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THE EFFECT OF LABORATORY CELL DESIGN ON FLOTATION MACHINE HYDRODYNAMICS, SOLIDS SUSPENSION AND PARTICLE RECOVERY

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ABSTRACT

A large lab apparatus was designed using a scale-down methodology based on the design legacy of the current FLSmidth commercial forced air flotation machines. This new apparatus, along with a new test methodology, was used to evaluate new rapid prototype concepts.

The apparatus was designed to monitor bubble size, power, pumping capacity, Jg, velocity profiles, froth character, and tip speed. The methodology developed follows a sequence that goes from hydrodynamic tests and solids suspension tests to a flotation kinetic test. This methodology has been demonstrated to be a good tool to determine the effect of machine design changes on flotation.

INTRODUCTION

Laboratory flotation cells have long been used to evaluate ore flotation performance. Most of the lab units used for the evaluations are versions of traditional design flotation machines that work very well but do not represent current high volume flotation machine geometries. As part of an effort to evaluate changes in flotation machine design, a "scale-down" approach was used to design a large lab scale test apparatus based on the design legacy of the current FLSmidth commercial flotation machines. This approach includes a hydrodynamic testing apparatus to evaluate our CFD and rapid prototype concepts.

This paper shows tests results from an apparatus designed to monitor bubble size, power, pumping capacity, Jg, velocity profiles, froth vision camera, and tip speed. The tests are set in a sequence that goes from hydrodynamic tests with water and solids to a flotation kinetic test. The procedure and the lab cell developed in this work have been shown to be a good tool to determine the effect of machine design changes on both hydrodynamic as well as flotation performance.

A better understanding of the effect of modifications in a lab device will provide a basis to guide full size flotation machine design and scale up.

LAB CELL GEOMETRIES

A new lab cell was designed considering the current FLSmidth commercial flotation machines geometries illustrated in the Figure 1.

Some of the important ratios from industrial sizes (Degner [2] and Degner et al [3]) were used as a basis for the scale-down: Rotor Diameter vs Cell Volume, Tip Speed vs Rotor Diameter, Froude Number vs Cell Volume, Air Residence Time vs Rotor Diameter, Specific Power vs Rotor Diameter, Recirculation Ratio vs Rotor Diameter, Jg vs Cell Volume and H/T Ratio vs Cell Volume. Equations used in this evaluation are presented in the Table 1, and, in Figure 2, one example of two parameters evaluated.

Based on this evaluation the following dimensions were defined.

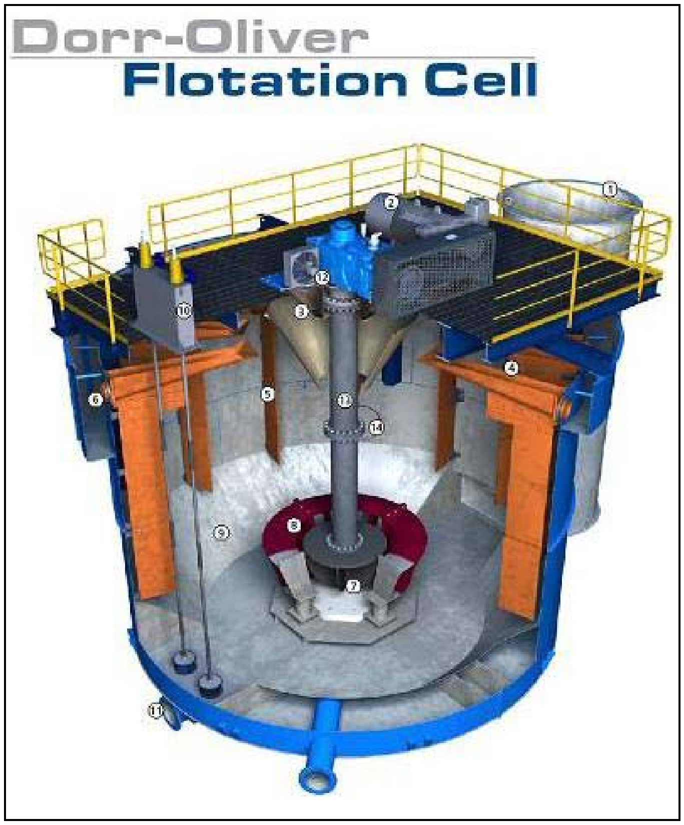

Figure 1. Forced Air Dorr Oliver Flotation Machine.

Table 1. Hydrodynamic Equations.

Specific Power	P/V
Air Residence Time	V/Q
Froude number	N^2D/g
Recirculation ratio	ND^3/T^3
Superficial air velocity	Q/Ac

Tank

We targeted two different cell sizes would be suitable for the lab, a round tank with dimensions of 254 x 254 mm (10 x 10-in) made of plexiglass and a round tank of 355.6 x 355.6 mm (14 x 14-in) made of stainless steel with two clear widows for inspection, one in the back of the cell and other close to the froth discharge.

Rotor and Stator

Two different rotor sizes were defined to match with the tanks, a 50.8 mm (2 –in) and 69.85 mm (2.75 –in). The stator was kept with the same geometrical dimensions found in the industrial sizes and it was scaled-down to match with the two different rotors and cells.

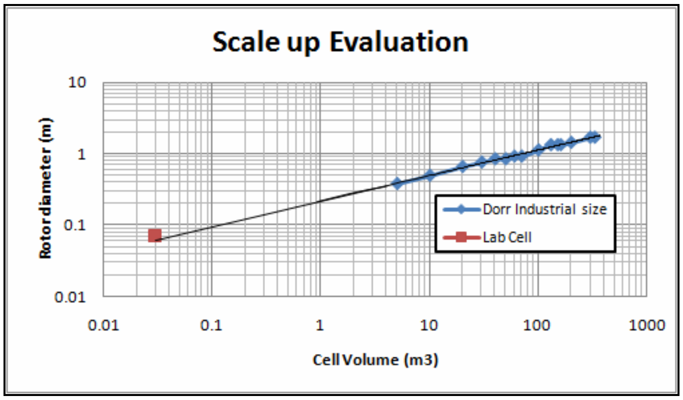

Figure 2. Scale-down, Dorr Oliver, Forced air flotation cell.

DESIGN EVALUATION METHODOLOGY

As a first step of the evaluation, hydrodynamic tests are run in water, with and without air; the models are confirmed and a first screening is done. After the first screening with the hydrodynamic tests, the second step is the suspension test using glass beads; a second screening is done and the best conditions for a flotation test are chosen for each design. A kinetic flotation tests using the glass beads is performed based on the previous results and the results of these tests are compared.

During the description of this methodology and its stages, some results with different designs will be presented. Results from 3 different Rotors: (1) Dorr Oliver Rotor (Base line to compare), (2) Rotor X and (3) Rotor Y and 3 different Stators: (1) Stator A, (2) Stator B and (3) Stator C.

Hydrodynamic Tests

The hydrodynamic tests as said were performed in water with different air flow rates and RPM's (tip speeds). The following parameters were monitored: (1) power, (2) air hold up, (3) bubble size, (4) velocity profiles and (5) pumping capacity.

The rotors were powered by a Glas-Col laboratory precision stirrer, with an integrated torque meter. The air flow to the cell was measured and controled by an Omega FMA-2600A Series mass flow controller. The bubble size was analyzed using an Anglo Platinum Bubble Sizer. The software utilized to analyze the images for regular conditions was the Anglo Platinum Bubble Sizer, and for the large bubbles (above 8 mm), the BubbleSEdit from Greek Softwares was used (Miskovic et al [4]). For each test, were counted and analyzed 15,000 to 110,000 of individual bubbles, depending on the operating conditions. Velocity profiles were taken in the stator/rotor area in the vertical length using several pitot tubes at the same time. In order to calculate the pumping capacity, a special part was designed and attached in the bottom of the tank; this was connected with a pipe that returns to the cell with a flow meter.

In the Figure 3, we can see the velocity profile for two different rotors in different Jg's and tip speeds. In this case one of the goals was get a more homogeneous jet along the stator and eliminate a negative velocity on the lower portion using a new design "Rotor X".

In the Figure 4, we can see a comparison between Dorr Oliver rotor and the "Rotor X" in terms of specific power and tip speed with different Jg's. The Specific power follows the behavior found in the velocity profiles showing that "Rotor X" is able to dissipate higher power under most conditions.

The results above were used to confirm our CFD models, as can be seen in Figure 5. This confirmation is very important and will save time in the future, where the new designs are tested using CFD first and only the most promising are tested in the lab.

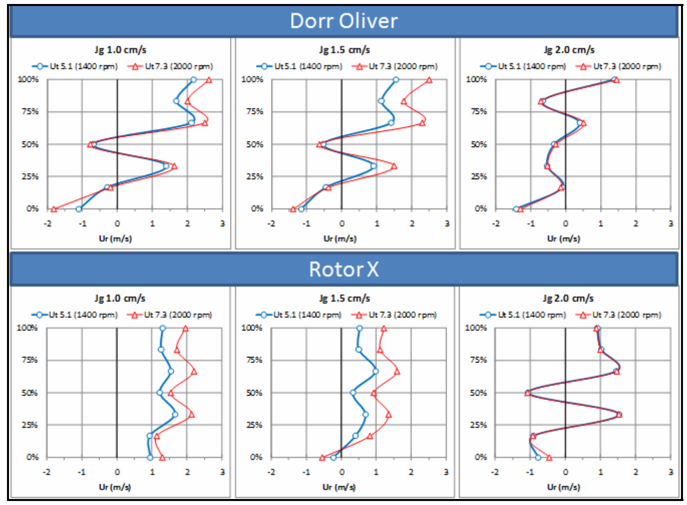

Figure 3. Velocity Profile for Dorr Oliver Rotor and Rotor X.

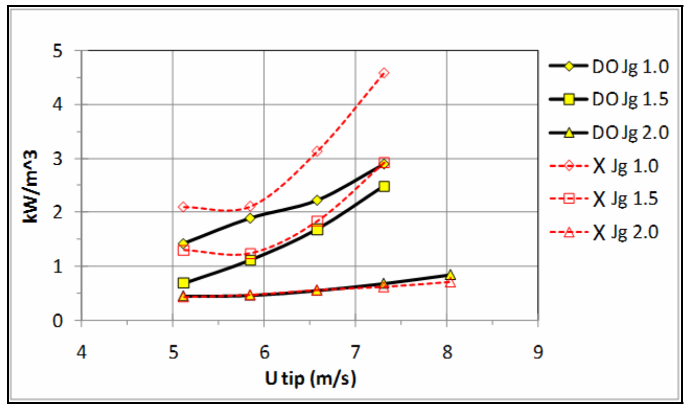

Figure 4. Specific Power vs Tip speed for the Dorr Oliver Rotor and "Rotor X".

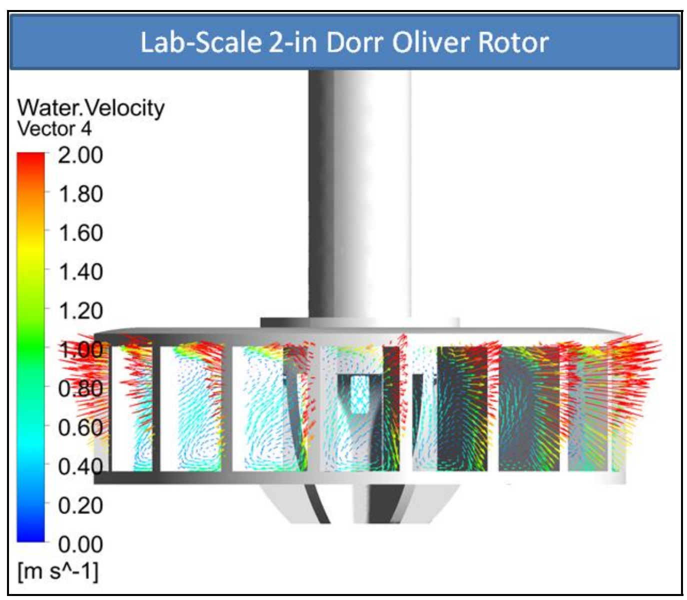

Figure 5. CFD Lab-Scale Dorr Oliver Rotor.

Suspension Tests

Going further in the evaluation, the second step is the suspension test. Glass beads were used as the particles to be suspended. This is very convenient since we can standardize on a mixed sizes with a constant size distribution.

Figure 6 shows a size distribution of the glass beads used for this specific evaluation, where the D80 is in 186 µ, and the tests were performed with 20% wt solids.

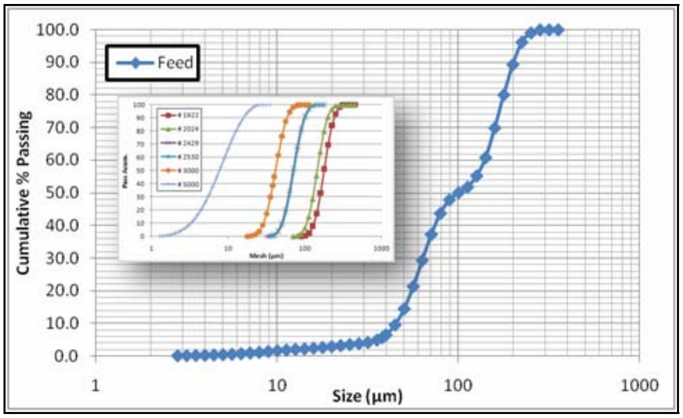

Figure 6. Glass Beads Feed Size Distribution.

The purpose of this is to test each new design regarding the capability to suspend different particle sizes in different air flow rates and tip speeds and the response of that in the specific power, sanding, air hold up, quiescent and mix zone and surface turbulence.

The global air hold-up (ε) was determined from the measured increase in slurry level using the formula:

$$\varepsilon = hg / ht + hg \qquad [1]$$

where hg is the rise in water level due to gas inclusion and ht is the static water level.

Sanding is the measure of solids settled in the bottom of the tank, and is measured in terms of depth measured from the bottom of the tank to the top of the settled solids.

Quiescent and Mixing zone and Surface turbulence are shown in the Figure 7. For the surface turbulence, the measurements are made from without air to the boiling state where the maximum sanding happens; that is none of the solids are in suspension or a few remain in suspension.

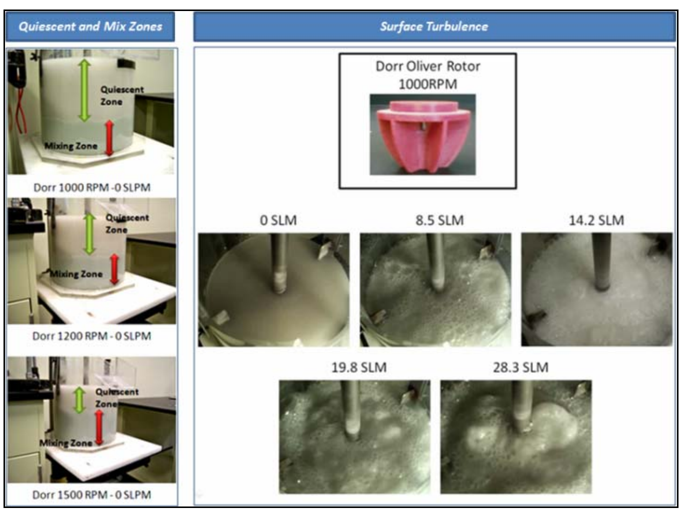

Figure 7. Surface Turbulence, From calm to boiling Surface.

Figures 8 to 10 show the results for specific power, sanding and air hold up for the Dorr Oliver rotor and a new design called "Rotor Y". The "Rotor Y" was designed to have a lower specific power, keeping the solids in suspension as well as Dorr Oliver. As we can see in Figures 8 and 10 below, it has less specific power and it begins to sand with 30 SLPM and Dorr with 33 SLPM; earlier than Dorr Oliver but not too different.

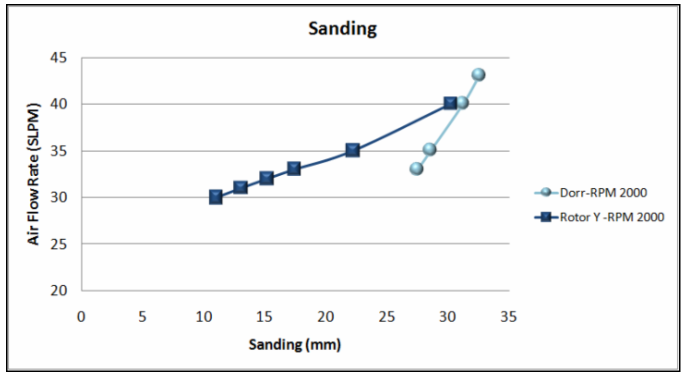

Figure 8. Sanding, Dorr Oliver Rotor and "Rotor Y".

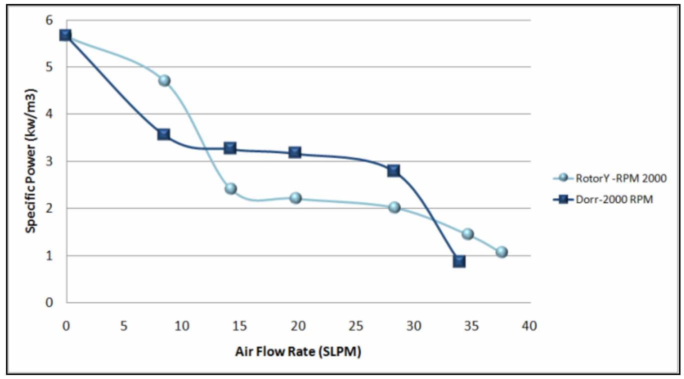

Figure 9. Specific Power vs Air Flow Rate at 2000 RPM, Dorr Oliver Rotor and "Rotor Y".

Figure 10 shows a different air hold up for the "Rotor Y"; lower than Dorr Oliver showing a change of flow pattern in the tank with this new design, and it also indicates that a change in the air residence time was made.

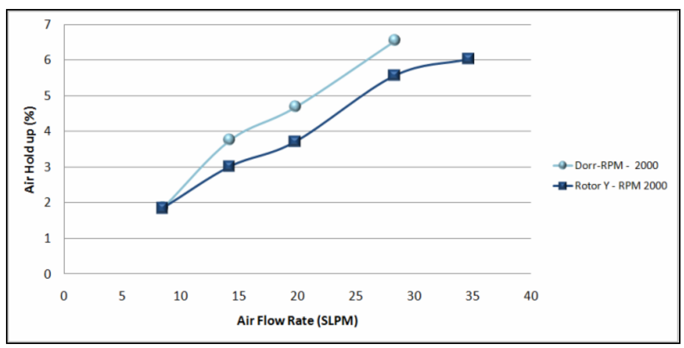

Figure 10. Air Hold up vs Air Flow Rate at 2000 RPM, Dorr Oliver Rotor and "Rotor Y".

Thus, the best operation ranges are chosen from the suspension test, which are the conditions where the sanding is not present or it appears to be minimum.

Flotation Tests

With the ranges for the flotation tests defined in the previous step, batch flotation kinetics tests are performed to determine the first-order rate constant (k) for the new designs chosen. The deliverables are: (1) recovery by size fraction, (2) fast and slow kinetic by size fraction, (3) Sb superficial bubble area rate, (4) specific power and (5) flotation probability.

The tests can be performed in two different apparatus:

- In the 355.6 x 355.6 mm (14 x 14-in) tank, that is a 30 L cell. The tank was modified to run in a JK batch flotation apparatus having a bottom drive thus allows a free area in the top of the cell. To keep the level controlled, a float switch linked with a make up water tank and solenoid valve were set. Figure 11 shows complete apparatus.

- In the 254 x 254 mm (10 x 10-in) tank made of plexiglass, that is an 11 L cell. The rotor is powered by a Real-Torque Digital™ Brushless Mixers, as seen in the Figure 12.

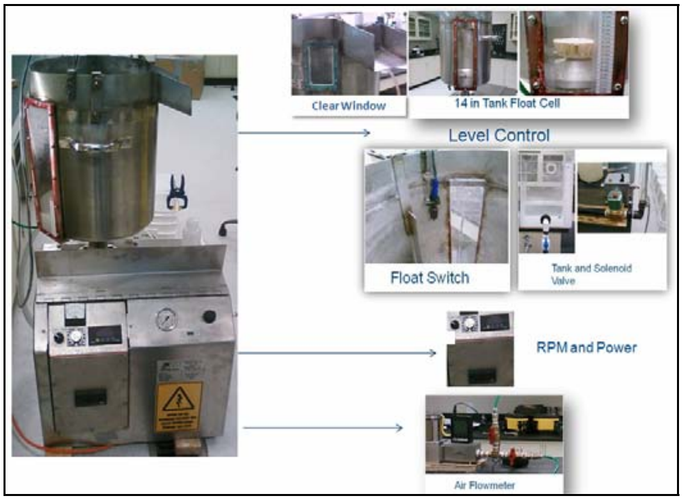

Figure 11. Flotation Cell Apparatus, bottom drive, 30 L cell.

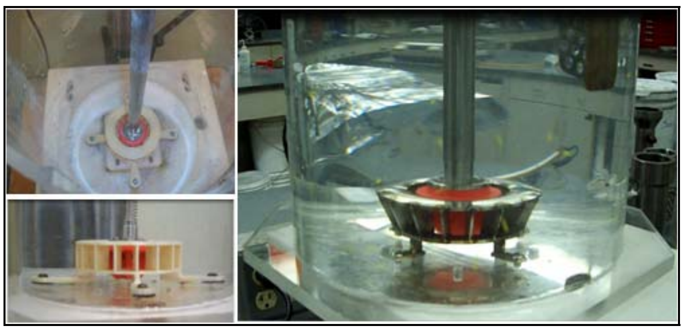

Figure 12. Flotation Cell Apparatus, top drive, 11 L cell.

All the tests were performed with 20% wt solids and with the froth depth controlled at 54 mm, the pH was 10.5 and using etherdiamine as the collector. The dosage for the collector was kept the same for all tests.

A bubble size distribution is done for each new design or a combination selected in the previous steps (eg. combination of a new rotor and new stator). Figure 13 shows the results for the Dorr Oliver Rotor at 1500RPM in different Jg's for different stator designs and Figure 14 shows the results from the Stator A with different rotors.

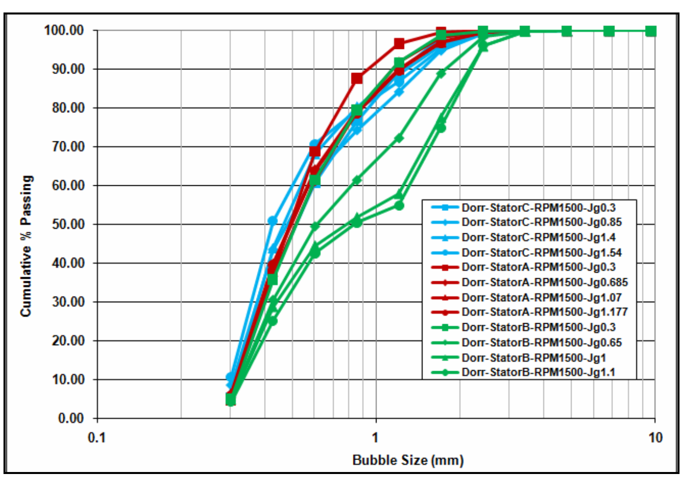

Figure 13. Dorr Oliver rotor, 1500RPM, different stators and Jg's.

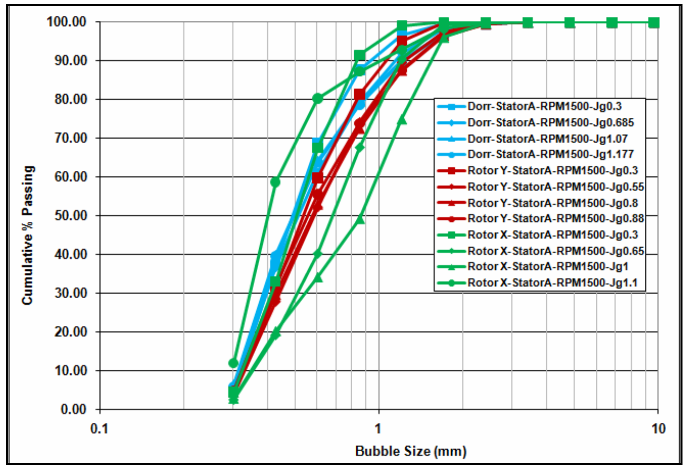

Figure 14. Stator A, 1500RPM, different Rotors and Jg's.

As can be seen in Figure 13, different stator designs give different results in the bubble size distribution considering the same rotor, and in Figure 14, keeping the same stator and changing the rotor, show also a production of different bubble size distribution curves. Thus, both rotor and stator play an important role in the bubble size distribution.

As one example of recovery and kinetics an analyses is made of the three different rotors: (1) Dorr Oliver, (2) Rotor Y and Rotor X with the Stator B; the results are shown in Figures 15 and 16.

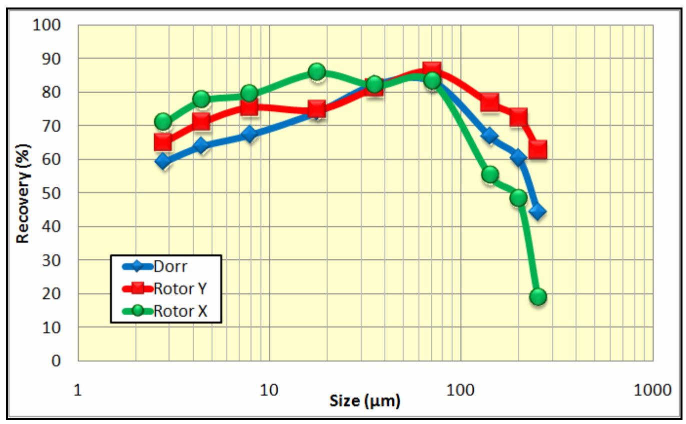

Figure 15. Recovery by size fraction, Stator B, 1500 RPM.

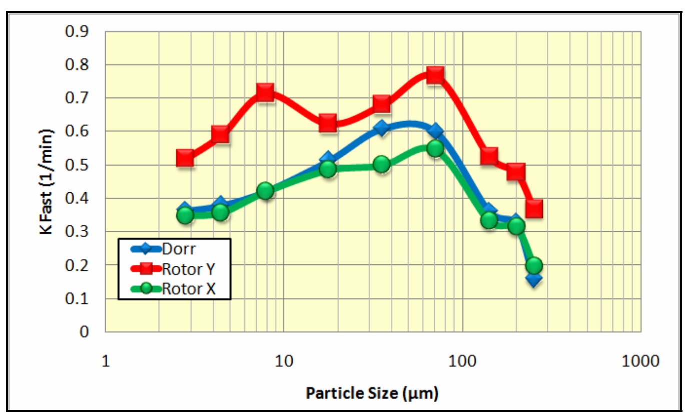

Figure 16. Kinetic by size fraction, Stator B, 1500 RPM.

Analyzing the recovery by size fraction we can see a better coarse particle recovery for Rotor Y, followed by Dorr Oliver and Rotor X. For fine particles best recovery was for Rotor X followed by Rotor Y and Dorr Oliver. The results seen in the previous sections showed the Rotor X has the highest specific power followed by Dorr Oliver and then Rotor Y, this helps to explain a better coarse particle recovery for Rotor Y where a system with less energy would decrease the detachment of coarse particles-bubbles. It also helps to explain a better Fine particle recovery for Rotor X and a poor performance for the coarse particle recovery since Rotor X presented the highest specific power that would increase the probability of attachment of fine particles-bubbles and increase of detachment of coarse particle-bubbles.

In terms of the kinetics, we can see that Rotor Y has better kinetics for all the particle size analyzed.

The flotation froth layer is also monitored, where the % of solids, water recovery and turbulence on the base of the froth are related with the surface turbulence and mix and quiescent zones in the suspension test, Figure 17 shows the image of a froth layer of one of these tests. Some results indicate that a mix zone maximized with a minimal quiescent zone to protect the froth base and decrease turbulence on it, allows a higher coarse particle recovery as we can see in Figure 18.

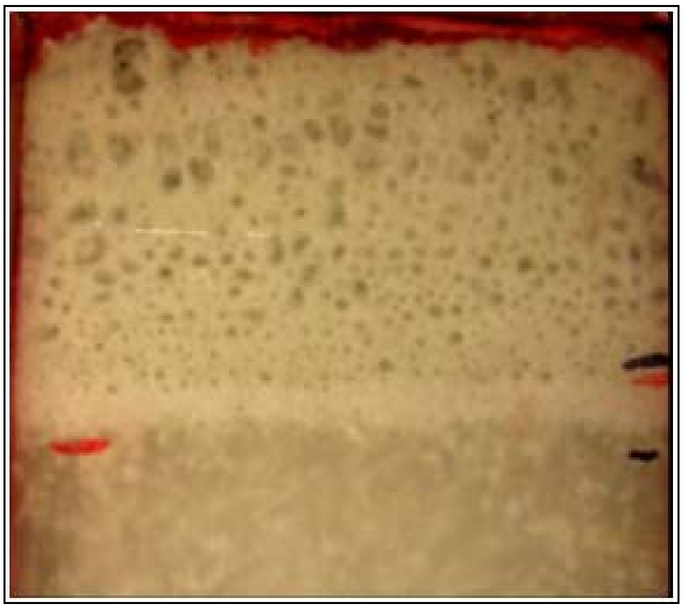

Figure 17. Froth Layer Monitoring.

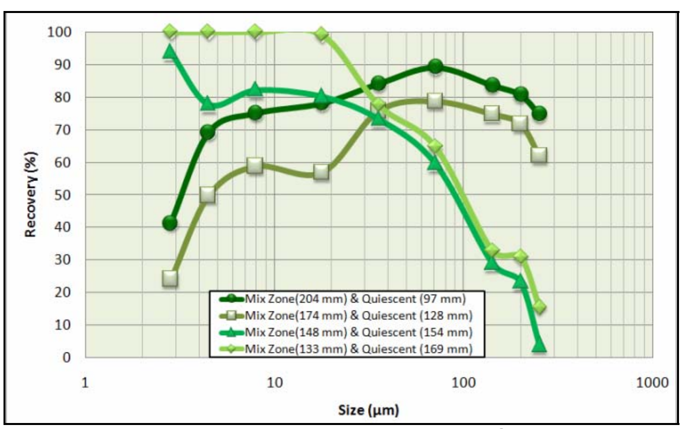

Figure 18. Recovery by size fraction, related with Quiescent and mix zones, Rotor X and Stator A at different Jg's, 1500 RPM

CONCLUSION

The apparatus and methodology presented in this paper have been developed to be able to study different designs for the forced air machine in a lab scale. The studies go from a CFD analysis, hydrodynamic tests, suspension tests to a kinetic flotation test. All the results presented showed a great coherency between all the stages of the methodology with featured differences between one design and other.

NOMENCLATURE

P	Power (KW)
V	Cell Volume (m^3)
N	Rotor Speed
Q	Air Flow (m^3/min)
G	Acceleration due to gravity
D	Rotor Diameter (m)
T	Tank Diameter (m)
H	Tank Height (m)
Ac	Cell Area (m^2)
Jg	Superficial Gas Velocity (cm/s)

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