

## Contents

Got Gas?: 1

Sampling in  
concentrators: 5

Thickener tank design  
options: 8

# Output

**Editor:**

Laura White  
laura.white@outotec.com  
www.outotec.com

## Got Gas?

Author: Rob Coleman

It is well recognised that successful flotation heavily depends on the pulp and froth phases. Research over the past decade has also shown that the gas phase plays an equally important role.

The recovery in a flotation cell is directly related to the amount of air added to the cell. Therefore there is a minimum air requirement for a given number of solid particles, below which efficient flotation cannot take place. The method by which the air is added to the flotation cell is also vitally important as it controls the size of the bubbles generated and the flow patterns in the cell. The flotation rotor and stator must be designed to provide sufficient turbulence for bubble-particle collisions to occur and be able to generate bubbles in a certain size range depending on the particle size to be floated. The correct flow patterns up the cell of particles and bubbles must then be formed so that the particles are carried up to the froth phase without significant drop-back occurring. In other words, if the gas phase is not handled properly, chances are the flotation cell is not performing as well as it could be.

So how good is the gas dispersion in your flotation cell and what can you do to optimise it?

There are actually a number of gas phase parameters that can be directly measured and used to optimise the performance of this phase. Typically the gas phase can be described by four parameters:

1. Gas hold-up
2. Bubble size and bubble size distribution
3. Superficial gas velocity
4. Bubble surface area flux

### 1. Gas Hold-up ( $e_g$ )

Gas hold-up is the volume of the gas in the pulp zone of a flotation cell. The volume of gas reduces the pulp volume and therefore decreases the residence time available for flotation. The gas hold-up depends on the amount of air added to the flotation cell and is a strong function of pulp viscosity. Through the proven design of the flotation tank and mechanism, gas hold-up in Outotec flotation cells is typically limited to between 5% and 15% of the total pulp volume, thereby maximising the cell volume and residence time.

### 2. Bubble size and bubble size distribution ( $d_b$ )

Bubble size and its distribution in a float cell's pulp zone directly affect the particle-bubble interactions and hence flotation performance. For optimal flotation performance, it is critical to generate bubbles of the correct diameter based on the size of particles to be floated. Smaller bubbles are generally required for fine particle flotation and larger bubbles for coarse particle flotation.

Let's look at the following example: 1 m<sup>3</sup> of air contains approximately 566 million bubbles of 1.5 mm diameter. At an aeration rate of 20 m<sup>3</sup>/min, 189 million bubbles/sec must be generated. Similarly, 1 ton of typical solids contain 1 billion (spherical particles) of 70 microns in size (after grinding). At a solids feedrate of 300 tph, there are 83 million total particles/sec. Of these 83 million particles/sec approximately 10% are collected in a rougher duty, 50% in a cleaner duty and 85% in a recleaner duty. This corresponds to approximately 23, 5 and 3 bubbles per particle. This may seem sufficient - however, due to issues such as poor liberation, incorrect reagent addition and pulp chemistry, and oxidation, flotation recoveries of 100% are never achieved. If the bubble diameter was 2.0 mm, there would only be 80 million bubbles/sec, which would reduce the number of bubbles per particle to less than one. So how do you ensure the optimal bubble size and distribution range? The actual design of the cell mechanism plays a vital role, as does the means of introducing air into the cell. It is also vital to work with a flotation supplier who really understands the intricacies of this process, as poor advice will lead to a waste of time and money.

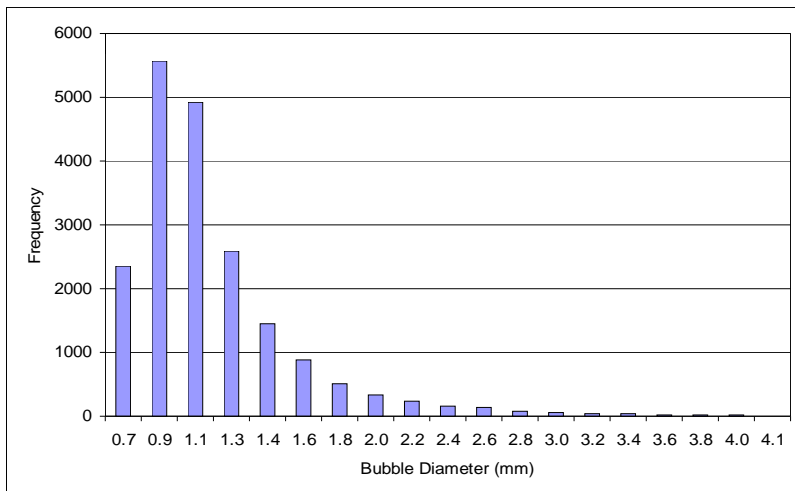
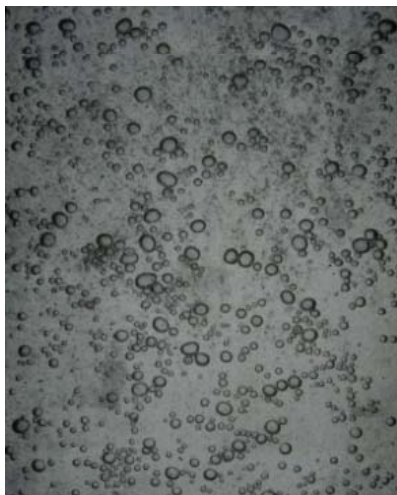
The bubble size and bubble size distribution can be measured in each flotation cell using a photographic Bubble Sizer. A sample of bubbles is photographed with a digital still camera and an automated image analysis procedure is used to size the collected bubbles from the digital images.



*Outotec flotation cell with photographic bubble cell*

There are two main methods of calculating the average bubble diameter of a distribution. The first is to calculate the average of all bubble diameters in the distribution (known as the average bubble diameter  $d_{10}$ ). The second is to calculate the sum of all bubbles' volume divided by the sum of all bubbles' surface area (known as the Sauter mean bubble diameter  $d_{32}$ ). The Sauter mean bubble diameter is always larger than the average bubble diameter as it takes more account of large bubbles with large volumes; therefore it is a better measure of bubble size. The Sauter mean bubble diameter is also used to calculate the bubble surface area flux, as discussed in Section 4.

Outotec's flotation mechanism is able to produce small bubbles with average bubble diameters between 1.0 mm and 1.5 mm and Sauter mean bubble diameters between 1.5 mm and 2.0 mm. In the figure below, the average bubble diameter and Sauter mean bubble diameter are 1.3 mm and 1.8 mm, respectively.



*Bubble size distribution in an Outotec cell, with measurement of over 20,000 bubbles*

### 3. Superficial gas velocity ( $J_g$ )

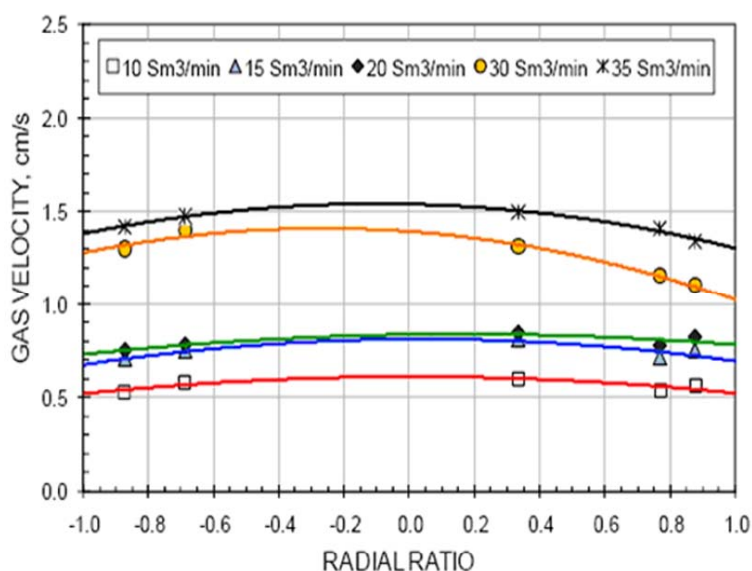
Superficial gas velocity is the bubble's upward velocity relative to the cell cross-sectional area. Superficial gas velocity is proportional to the air addition rate and can indicate local flow patterns and gas short-circuiting. Excessive air addition increases bubble size, as the mechanism is unable to disperse the air, and is therefore detrimental to flotation performance. Controlling the air rate within an optimal range is very important.

The average rise velocity of bubbles in the flotation cell can be measured in combination with the bubble size measurements from the Bubble Sizer. A cylinder connected above the viewing chamber is filled with water before the bubble sizing takes place. During the bubble size measurement, the water in the chamber is displaced by the rising air bubbles and the water level drops. The time taken ( $t$ ) for the water level to fall a known distance,  $L$ , is measured and the superficial gas velocity calculated from the following equation:

$$J_g = \frac{L}{t}$$

Adjustments are then made to account for the pressure difference between the location of the sampling valve and where the measurement is made in the cylinder. Typical superficial gas velocities in Outotec flotation cells are between 0.5 cm/s and 1.5 cm/s. As the air rises into the froth zone, the superficial gas velocity increases with decreasing surface area in the froth zone.

Superficial gas velocity measurements performed radially across a flotation cell can provide information on the gas dispersion efficiency. A typical velocity profile across a cell is shown in the figure below. It is common for the superficial gas velocity to be slightly higher in the middle of the cell due to the air addition there. As the air rate increases the bubbles rise faster in the cell centre as the mechanism becomes less efficient at air dispersion, until the air cannot be dispersed and "boiling" occurs. Measurements of superficial gas velocity can also provide information on mechanism wear. If there is, for example, an uneven distribution across the cell the stator could be worn out on one side.



Another important application of superficial gas velocity is the measurement of the velocity profile down a bank of flotation cells, such as a rougher circuit, or a cleaner circuit. The velocity profiles down a bank can either be increasing (low at the front of the bank, high at the end), decreasing (high at the front, low at the end), balanced (equal across the bank) or unbalanced (increasing and decreasing from cell to cell down the bank). As the air addition to most flotation cells is by visual inspection of how the concentrate flows over the lip, it is common to find an unbalanced profile down most banks of "unmonitored" flotation cells.

Recent test work by various researchers at concentrators around the world underlines the significant benefits from varying the  $J_g$  profile across the bank. On the cleaner circuit at one concentrator, for example, the “as-measured” profile was unbalanced. After changing the profile to increasing, a recovery improvement of over 30% was achieved, at the same concentrate grade. These down-the-bank superficial gas velocity measurements were performed in conjunction with metallurgical surveys to determine the grade-recovery curve at the different conditions. From this the optimum profile for the best performance can be quickly determined. Off-the-shelf on-line superficial gas velocity probes are also now available that can be used to monitor and control the profiles automatically.

#### 4. Bubble surface area flux

Bubble surface area flux is the amount of bubble surface area rising up a flotation cell per cross-sectional area per unit time. It depends directly on the bubble size and superficial gas velocity and at shallow froth depths is linearly proportional to the first order flotation rate constant. So generally, the greater the bubble surface area flux, the higher the recovery rate in the pulp zone of a cell. However if excessive air is added the recovery rate in the pulp zone can decrease due to “boiling”.

A significant amount of test work has been performed on bubble surface area flux over the past fifteen years, particularly in the AMIRA P9 Project, where Outotec is a participant. The relationship between bubble surface area flux and the first order flotation rate constant has been successfully validated and holds for cells of all sizes, from 60 litres to 300 m<sup>3</sup>. It is essentially a direct measure of pulp zone flotation efficiency.

The bubble surface area flux can be measured directly using the following equation:

$$S_b = \frac{6 \cdot J_g}{d_{32}}$$

Where:

- $S_b$  = Bubble surface area flux (cm<sup>2</sup>/cm<sup>2</sup> s)
- $d_{32}$  = Sauter mean bubble diameter (cm)
- $J_g$  = Superficial gas velocity (cm/s)

Typically in Outotec flotation cells the bubble surface area flux ranges between 30 s<sup>-1</sup> and 60 s<sup>-1</sup> and can be varied directly by changing the air addition rate. This is another distinct advantage of forced air flotation cells.

#### Summary

The gas phase of any flotation cell is critical for optimum cell performance. Understanding and being able to vary the four key parameters in the gas phase can bring real results – with over 30% recovery improvement at the same grade, in one particular case. The key is using the right flotation partner to provide the tools and expertise to benchmark the gas dispersion in your current flotation cells. With this valuable information it becomes far easier to get the most out of your operation.

---

*Dr Rob Coleman is currently Technology Leader – Flotation for Outotec Pty Ltd in Australia. He has a Chemical Engineering degree from the University of Witwatersrand in Johannesburg and a Doctorate in Minerals Processing from the JK Minerals Research Centre - University of Queensland. He has over 14 years experience in the operation, design, modelling, simulation and optimisation of flotation circuits and has published and presented papers at many international conferences.*

If you would like more information, click here to contact

[rob.coleman@outotec.com](mailto:rob.coleman@outotec.com)