Gas dispersion measurements as a diagnostic tool for the performance of industrial flotation cells at Minas-Rio *

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Abstract

Anglo American's Minas-Rio complex began operations in August 2014. The processing plant, produced approximately 15 million tonnes of dry concentratein 2017. Concentration of the oreto obtain a pellet feed concentrate is achieved using reverse froth flotation, where silica is separated from hematite by floating the silica. Maximizing the recovery of the hematite in the flotation cells is of extreme importance. Hydrodynamic properties, i.e. bubble size (d_{32}) and superficial gas velocity (J_g) have been proven industrially to define gas dispersion and therefore flotation cell performance. The Minas-Rio Hydrodynamics Program was initiated in order to understand flotation cell hydrodynamics. Superficial gas velocity and bubble size measurements were carried out using the Anglo Platinum Bubble Sizer (APBS). The measurements were carried out on roughers, cleaners and scavengers in order to map the cells and understand how gas is dispersed in the cells. From the measurements it was discovered that some of the cells were not dispersing gas evenly; i.e. higher J_g and d_{32} values measured closest to the impeller, whist low J_g and d_{32} values were measured furthest from the impeller. Subsequently, a flotation impeller change program was undertaken in order improve gas dispersion in the cells and thus flotation cell recoveries.Furthermore, from the bubble images captured with the APBS camera, it was discovered that some cells had bubbles which were larger than expected and that can be associated with a lack of the frothing reagent.

Keywords: Flotation; Hydrodynamics; Dispersion; Bubble size.

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1 INTRODUCTION

Froth flotation is a separation process whereby hydrophobic particles are selectively collected by air bubbles. Froth flotation having been deemed as one of the most important and effective methods of concentrating minerals, dates back to 1905 where it was initially used to recover zinc minerals. It is currently widely used for upgrading of various sulphide minerals such as platinum group minerals, chalcopyrite, galena and sphalerite as well as oxides such as hematite and phosphates.The dominant application for froth flotation in iron ore in Brazil is reverse cationic flotation which is contrary to the majority of the worldwide utilization i.e. direct flotation.

Anglo American's Minas Rio Operation, which commenced its operations in August 2014 currently uses froth flotation to concentrate the various itabirite ores. The duty of 22 FLSmidth160 m^3 mechanical flotation cells is employed to concentrate ores to form a pellet feed concentrate. The cells are configured to contain Roughers, Cleaners and Scavengers for different duties.

Hydrodynamics in industrial flotation cells have a significant impact on the recovery of the mineral of interest and the understanding thereof can lead to performance improvements. The Minas Rio Hydrodynamics Program was initiated in order to understand flotation cell hydrodynamics i.e. utilize bubble size and gas superficial velocity to define gas dispersion in the cells for benchmarking and optimisation.

1.1 Objectives

The objectives of the Minas Rio Hydrodynamics Program were:

- To measure bubble size and superficial gas velocity in various flotation cells at Minas-Rio.
- To use this data to develop a database to be used for cell benchmarking, instrument calibration and performance improvement.
- To use the data to diagnose sources of gas dispersion problems in the cells.

1.2 Literature review

Hydrodynamic characteristics are known to be one of the most important factors which affect separation efficiency in conventional flotation cells and this is true for reverse flotation of iron ore as well. The pulp phase kinetics of true flotation of silica are directly proportional to the bubble surface area flux (Gorain et al., 1996). Furthermore the importance of the effect of hydrodynamic characteristics on entrainment of the hematitein reverse flotation of iron ore was highlighted by Lima et al. (2016).

The main gas measurements which are accepted worldwide for hydrodynamic measurements are - bubble size (d_{32}), superficial gas velocity (J_g) and gas hold up (ε) (Schwarz & Alexander, 2005). Superficial gas velocity (J_g) is the volume of air passing per unit cross section area of a flotation cell per unit of time. The bubble size is defined using the Sauter mean diameter (d_{32}) which is the diameter that gives the same volume to surface are ratio as the bubble size distribution. These measurements define gas dispersion which is the effectiveness with which air is distributed through the volume of a reactor (Vinnett et al., 2013).

The relationship between bubble size (d_{32}) and superficial gas velocity (J_g) in conventional cells has been found to be generally a near linear correlation with a positive slope. For mechanical cells in a Copper/Molybdenum concentrator the relationship shown in Figure 1 below was established. The abnormal behaviour of the first rougher cell is easy to see from the deviation from the straight line at high J_g.

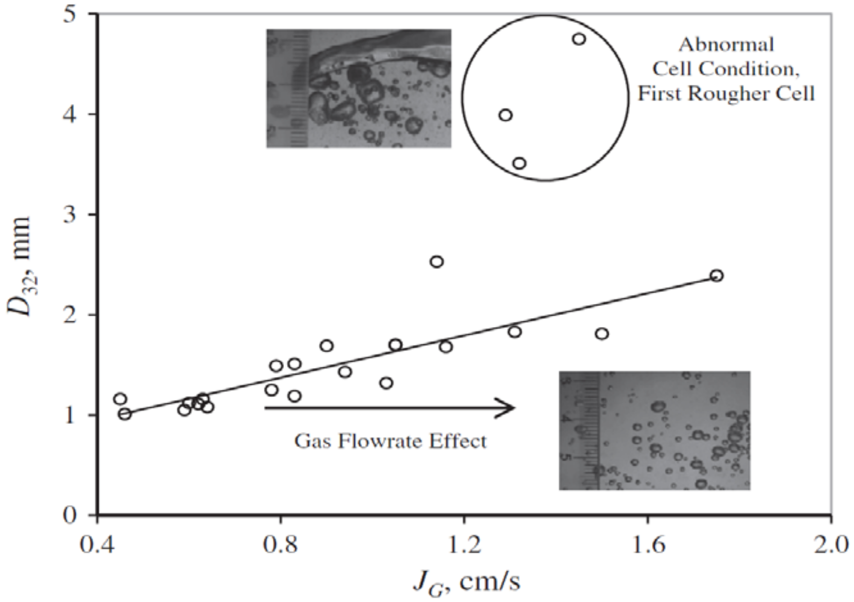

Figure 1: Sauter mean diameter, d_{32}, as a function of superficial gas rate, J_g, in an industrial flotation plant (Vinnet et al., 2013)

The relationship of an increasing bubble size with an increasing superficial gas rate was also demonstrated by Gorain et al. (1996) as shown in Figure 2. In this work different impellers were placed inside the same pilot scale cell and it shows that while the bubble size generated at a particular gas rate is somewhat dependent on impeller type, the overall trend remains the same.

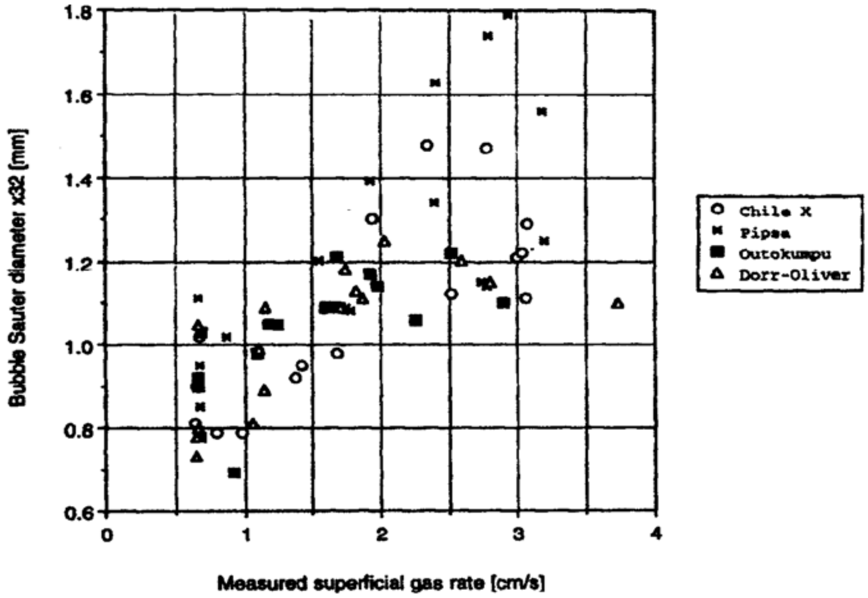

Figure 2: Bubble Sauter diameter as a function of measured superficial gas rate (Gorain et al., 1996)

When the expected correlation is not observed and there is a dramatic non-linear increase in bubble diameter as demonstrated for Rougher 1 in Figure 1 it can be associated to insufficient frother dosage, lack of maintenance of the cell mechanism and or gas injection system design problems for columns(Vinnet et al., 2013).

The two hydrodynamic properties; bubble size and superficial gas velocity can be measured using the Anglo Platinum Bubble Sizer (APBS)shown in Figure 3. The device was developed by Stone Three Venture Technology and commissioned by Anglo American Platinum (Taute and McClelland, 2006).

Figure 3: Anglo Platinum Bubble Sizer (APBS)

The APBS is comprised of two main measurement components; the bubble size measurement component and the superficial gas velocity measurement. The bubble size measurement is based on the principles of the McGill Bubble Sizer which consists of a sampling tube attached to an inclined viewing chamber. The sampling tube is immersed in the flotation cell below the pulp/froth interface. Bubbles rise from the flotation cell into the tube and into the viewing chamber where they spread out across the inclined viewing pane in a single layer. Here they are photographed using a digital video camera. Details of the McGill Bubble Sizer can be found in other sources such as Chen et al. (2001) and Hernandez-Aguilar et al. (2003). The superficial gas velocity measurement is based on the principles of the JKMRC Jg Probe which consists of a Perspex tube/probe and a pneumatically controlled valve on one end, whilst the other end has a water inlet and an air release valve. The probe is filled with water and the top and bottom valves are closed before the tube is immersed into the flotation cell below the pulp/froth interface. The pinch valve at the bottom is opened to allow gas to rise into the tube and to release the water into the flotation cell. The gas displaces the water at a rate equal to the velocity of gas flowing through the flotation cell. A detailed explanation of the JKMRC J_g probe can be found in Gorain et al. (1996).

2 DEVELOPMENT

2.1 Materials and methods

In order to carry out the bubble sizing and superficial gas velocity measurements as well as the analysis thereof, the following were required:

- Anglo Platinum Bubble Sizer
- Bucket of water with 40-100 ppm frother
- Frother syringe
- Charged battery pack for backlight
- Camera with required settings applied
- Stopwatch
- Notepad and pen
- Tape measure
- Froth depth measure
- Computer with Anglo Platinum Bubble Sizer image analysis software

3.2 Trials and conditions

The procedure used to carry out the APBS measurements at Minas-Rio was defined by the University of Cape Town´s Centre for Minerals Research.

Initial bubble size and superficial gas velocity measurements were conducted on rougher cell CF05in order to map the dispersion in the cell. The particular cell was chosen as it is a stand-alone cell with individual air and level control and good access to the froth surface. The measurements were carried out at varying distances from the impeller and at different depths below the pulp/froth surface. Learnings from these “commissioning” measurements were then extended to other cells such as scavengers.

3.3 Results and discussions

3.3.1 Flotation cell mapping – CF05

Rougher cell CF05 is the first cell where mapping using the APBS was conducted. The mapping was conducted at various points around the cell and therefore varying distances from the cell impeller. The relationship between the measured superficial gas velocity J_g was then plotted with the Sauter mean diameter d_{32} as depicted in Figure 4.

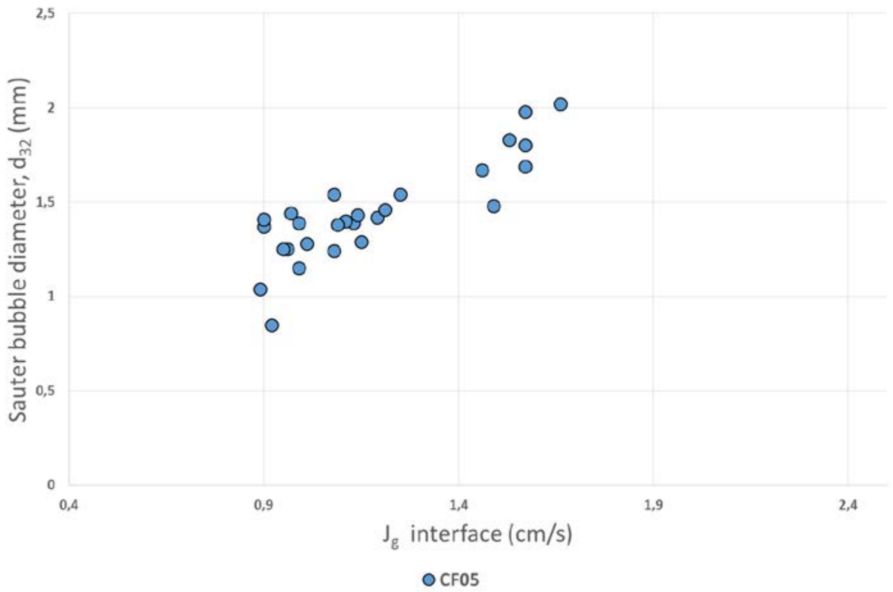

Figure 4: J_g vs d_{32} for Rougher CF05

In general, from Figure 4, a trend of increasing d_{32} with an increase in measured J_g is observed. This is in agreement with the observations made by Vinnet et al. (2013). A similar pattern and results were observed by Gorain et al. (1996). However, the data shown in Figure 4 was generated from measurements at similar nominal air rates but different distances from the impeller, therefore the spread of the data can be used as an indication of the effectiveness of dispersion of air throughout the cell.

Rougher cell CF05 was also observed for whether a change in the distance where the APBS measurement was conducted had an effect on the measured superficial velocity. The distance of measurement was relative to the distance from the cell impeller. Figure 5 shows the box plot of superficial velocity as a function of distance from the impeller.

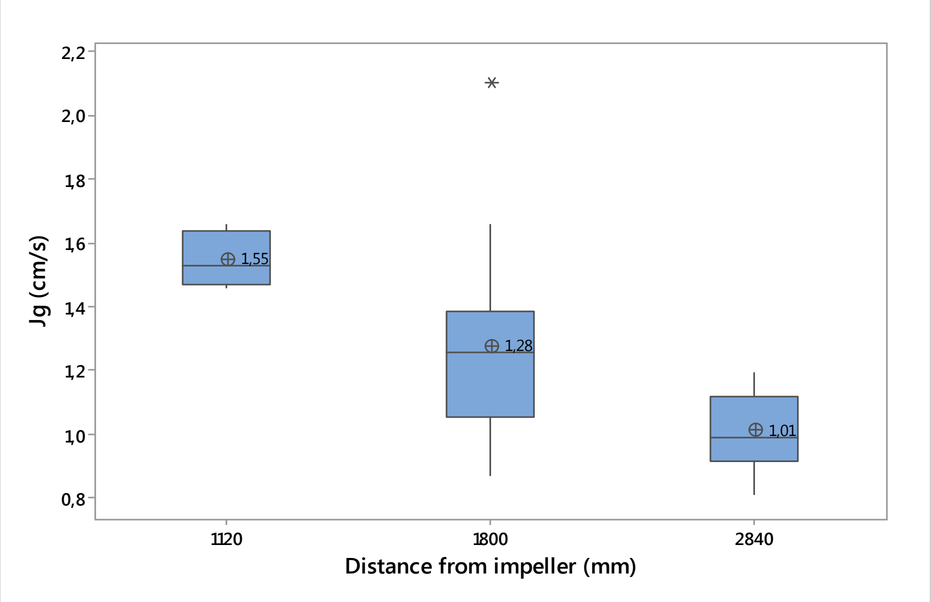

Figure 5: Box plot superficial velocity as a function of distance from the impeller

From Figure 5 it was observed that the averageJg values measured closest to the impeller (1120 mm) were 53% higher than the average J_g values measured furthest from the impeller (2840 mm). This indicates gas dispersion problems within the cell. The gas dispersion problems may be as a result of a worn out impeller and may also be due to slurry rheology. With viscous material i.e. high solids concentrations, small bubbles are created in the impeller zone or closest to the impeller but the bubbles are poorly dispersed throughout the cell (Shabalala et al., 2011).

Figure 6 shows two images of bubbles captured during the bubble size measurements on flotation cell CF05 and their respective size distribution is shown in Figure 7.

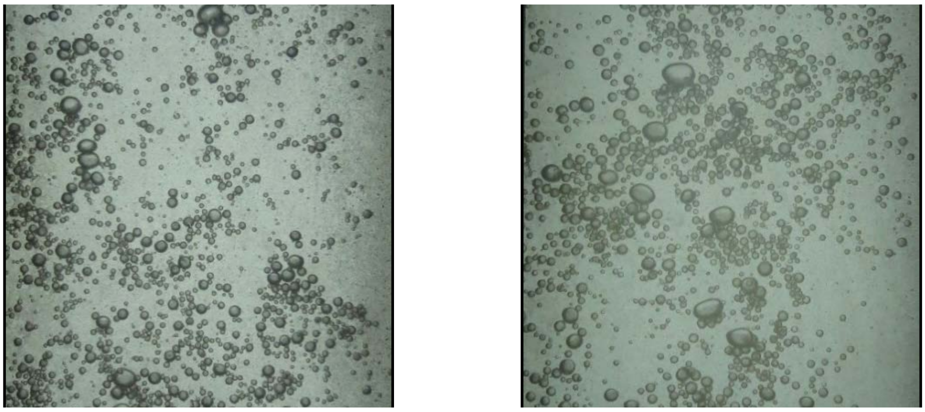

Figure 6: CF05 Bubble images

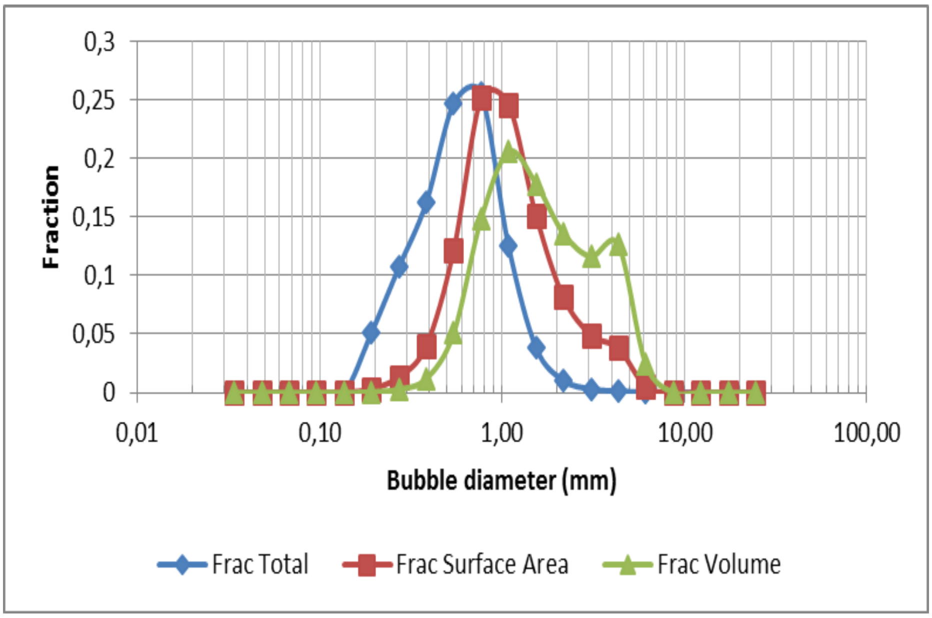

Figure 7: CF05 corresponding bubble size distributions

If rheology was the main contributor to the poor dispersion then one would expect to see many small bubbles in the distribution. This is not the case for CF05 and so rheology is unlikely to be the primary cause. Furthermore the bubble size distribution can be used to determine if there is sufficient frother in the cell where larger observed bubbles and a bimodal distribution are as a result of lack of frother (Nesset et al., 2005). The bubble size observed in Figure 6 does not point to a lack of frother in the Rougher cell CF05.

As a result of the observed poor gas dispersion, an inspection by FLSmidth was conducted on Minas-Rio flotation cells with the aim of evaluating the mechanical condition of the cells. Rougher cell CF05 whose gas dispersion data is shown in Figures 4, 5 and 6 was identified as having a rotor and stator with severe wear and needing immediate change of the impeller. Figure 8 shows the state of the cell's impeller.

Figure 8: Rougher cell CF05 impeller

A comprehensive programme of impeller maintenance and replacement has commenced at Minas-Rio based on the findings of the hydrodynamic studies.

3.3.2 Flotation cell troubleshooting - Scavegers

Post Rougher cell CF05, troubleshooting using the APBS commenced on Scavenger cells CF19, CF20, CF21 and CF22. CF19 and CF21 are Scavengers on Line 1 of the flotation circuit whilst CF20 and CF22 are Scavengers on Line 2 of the flotation circuit. Figure 9 shows the Sauter mean bubble size as a function of the measured J_g for Scavenger cell CF19. The measurements depicted are for two situations; before the installation of a new impeller and after the installation of the impeller.

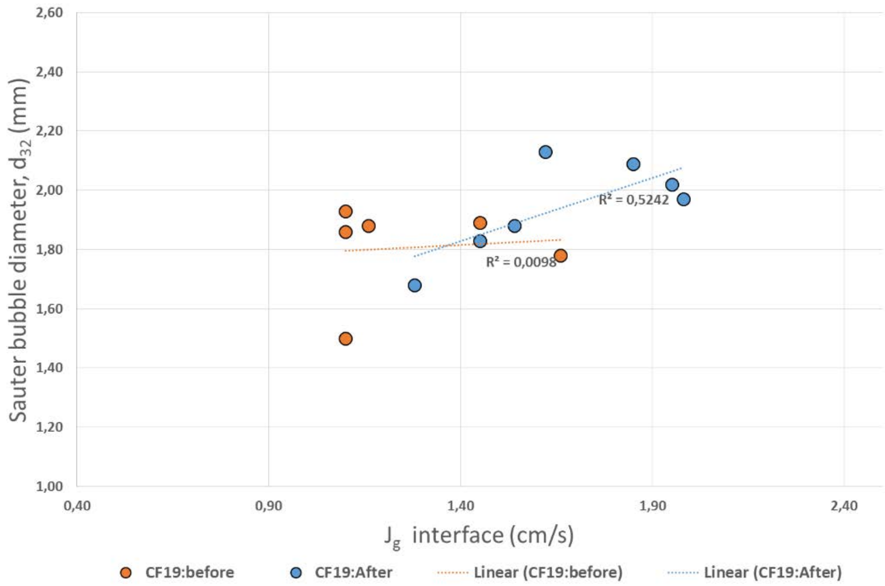

Figure 9: d_{32} vs J_g for CF19

From Figure 9 it can be seen that prior to the impeller change, the expected d_{32} vs J_g relationship as explained by Gorain et al. (1996) and Vinnet et al. (2013) was not observed. The data could not be fitted by a regression line and resulted in an R-squared statistical measure of 0,0098. Subsequent to the replacement of the impeller, an improvement in the response of the Sauter mean bubble size to changes in superficial velocity was observed. With the limited number of measurements that have been conducted, an R-squared statistical measurement of 0,524 was observed.

Figure 10 shows the d_{32} as a function of the measured J_g for Scavenger CF20. The measurements were conducted before and after an impeller change from an old to a new impeller.

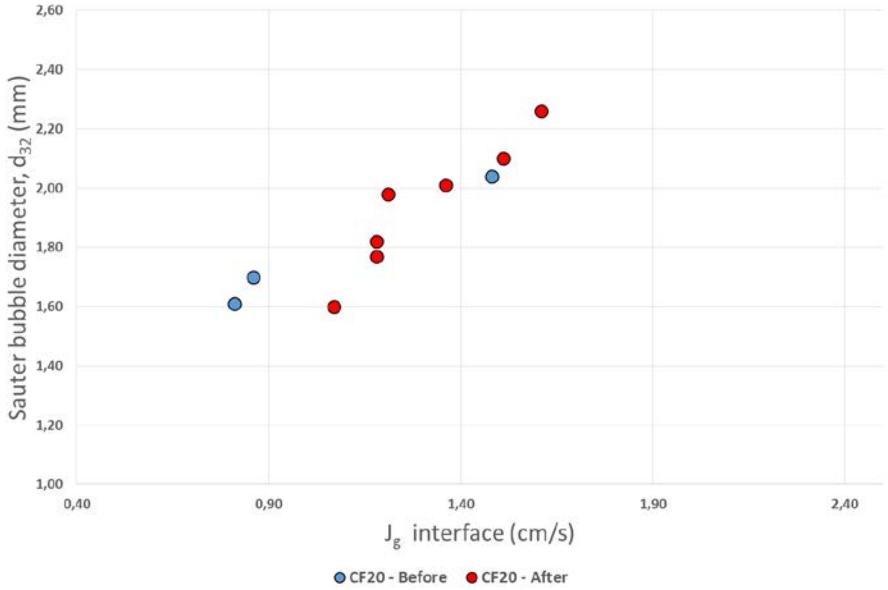

Figure 10: d_{32} vs measured J_g for CF20

From Figure *10* an evident trend of an increasing Sauter mean diameter with an increase in the measured superficial velocity is observed for the situation both pre and post the impeller change. This shows an improvement in the gas dispersion after an impeller change.

Figure 11 shows the Sauter mean diameter as a function of the measured superficial velocity for Scavenger CF22. The points measured are for a situation before any impeller changes.

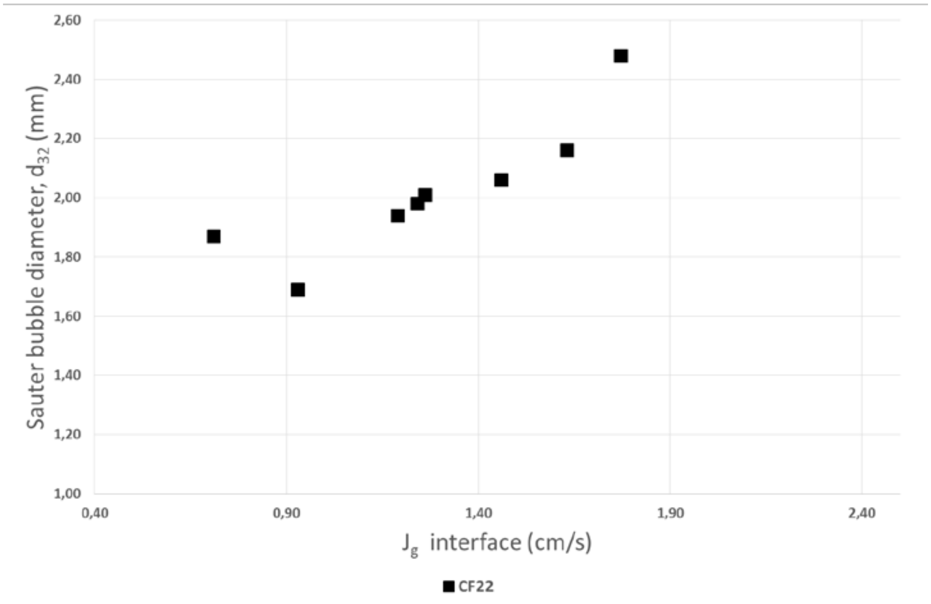

Figure 11: d_{32} vs measured J_g for CF22

From Figure *11*, for CF22 the relationship between an increase in Sauter mean diameter with an increase in measured superficial velocity is observed. However, the measurements were done at a similar distance from the impeller as well as a similar nominal air rate, this then shows very poor dispersion as different $J_g$and d_{32}values are observed for a constant nominal air rate.

The gas dispersion measurements not only led to a diagnosis of cells which have worn out impellers and were thus operating inefficiently, it also led to other investigations that are currently being conducted separately to this. The investigations are:

- Slurry density investigations – impellers struggle to disperse air adequately if the slurry density is too high leading to differing J_g and d_{32} measurements across a flotation cell.
- Insufficient frother dosages in other cells - bubble size distributions can be used to determine if there is sufficient frother in the cell where larger observed bubbles and a bimodal distribution are as a result of lack of frother.

3 CONCLUSION

From the results obtained, the following conclusions are made:

- This work has shown that it is possible to extend the use of diagnostic techniques developed for sulphide flotation to understand some of the fundamentals of iron ore reverse flotation.
- Mapping of the hydrodynamic properties of a rougher cell highlighted poor gas dispersion which could be linked directly to the condition of the cell impeller.
- Improvements in gas dispersion after replacement of worn impellers could be quantified.
- The effect of frother dosage and slurry rheology on gas dispersion in a flotation cell could be determined from the mapping of the hydrodynamic properties in the flotation cells.

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