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Measurement of Solids in Coal Slurry Lines with an Impedance Cell Technique

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ABSTRACT

The aim of the research was to investigate the feasibility of using an impedance cell and ratio-transformer bridge to measure solids content in coal slurry pipelines. It appeared that this technique could be developed to measure variations in conductance which correlate with solids content. Successful implementation of the measurement technique would have a variety of applications in existing coal wash plants and the potential for automatic process control.

A small pilot plant was designed for a feasibility study. This was a closed loop system in which the coal was uniformly dispersed in a tank with a variable speed agitator and then circulated through an external pipe returning to the top of the tank. The impedance cell was located near the end of the external pipe. Slurry concentrations were varied from clean tap water to 50 per cent solids by weight with the addition of weighed quantities of dry coal dust. Ratio-transformer bridge measurements showed that variations in individual observations were equivalent to measurement errors of about two per cent. These probably reflect variations in concentration of the mixture in the pipe. Data for increments in concentration of one per cent indicate that this is about the limit of resolution of the current system.

The paper discusses the principles of operation of the impedance cell and measurement system. Results from the pilot study and proposed improvements in the impedance cell design are examined.

INTRODUCTION

Product coal is sold under contracts outlining strict customer specifications. The objective of coal beneficiation is to prepare a product that meets these specifications at an acceptable cost and recovery from a highly variable raw resource. The variability of the feed stock requires an efficient preparation process which is capable of responding rapidly to changes in quality by making automatic adjustments in the various plant circuits based on reliable and accurate on-line monitoring.

Efficient operation of a coal wash plant depends on optimising feed rates, concentrations and chemical additions in the various circuits. Solids content is currently measured with nucleonic transmission gauges (Sigal, 1981) although this type of gauge is restricted by cost, complexity and safety concerns to limited plant applications, for example, dense medium cyclone feed, flotation cell feed, thickener underflow pipelines and to obtain dense medium (magnetite density) control.

The aim of the research was to investigate the feasibility of using an impedance cell in conjunction with a ratio-transformer bridge to measure solids concentration in slurry pipelines. Ratio-transformer bridge systems with resolutions of several parts in 105 or 106 have been routinely applied to measuring small variations in either capacitance or resistance (Moore *et al*, 1988). It appeared that this technique, coupled to a relatively inexpensive impedance cell, could be developed to measure small variations in conductivity of a flowing slurry stream that correlate with the solids content. The ultimate goal of this line of investigation is to develop an accurate and inexpensive slurry concentration meter that does not rely on nuclear sources. The meter would have a variety of applications in existing coal wash plants and the potential for use in automatic process control.

Flotation circuit concentrations are in the range between five and 15 per cent solids by weight. A concentration meter designed for this application needs a resolution of ten per cent to be practically useful. Dense medium cyclones operate in the range between 40 to 55 per cent solids and the required accuracy is again ten per cent. Measurement of overflow and underflow concentrations would be of significant benefit in optimising cyclone performance. The meter could also be used in several other locations such as spirals and tailings pipes (three to five per cent solids) or the thickener underflow line (up to 30 per cent) to improve overall plant performance and recovery rate. Even relatively crude or comparative measurement in several plant locations could provide improved plant operation. For example, in several circuits there are multiple units operated in parallel within a module. The distribution in these units is generally poor. A system of probes that are regularly scanned by a central monitor and programable controller would provide better control, either manually or automatically, to considerably improve the module performance. Measurement techniques that are relatively simple and inexpensive would be ideal for developing a parallel monitoring system.

LABORATORY EVALUATION OF CONDUCTANCE SLURRY CONCENTRATION MEASUREMENT

The feasibility of using the ratio-transformer technique for conductance measurement of solids content in coal slurry lines was investigated in several stages. A ratio-transformer bridge and conductance cell was used for the measurements. In this arrangement, shown in Figure 1, the capacitor (Cc) is variable

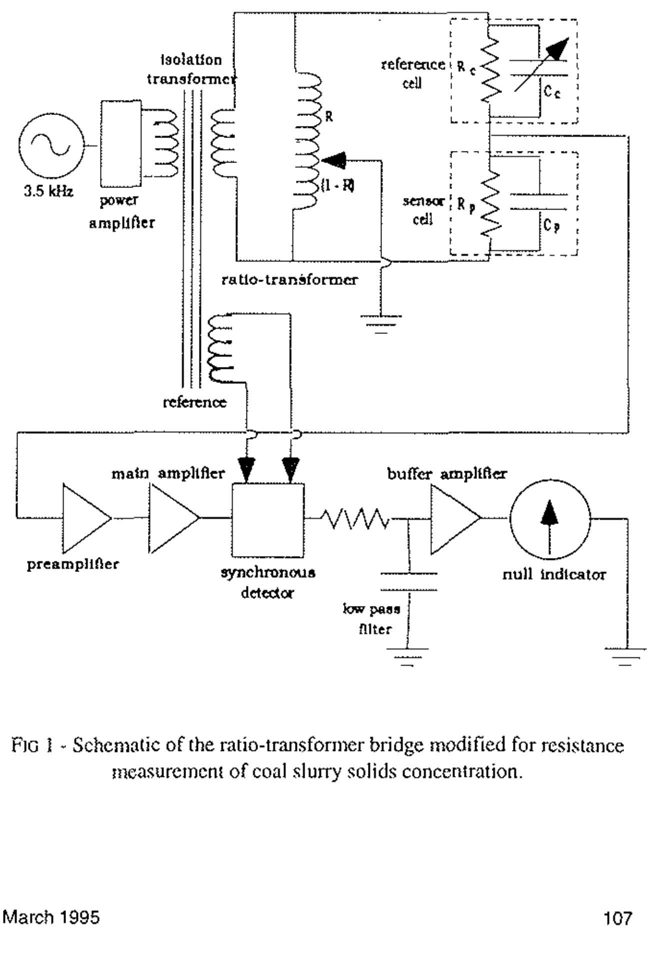

FIG 1 - Schematic of the ratio-transformer bridge modified for resistance measurement of coal slurry solids concentration.

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and the resistor (Rc) has a value similar to the resistance anticipated across the sensor (Rp). Cc is a 500 pF radio tuning capacitor with a parallel fixed capacitor that was changed as required to give a variable range in the region of 2500 pF. The capacitors were used to balance the capacitance component of the impedance cell to remove the out-of-phase (quadrature) component of the signal.

Initial laboratory testing to determine the relationship between solids content and electrical conductance indicated that the two quantities were correlatable. In these tests, samples were prepared in plastic bottles and thoroughly mixed prior to pouring into a beaker to a predetermined level. Electrodes mounted on a frame were immersed in the slurry. Thus, the depth of immersion of the electrodes was kept constant for all samples. This was important as the area of contact between electrodes and slurry affected the conductance. Testing over the concentration range from 0 to 50 per cent solids by weight provided encouraging results, although it was obvious that there were problems associated with the technique. A major difficulty in obtaining good correlation arose from the tendency for coal particles to settle relatively quickly in the water suspension. This caused rapid drift in the conductance. Thus, the early investigations were not interpreted as being a final assessment of the measurement technique and were instead used to conclude that conductance measurement could be adapted to determine slurry solids content under appropriate conditions.

A laboratory scale pilot plant was constructed in which coal slurry at various concentrations could be pumped in a closed loop hose circuit connected to a reservoir. This equipment is shown in Figure 2. The reservoir was a 250 litre plastic tank with a bottom outlet. An agitator was mounted so that the impeller was immediately above the bottom surface of the tank. This provided good mixing in the lower region of the tank and minimised settlement of solids. Constant stirring close to the bottom was found to be important, particularly with higher solids content, as the motion induced by circulation was inadequate to prevent settlement. Appropriate lengths of 20 mm internal diameter Nylex hose were connected to form the flow circuit. A 0.6 kVA Davey dc variable speed motor and centrifugal pump unit provided the required flow rate.

Electrodes were mounted in a vertical section of the hose approximately 2 m downstream of the pump to minimise turbulence effects and segregation of the solid and liquid fractions. Details of the electrode assembly are shown in Figure 3. The two electrodes were constructed from copper tube with a 22 mm outside diameter (19 mm inside diameter). An arbitrary electrode length of 110 mm was used in the design. The electrodes were inserted into the cut ends of the Nylex hose. A short length of hose connected the two electrodes. A 10 mm long plastic spacer was inserted between the electrodes to separate them (with a known distance) and to minimise the build up of conductive solid material in the space between them. The outside diameter of the spacer matched the electrodes, although the inside diameter was slightly larger, namely, 20.6 mm. The electrode configuration was designed to have an impedance in the range between 1 and 5 kΩ.

Measurements were taken as the solids concentration was varied over a known range from clean tap water to 50 per cent by weight. The plastic tank was positioned on a scale and filled with 100 kg of tap water. The agitator and pump were started and a resistance measurement taken from the ratio-transformer bridge. This value represented the zero per cent solids baseline. A period of approximately five minutes was allowed before the measurement was taken and this procedure was adopted for all measurements. Thus fluctuations in the reading could be observed and evaluated and the slurry had sufficient time to mix thoroughly. Air dried filter cake from a Bowen Basin wash plant

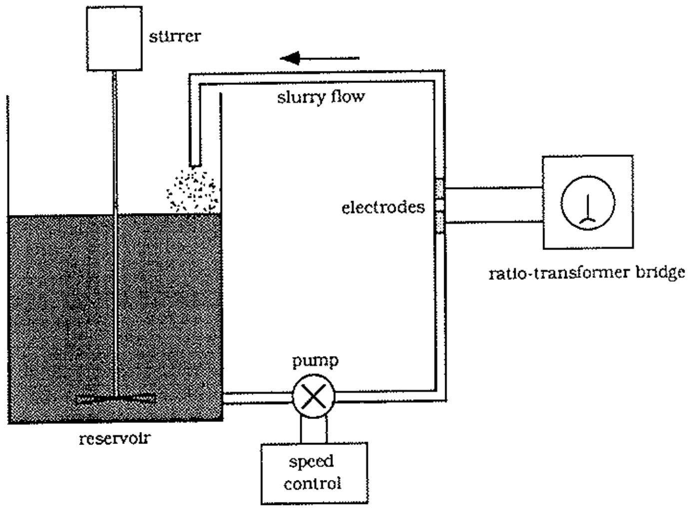

FIG 2 - Slurry concentration measurement pilot plant.

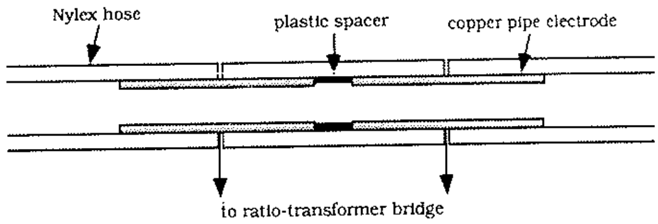

FIG 3 - Pilot plant electrode section.

was used in the experiment. Coal was initially added in 1 kg increments until ten samples had been added. The resistance was measured with each addition. Hence the relationship between resistance and solids content was established for one per cent solids increments to a concentration of ten per cent by weight. Above this concentration, the coal was added in 5 kg increments to a concentration of 50 per cent solids. This value approached the maximum solids content at which the impeller pump was capable of operating and also represented the maximum concentration likely to be encountered in operating wash plants. The results are presented in Table 1.

The complete data set was obtained over two experimental sessions. Initially, measurements were made on slurries to 35 per cent solids. The pilot plant was then left standing for five days with the tank covered before the last three observations were obtained. Precautions were taken to ensure that this did not affect the overall correlation and a repeat reading was made of the 35 per cent solids suspension before any further coal was added. The plant was run for approximately 20 minutes to ensure that the solids were well mobilised before this reading was taken. The value for resistance obtained from the first set of readings was 938 Ω. The repeat measurement gave a resistance of 936 Ω. This is in excellent agreement with the original value. However, the capacitance in the reference cell needed to be increased from 2160 to 2660 pF to remove the quadrature component. This may reflect some chemical changes in the coal and water mixture. The final three measurements provided values that fit the trend of the previous data set.

TABLE 1

Slurry concentration resistance measurements.

Per cent solids (weight)	Resistance (Ohms)
0	1347
1	1330
2	1309
3	1292
4	1274
5	1262
6	1251
7	1237
8	1221
9	1207
10	1199
15	1137
20	1096
25	1040
30	976
35	938
40	893
45	860
50	837

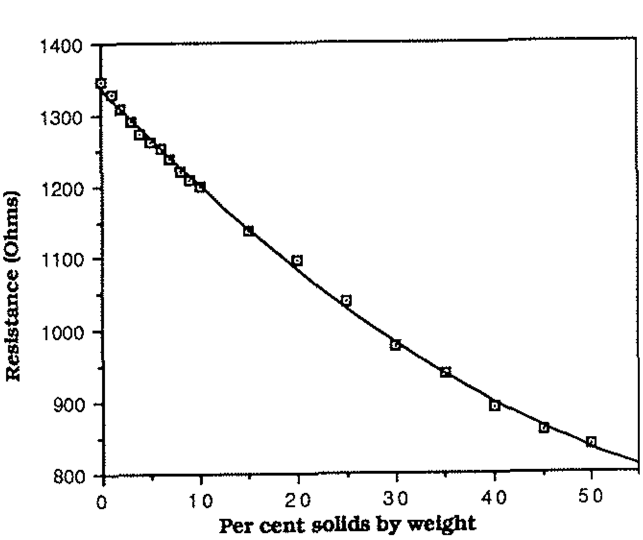

FIG 4 - Graph of coal slurry resistance against concentration.

The data have been plotted in Figure 4. This graph illustrates a promising relationship between cell resistance and coal per cent solids. If a simple model for the electrical conductance of a two-phase mixture with conductances σ_a and σ_b and respective volume fractions fa and fb is assumed, then the sample average of:

$$\sigma = f_a\sigma_a.f_b\sigma_b \qquad (1)$$

explains the general trend of the non-linear variation of resistance and concentration that is observed. A second order polynomial curve provides an excellent fit, with the R^2 coefficient indicating good correlation at a value of 0.999.

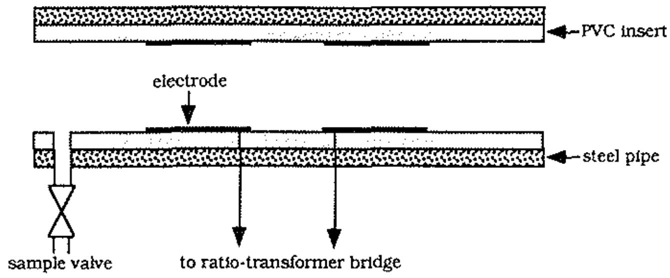

FIG 5 - Tailings pipe electrode test section.

The numerical values of resistance are not significant per se and are related to electrode dimensions and separation. The separation between conducting surfaces is particularly important. It is therefore suggested that future work in the area should examine the relationship between conductivity (or resistivity) values, which are independent of cell dimensions, and per cent solids. This approach would require calibration of the cell. The results shown in Figure 4, however, indicate that measurement accuracy of better than three per cent is possible using the current approach.

The operation and suitability of the measurement technique were assessed by noting the variability of the output signal over periods of measurement at fixed concentrations. Some irregular fluctuations of the bridge output were evident, although no attempt was made to quantify their magnitude or behaviour in the pilot plant tests. The fluctuations in the resistance at all concentrations were attributed at least partially to the experimental technique, namely, a result of inconsistent mixing and continued settlement and remobilisation of particles. Thus, the meter fluctuations were to an extent probably following the real variations in the solids concentration. A series of measurements taken simultaneously with sample collection from the slurry line and subsequent solids analysis would therefore be expected to show better correlation. The fluctuations may also be ascribed to the geometry of the conductance cell. For example, recent work by Holdich and Sinclair (1992) found that non-intrusive electrodes provided erratic values during calibration with non-conducting mineral slurries.

The variable speed pump was adjusted to vary the slurry flow to gauge the effect of variations in flow rate on measurement. No significant change to the bridge output was detected over a range of flow rates. Similar findings were reported by Holdich and Sinclair (1992). This work also showed that particle size and size distribution has an insignificant effect on the conductance.

The effect of varying the electrode separation was examined by increasing the electrode spacing to 200 mm. This increased the impedance to the range between 10 and 20 kΩ. There was no change evident in the bridge output fluctuations as a result of this modification.

COAL WASHPLANT SLURRY CONCENTRATION MEASUREMENTS

Preliminary field testing of the conductance measurement technique involved the construction of a suitable test section, shown in Figure 5, for insertion into a slurry pipeline in an operating wash plant. This work was undertaken at the Rhondda Mine wash plant near Ipswich to determine practical measurement criteria. The thickener underflow pipeline was selected for the work. This choice was not considered ideal from a research perspective. However, insertion of a test section into this line was considered to be the least disruptive to wash plant operation and was quite suitable as the investigation was a preliminary evaluation of the measurement technique.

The approximately 0.7 m test section incorporated non-intrusive measurement electrodes and a valve for collecting small (one litre) samples of slurry. Samples could then be collected and laboratory analysed for solids content. Thus, by simultaneous electronic measurement and sample collection from the same section, the system could be calibrated by regression analysis over a range of operating conditions and concentrations. This work was, however, not completed.

The test section was originally positioned horizontally immediately adjacent to the underflow pump. This was considered to be the best location for avoiding vertical stratification of the solid and liquid components within the pipe. A degree of stratification would be expected to occur in the long horizontal sections of the pipe. However, the 45 kVA variable speed tailings pump emitted considerable electrical noise and rendered the ratio-transformer bridge unusable in this location. The test section was therefore repositioned some 25 m further along the tailings pipeline. With suitable earthing, the operation of the equipment was not significantly affected by electrical interference in this location.

An anticipated problem in using conductivity measurement to determine solids concentration in operating wash plants is the considerable variability in conductivity of raw feed water. It should also be noted that magnetite used for dense medium separation has the potential to 'confuse' conductivity observations if a high magnetite concentration occurs in the slurry at the measuring location. However, because of its magnetic properties and relatively high magnetic susceptibility, the magnetite concentration could be observed with a second bridge system. Data from the second system could then be used to adjust for the effect of magnetite on conductivity readings of the slurry. Thus, successful implementation of the measurement method may depend on the application of a second ratio-transformer system to compensate the slurry measurement signal. Development of this technique would therefore require extensive plant testing under a range of operating conditions.

CONCLUSIONS

The pilot plant tests have shown that the monitoring of coal slurry concentration based on resistance measurement with the ratio-transformer is feasible in a practical environment. Furthermore, the set of ten initial measurements at increments of one per cent solids has shown that resolution to this precision is attainable. A meaningful assessment of the accuracy of the technique, however, would require statistical analysis of a larger data set. Several concerns regarding practical implementation remain. These include the effect of variable solids composition and water chemistry on measurement in the wash plant environment. The finding that the quadrature adjustment may change over extended periods of measurement also needs to be addressed. However, this factor has a technical solution in that an electronic system could be designed to automate the adjustment.

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