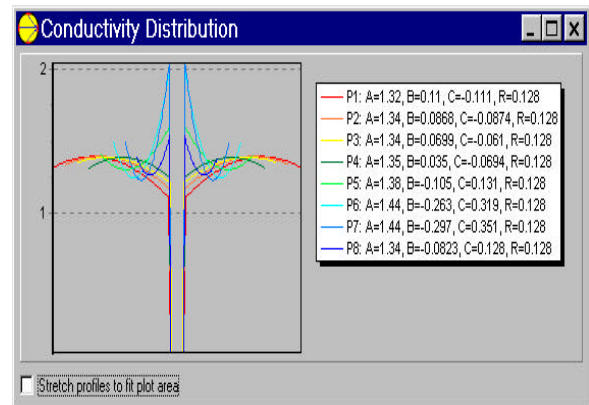


Figure 7: Fitted radial conductivity profiles derived from ERT measurements using a parametric reconstruction

This approach offers considerable potential for gaining a better understanding of the internal characteristics of the cyclone under different operational conditions.

3.4 Three dimensional visualisations

Since measurements can be obtained using a three dimensional array of electrodes probing the entire volume of the separator, it is possible to measure the three-dimensional conductivity map at steady state. The information can be rendered as a series of 2D images or as an interpolated block (Figure 8 (a, b)). The visualisation can be presented and manipulated in 3D (Figure 8 (c)).

In due course, comparisons will be possible with concentration profiles predicted from theoretical principles based, for example, on computational fluid dynamics. A future paper will consider this in more detail.

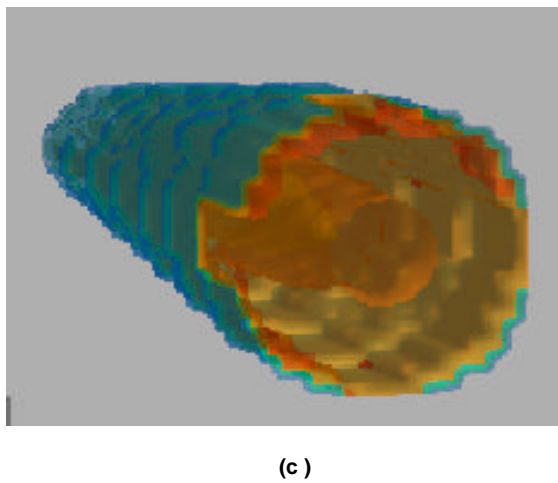
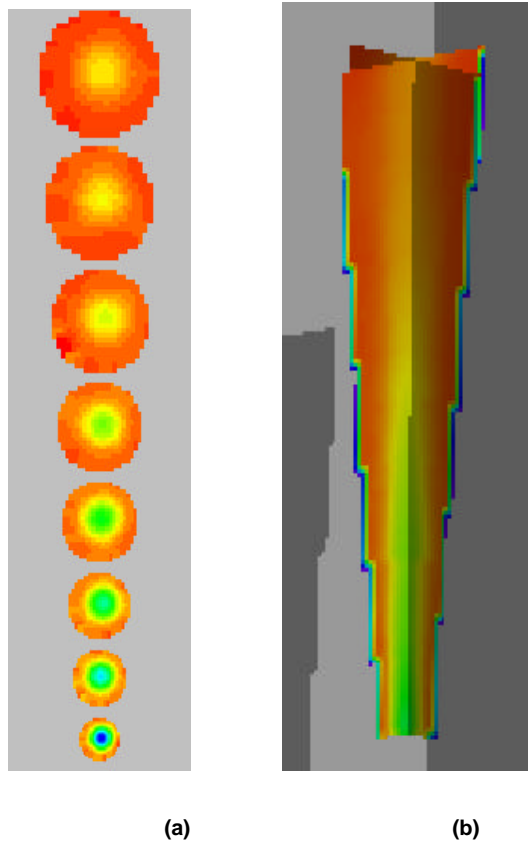


Figure 8: Visualisation of conductivity within a hydrocyclone

Information of this type is also useful in determining the validity of zone (phenomenological) models for hydrocyclones [2]. Analysis of ERT data is also relevant to understanding the sharpness of classification in hydrocyclones, by identifying zones where particle accumulation may appear to be occurring inside the separator.

4. CONCLUSIONS

New applications for ERT in routine measurement and control of hydrocyclones have been identified.

It has been demonstrated that ERT sensor technology can be applied successfully to industrial separators and operated under industrial environments.

The information provided by ERT, and other tomographic methods, provide a rich source of data for model development.

A notable feature of the work is the demonstration of the use of parametric reconstruction to deduce key process parameters (air core size and location, solid concentration profiles).

A further significant application lies in the use of the method for auditing the state of the classification process and hence to detect and predict the likely onset of faults (e.g. spigot wear) which could cause deterioration of process performance if left unchecked.

Further work is proceeding to explore these concepts and to integrate the technology into control based test circuits. This has been the subject of patent application.

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