Short communication

Electrode arrangements for continuous measurement of dispersion conductivity in lab flotation cells

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ABSTRACT

Electrical conductivity, an intensive property of materials, has been used in flotation for measuring important process variables such as froth depth, bias rate, solid and gas holdup. Most of these applications were based on a sensor that included a conductivity cell made up of metallic ring electrodes flush-mounted to the internal wall of a tube. The use of this approach in lab mechanical cells produces unreliable conductivity measurements as the introduction of the sensor in the relatively small volume of the unit significantly affects its hydrodynamics. A new approach was devised for measuring the conductivity of dispersions in the unit by using cell walls and impeller shaft as electrodes. The use of this approach led to the design of flotation cells that successfully measured the conductivity of sodium chloride solutions and slurries. Results demonstrated reproducible measurement of solution and slurry conductivities; calculations of solids holdup using Maxwell equation for slurries with pulp densities as high as 30% by weight showed relative holdup errors of about 2%. Testing of a cylindrical cell made with side-by-side cylinders of conducting stainless steel and non-conducting plastic, demonstrated that conductivity could be measured independently of the level in the cell, a result necessary for developing on-line measurement of gas holdup during lab flotation testing.

1. Introduction

The ability of water to conduct electricity has been often exploited in mineral processing to estimate the concentration of dispersed phases in liquid dispersions. Maxwell demonstrated that the conductivity of a liquid is affected by the volumetric fraction of dispersed phases suspended in the liquid and proposed an equation relating these variables (Maxwell, 1873). Applications of this equation include the determination of solid content of a slurry in tanks (MacTaggart et al., 1993; Arizmendi-Morquecho et al., 2002) and in thickeners (Gomez et al., 1998), froth depth in flotation machines (Maldonado et al., 2008a, 2008b; Riquelme et al., 2014), bias rate in flotation columns (Maldonado et al., 2008a, 2008b), and gas holdup (Uribe-Salas et al., 1994; Sanwani et al., 2006; Gomez and Finch, 2007). Several of these applications were based on the use of a sensor based on a cylindrical conductivity cell made with an arrangement of parallel ring electrodes flush-mounted to the internal wall of a tube filled with the dispersion being characterized (Uribe-Salas et al., 1994; Gomez and Finch, 2007). This arrangement generates an electric field, which not only extends through its whole volume, but also results in cell constants independent

of conductivity changes of the dispersion being measured. The use of this approach in lab flotation machines was not successful, as the introduction of the sensor in the relatively small volume of the flotation cell severely affects the hydrodynamics of the unit, producing unreliable conductivity measurements with high levels of noise. The geometry and size of lab flotation cells made necessary a different concept, which was to find electrodes that once installed allow the flotation cell to perform also as a conductivity cell. This was achieved by using the walls of the cell and a metallic tube around the impeller shaft as electrodes, which are capable of generating an electric field extending along the whole cross-sectional area of the cell and at the same time, is symmetrical along the cell vertical axis. As our final goal is to develop an on-line technique for measuring gas holdup during lab flotation testing, it is important to develop electrode arrangements that results in cell constants that not only are independent of the conductivity of the dispersion in the cell, but also of its volume.

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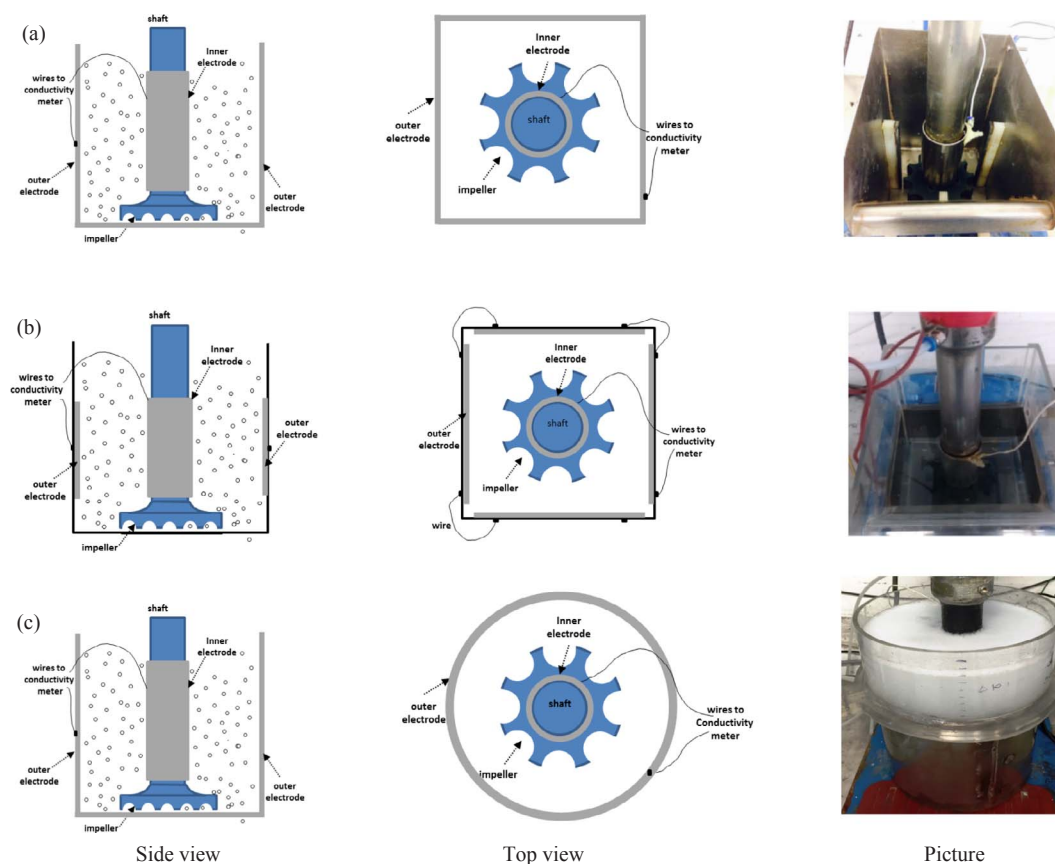 E-mail address: Miguel.maldonado.s@usach.cl (M. Maldonado).

Fig. 1. Electrodes arrangement used in a: (a) rectangular-SS walls, (b) rectangular-plastic walls, and (c), cylindrical SS-plastic wall.

2. Experimental work

2.1. Electrode configurations tested

Three flotation cells were designed and constructed to test the use of the cell-walls/impeller-shaft approach, to measure the conductivity of the fluid or dispersion in the cell: (i) a 2.5 L rectangular cell, 14 × 14 cm cross sectional area, with stainless steel walls (Fig. 1a); (ii) a 4 L rectangular cell, 16.5 × 16.5 cm cross sectional area, with plastic walls internally covered with large stainless steel plates (Fig. 1b); and (iii), a cylindrical vertical cell, 20 cm in diameter, with a wall made of side-by-side stainless steel (bottom) and plastic (top) cylinders (Fig. 1c). A stainless steel tube installed around the impeller shaft was used in all cases as the inner electrode.

Tests run on the rectangular cells (Fig. 1a and b), demonstrated that electrode arrangements based on the new concept reliably measured the conductivity of saline solutions, and also the solids content of sand slurries by use of Maxwell equation (Maldonado et al., 2016). The electrode configurations tested measure the conductivity in the whole volume of the cell, which is necessary for small units, but at the same time this value decreases as the total volume of fluid in the cell diminishes as concentrates are being collected. As the goal is continuous tracking of gas holdup during flotation tests, a search for a configuration limiting the measurement to a fraction of the volume occupied by the dispersion in the cell was necessary. The cylindrical cell, with a wall made of conducting stainless steel and non-conducting plastic cylinders, was devised for this purpose (Fig. 1c).

2.2. Testing equipment and procedure

Several components were required to accomplish the determination of cell electric performance of the cells (Maldonado et al., 2016). The process signals were centralized into I/O modules connected through Modbus Ethernet I/P communication protocol (STB Advantys Schneider Electric). A human machine interface (HMI) to monitor and supervise operation was developed in iFIX 5.3 platform (General Electric). As the electrical conductivity of liquids is strongly affected by temperature, provisions were necessary to maintain the temperature of the sample constant, which increased as a consequence of the energy released by the impeller agitation. A peristaltic pump (Masterflex, model IP 7591-22) was used to continuously circulate a flow of the dispersion in the cell through a glass heat-exchanger immersed in a water-ice bath. The pump speed was adjusted to maintain the temperature in the cell, monitored through an RTD probe installed in the unit, at 25 $\pm$ 0.1 °C.

Continuous tracking of the conductivity of the fluid in the cell was done by connecting electrodes to a Mettler-Toledo conductivity meter (model M300 Thornton) calibrated using a two-point procedure. Standard solutions of 1.11 and 5.15 mS/cm, prepared by addition of sodium chloride (Sigma Aldrich) to distilled water, were used in the calibration. Specific conductivities of solutions were independently determined using a hand-held electrode with a cell constant of one and its associated meter (Hach sensION + IC5). The cells were operated in a Denver flotation machine with a constant volume of solution, to eliminate level effects on conductivity measurements, and with impeller speeds lower than 1000 rpm to avoid air entrainment, which was inevitable at higher speeds even with the air supply inlet completely blocked.

3. Results

3.1. Cell constant determination

Measurement in a series of sodium chloride solutions with specific conductivities up to about 10 mS/cm were performed in the different
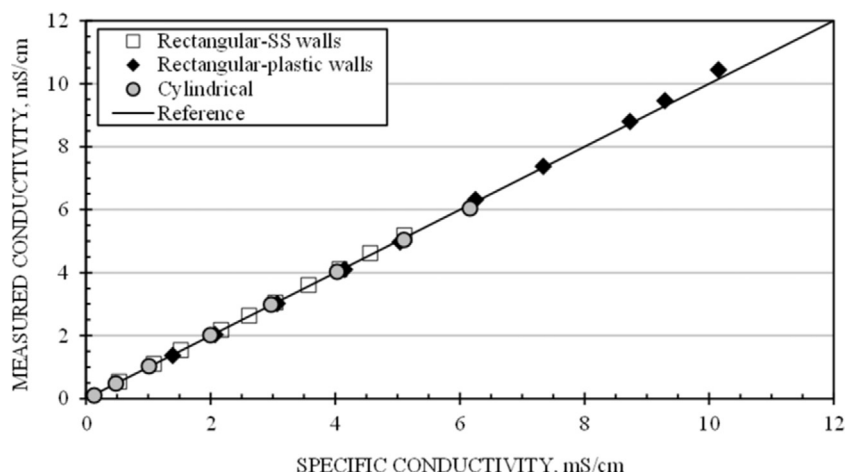
Fig. 2. Conductivity of sodium chloride solutions measured in flotation cells with different electrode configurations.

flotation cells. The results showed, for the three tested cells, excellent agreement between the measured conductivities and those determined with the portable unit (Fig. 2). This result indicates that the electrode arrangements define conductivity cells that can be characterized by a single value of cell constant regardless of the conductivity of the solution or dispersion in the cell.

3.2. Solid holdup measurement

Testing the cells ability to determine volumetric fractions of disperse phases was demonstrated through measurements of solid holdup of sand slurries (density 2.58 g/cm^3, size fraction 75–105 µm) in sodium chloride solutions. The test solids holdup was calculated from the densities and weights of solution and sand used. The solids holdup was measured by application of Maxwell's equation. Solutions of known conductivity, 4.61 and 0.97 mS/cm, were used as the liquid medium for slurries prepared by addition of a known weight of solids in the measurements with the rectangular-SS walls and cylindrical flotation cells, respectively. The cells were run with no removal of solids and ensuring that particles were uniformly suspended during the measurement. The conductivity of the dispersion was continuously monitored and, after steady-state conditions were reached, the dispersion and solution specific conductivities were used in Maxwell equation to calculate the solid volumetric fraction.

Measurements completed in pulps with up to 30% solids by weight, showed for both cells, a strong correlation with solids holdups calculated from solids addition (Fig. 3); the average relative errors were about 2%. These results demonstrated that electrode arrange-

ments based on the new concept, not only reliably tracked the conductivity of solutions, but also that of slurries.

3.3. Conductivity measurements with level changes in the cell

Measurements completed to test the ability of the cylindrical flotation cell for determining volumetric fractions of dispersed phases, when the volume of liquid inside the cell varies, were accomplished by measuring the conductivity of sodium chloride solutions after consecutive additions of liquid. The results showed as expected, and for every solution, an initial linear conductivity increase with solution volume, but once the level of the solution reached the top of the metallic portion (about 6 L) and start filling the plastic portion of the cell, a constant conductivity was measured independently of the level in the cell (Fig. 4). This result provides an opportunity for developing on-line measurement of gas holdup during lab flotation testing.

4. Conclusions

A new concept for designing electrode arrangements to measure electrical conductivity in lab flotation cells was successfully demonstrated for flotation cells driven by a Denver mechanism. Electrode configurations using a cell-walls/impeller-shaft approach were devised to measure the conductivity of the total volume of solution or dispersion in the cell. Measurements demonstrated that the conductivity of sodium chloride solutions and slurries of 75–105 µm sand particles were reproducible, and allowed calculation using Maxwell equation of solids holdup with relative errors of about 2%, as long as
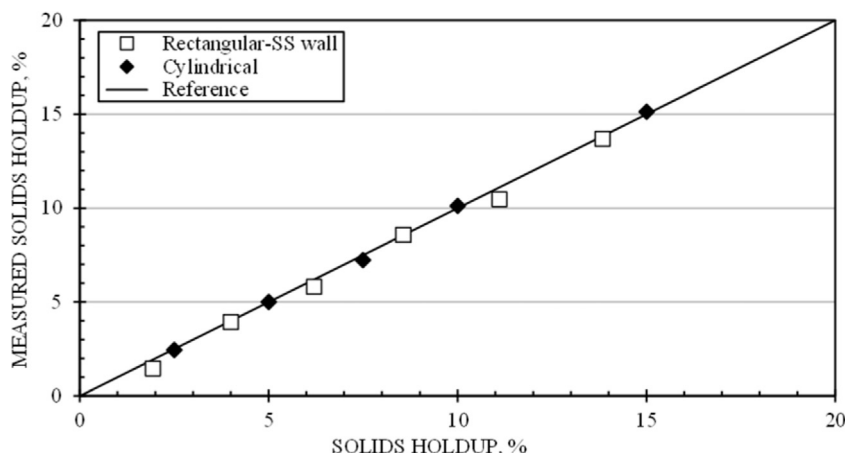

Fig. 3. Solid holdup measurements in flotation cells with different electrode configurations.
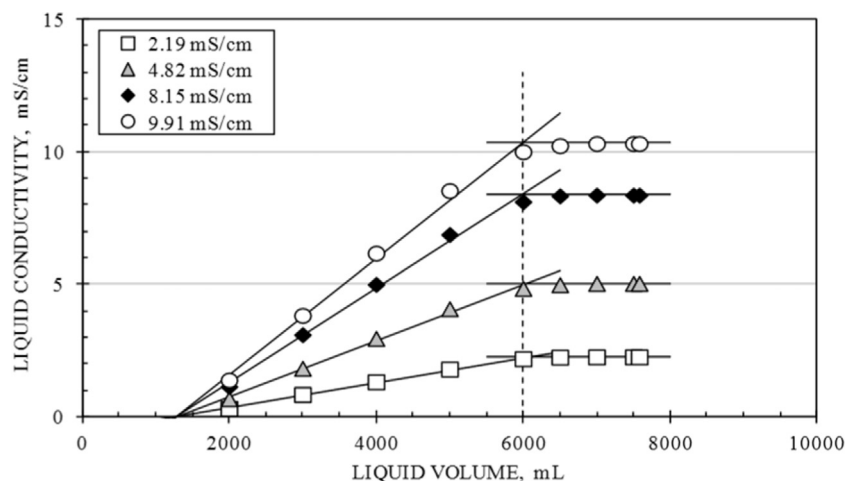
Fig. 4. Conductivity in the cylindrical cell as a function of solution volume in the cell.

the total volume of solution or pulp in the cell (level) was maintained constant. The testing of a cell made with side-by-side cylinders of different materials, a conducting metallic at its bottom and a non-conducting plastic at its top, demonstrated that conductivity can be reliable measured independently of level variations, as long as the liquid in the cell fills completely the metallic portion of the cell. This result provides an opportunity for developing on-line measurement of gas holdup during lab flotation testing using conductivity measurements.

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