SELECTION OF MECHANICAL FLOTATION EQUIPMENT

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Abstract

Design and selection of correct flotation equipment is critical to the success of any flotation concentrator. Traditionally, selection has been based on residence time scale-up from batch and/or pilot testing. However reviewing other factors such as froth carry rate and lip loading is now considered to be equally as critical to ensure optimum performance. This paper reviews the selection methodology used for modern flotation tanks, detailing the information required to ensure the best results. The paper will also discuss various configuration and layout considerations and how these can impact future plant performance.

Key words: Flotation, Equipment Selection, Plant Design.

INTRODUCTION

Selection of flotation equipment based predominantly on residence time, is a process that has been taught in undergraduate university courses for many years. The residence time is typically derived from interpretation of kinetic flotation curves for targeted minerals, obtained from laboratory or pilot scale flotation testing.

While the required residence time is certainly an important factor in determining the size and number of flotation cells required, other factors should also be taken into account to derive a more sophisticated equipment selection solution. This paper will review those factors and the importance of their consideration in flotation equipment selection.

EQUIPMENT DESIGN OPTIONS

Tank Type

Historically flotation cell tanks have been of the square 'hog-trough' design, which are also known as conventional flotation cells. In a bank of conventional cells, the slurry enters at the front of the bank and passes along the bank through each cell in turn, of which there are typically from two to eight individual cells. Earlier conventional cell models suffered from high levels of material bypassing the mixing mechanism due to either small or non-existent bulk heads between each cell, or inefficient mixing. Modern conventional cell designs are far more efficient units than their predecessors, and are still used (and sold) in many countries today.

There are two main tank types of conventional cell design; one tank design with a U-shaped floor, and one tank design with a flat floor. The most modern conventional cell design is the U-cell (Figure 1). In addition to large bulkheads delineating the slurry entry and exit to each cell, this cell has the added advantage of a U-shaped floor to maximize the effectively mixed volume per cell. The more simple design of a flat bottom cell often has dead zones in the cell corners, potentially leading to a buildup of particles (sanding). This unmixed cell volume is inactive for flotation purposes and hence the overall flotation bank residence time is reduced.

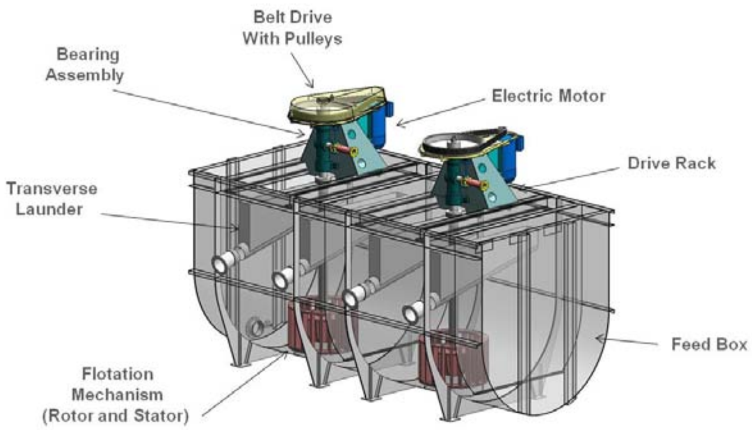

Fig 1: Conventional U-cell design.

Other limitations of conventional flotation cells are that they typically have only a single automatic air controller per cell bank (although each cell has a manual trim valve) and a common slurry level controller per bank. The requirement for less control instrumentation and valves, plus the fact that each cell shares at least one common wall/bulk head with neighboring cells, makes these conventional style cells very cost effective.

Modern flotation cell design is based on a cylindrical tank (Figure 2), and these are commonly known as Tank Cells. The cylindrical tank design allows for a more even flow pattern than the earlier 'hog-trough' style cells and consequently these units have better air and solids dispersion throughout the tank. Each tank can have their own mechanism, automatic air control and level control, which gives the operator much more control over each individual tank, rather than just a combined bank (as per conventional cells).

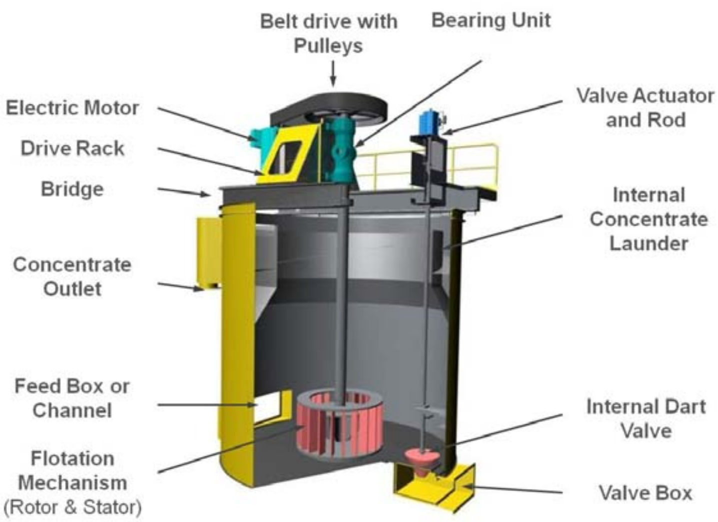

Fig 2: Tank cell design.

Another advantage of the tank cell design is the ability to symmetrically alter the froth surface area to suit the flotation duty at hand. This is normally done by adjusting the size of concentric crowders, and/or using different launder configurations. The net result is that the tank shape and design is optimized for the intended flotation duty. This versatility and the high degree of control makes tank cells suitable for many flotation duties and often the best choice for a given flotation application.

Tank Lining

Flotation tanks are typically made with mild steel that requires corrosion protection from process fluids. Surface protection (lining) of the tank thereby improves the operational life of the equipment. The choice of lining is made based on a number of factors, including solid particle size, abrasive index of the ore, expected plant life, and the reagents that are to be used.

Flotation cell lining can range from a one or two coat spray epoxy lining, which is suitable for fine ores with low abrasiveness; to natural rubber linings for coarse and/or abrasive ores; to butyl rubbers, which can be required when petroleum derivatives and corrosive chemicals (such as sodium hydrosulphide) are being used. As rubber lining is typically more expensive that epoxy lining, various combinations of linings, (such as having the bottom half of the tank lined in rubber and the top half in epoxy), can be used in certain situations to reduce capital outlay, whilst still getting the benefits of using the superior lining material. It is recommended that areas which experience high flow rates, such as feed boxes, discharge boxes and transfer ducting are always rubber lined.

Self Aspirated versus Forced Air

Mechanical flotation cells can be broken down into two broad categories based on how air is introduced to the cell. In a *self aspirated* flotation cell, air is introduced to the slurry using the vacuum created by the rotor. In a *forced air* flotation cell, air is generated external to the cell by a low pressure blower, and pumped down the shaft of the flotation cell to the rotor.

There are several major design differences between these two cell types, the most obvious being the location of the rotor in the tank. In a self aspirated machine the rotor is typically located near the top of the tank, whereas in a forced-air machine it is located at the bottom. This has implications on pumping efficiency and slurry circulation in the tank, which means that in self aspirated cells additional in-slurry wear components are required, typically in the form of a draft tube and false floor, to direct the flow of slurry throughout the tank. With the energy input to the cell being towards the top of the tank, these components are required to facilitate flow throughout the vessel to ensure that particles reach the collection zone where particle bubble attachment occurs. If this flow pattern is disrupted by sanding or coarse particles (for example, from a blocked cyclone upstream) it can significantly reduce the performance of the unit resulting in recovery loss.

Forced air flotation tanks have the rotor located at the bottom of the tank, which means particles entering the tank are immediately drawn into the active mixing and collection zone, maximizing the chance of particle-bubble collision, bubble attachment, and particle recovery. The only other internal mechanism component required is the stator, which as the name suggests is a stationary group of baffles located around the outside of the rotor that assists by directing slurry flow from the rotor. A forced air flotation machine has less wear components exposed to the slurry compared to a self aspirated flotation machine.

Self aspirated flotation machines have historically been favored in low technology processing plants, as air addition is one less variable that must be controlled. However with most modern plants having computer based control systems, the ability to accurately control the air addition rate in to the flotation cell gives the operator a valuable additional variable that they can use to maximize plant performance and therefore profitability. To this end, numerous authors (Cooper et al. 2004, Doucet et al. 2006, and Hadler et al. 2010) have reported improvements in flotation circuit performance by controlling and optimizing air additions into flotation banks. This is a key advantage of forced air flotation machines over self aspirated flotation machines.

There are operational differences between both cell designs that are also important to consider. If sanding of the flotation cell occurs in a scenario such as a power failure, it is generally easier to restart a forced air type tank. This is partly due to the rotor being located at the bottom of the tank, where particles may settle out from suspension, and partly due to the ability to operate the forced air rotor without any air (i.e. the air control valve is kept closed). These two design features allow the operator to maximize the power transferred to any sanded material by the rotor, thereby giving the operator the best chance of resuspending any settled solids.

Conversely a self aspirated machine has its rotor located near the top of the tank, which is generally above any settled particles, and this makes it difficult to resuspend the settled material. Secondly by the nature of how a self aspirating rotor operates, when the rotor is rotating it will be inducing air into the slurry, which reduces the slurry pumping efficiency compared to if the air was absent.

Further operational differences are seen in behavior of the froth layer at the top of an operating tank of each design. A forced air flotation machine typically has stable, consistent froth flow over the lip at the top of the machine. This is because the rotor is located at the bottom of the tank and the distance of the rotor to the froth zone minimizes turbulence in the upper region, which is conducive to a stable froth zone. As previously discussed a self aspirated flotation machine has the rotor located near the top of the flotation cell, which leads to more turbulence in the upper region of the cell. This is also the region of the froth phase and so therefore it is not surprising that froth phase turbulence is often observed on a self aspirated cell (especially as the rotor wears). This will lead to reduced flotation cell performance.

Blower selection for Forced Air Machines

Forced air flotation machines require a low pressure air blower for air supply. A blower is selected to provide a volumetric range of airflow at a given pressure. The required air volume is determined from the cell froth surface area multiplied by the appropriate superficial gas velocity (or range of velocities) for the mineral type being targeted in the flotation plant. The required air pressure is calculated based on the height of the flotation tank(s), the slurry specific gravity, and any air line losses between the blower manifold and discharge at the flotation cell rotor.

Traditionally flotation plant design blower selection and control has been based on using an oversized positive displacement blower, or an industrial fan, with any excess air discharged to atmosphere. While easy to select and design, this type of circuit contains inefficiencies especially when it comes to energy consumption. Larger flotation circuits today generally use multistage centrifugal blowers to ensure efficient supply of air by only generating the required air volume that the flotation circuit demands. Multiple units are generally selected and operated in a duty/duty/standby configuration to ensure they can handle a range of airflow rates. An outline of a philosophy for selecting flotation blowers for modern flotation plants is given by Ayoub (2012). It is recommended that the metallurgist works closely with blower suppliers when selecting blowers for the project to ensure that blowers are selected to cover the range of operating conditions that the plant is expected to encounter over its life.

Belt drive versus Gearbox

The method of power transmission to the rotor is an important factor to consider when selecting flotation cells. Most small flotation cells utilize a basic belt drive system, where the rotational speed of the motor is reduced using the ratio of drive to driven pulleys to achieve the correct speed for the rotor. This method of power transmission can be used for larger cells too however there is a practical design limitation due to the size of the driven pulley required for these tanks. In addition as these systems get larger the size (and the cost) of the drive rack to mount the pulleys and motor increases. Care should be taken when installing the pulleys and belts to ensure correct alignment and tensioning, as incorrect installation and maintenance practices can lead to energy wastage and increased wear.

Using a gearbox to achieve the required rotor speed for flotation cells is becoming increasingly popular on larger flotation cells. Not only are these units being designed specifically for flotation duties but care has been taken to ensure easy removal for maintenance in operating flotation plants. Flotation tanks also generally require less steel work to mount a gearbox drive on the bridge (compared to a belt drive) and can typically use a lower specification motor (4-pole) as opposed to their belt driven counterparts that require higher motor specifications (increasing number of poles with drive size and reinforced bearings).

Slurry Level Control

The choice of level control valve type is an important factor in flotation cell selection as accurate and responsive slurry level control affects the quantity and quality of product that is recovered from each cell, hence has a major affect on metallurgical performance. Two main types of valves exist for flotation cell slurry level control: dart valves and pinch valves.

Dart valves are hung from the top of the flotation cell by a shaft connected to a dedicated frame. Level control is effected by an actuator and positioner mounted to a dart shaft running down to a polyurethane plug, which moves up and down into the dart seat. Dart valves can be installed as a single dart or in pairs (as dual dart valves). The advantage of dual dart valves is that this allows accurate level control over a wider range of slurry flow rates, as one valve can be closed and the slurry level controlled using only the second valve if flow rates are significantly reduced. This is very useful where a circuit may have a partial plant shutdown but remain operating at reduced throughput, or in a flotation circuit where recirculating loads can build up, which can lead to significant variations in slurry flow rates. When selecting dart valves for slurry level control it is recommended to opt for dual dart valves, as the extra cost is minimal over a singular dart valve while providing significant additional operational flexibility.

Pinch valves may also be used for slurry level control and these are installed in the discharge side of a flotation tank, between two welded spool pieces. Pinch valves control the slurry level in the tank directly by squeezing a flexible sleeve and restricting the flow of slurry through the valve. Pinch valve sleeves can therefore undergo significant wear and hence flexible but wear resistant materials have been developed. Although there is no restriction to operating dual pinch valves, normally only a single pinch valve is installed per flotation tank for level control. This therefore limits the dynamic range of slurry flow rates that the valve can successfully control, and hence pinch valves are ideal where there is a low variation in volumetric flow.

Instrumentation and Control

In forced air flotation machines with the ability to control the air addition rate, it is important to ensure that high quality instrumentation and valves are used. First and foremost is the air mass flow meter, used to measure the amount of air being introduced to the flotation cell. These instruments typically measure the mass flow of a gas passing by measuring the difference in temperature between a reference (heated) electrode and a measuring electrode. These instruments need to be robust and able to withstand prolonged heat and weather exposure, with several commercial models having established themselves as reliable manufacturers for use in mineral processing applications.

The air control valve and positioner work in conjunction with the air mass flow meter to control the air flow rate to a given flotation cell. A range of valve types are possible to use for controlling the air flow rate, and key factors to consider in valve selection are the pressure loss across the valve, the valve cost, and the valve dynamic operating range. Normally a polished disc, butterfly valve with a positioner is used to control the air flow rate. Whilst having a somewhat limited operating range, these valves provide good control and have the advantage of being relatively low cost and having a low pressure drop across the valve.

Froth cameras are a relatively recent addition to the standard set of instruments that may accompany a flotation cell. The camera is mounted on top of the cell and directed at the froth to provide continuous monitoring of the froth velocity, and typically real time froth video to the control room. As part of a digital control system (DCS) this can be used to allow continuous monitoring of the froth velocity from all flotation cells in a concentrator. This can be used in conjunction with on-stream analysis to maximize production (Brown et al. 2001, Carr et al. 2009). It is also possible to utilize more advanced features of froth camera technology to monitor froth color, bubble size, bubble breakage, and other froth properties as part of a more advanced control system.

KEY SELECTION CRITERIA

Residence Time and Flotation Circuit Volume

The residence time of a flotation bank is the amount of time required in the flotation bank to achieve the desired mineral recovery. Typically the design residence time is based on a laboratory or pilot plant residence time, multiplied by a scale up factor (typically from 1.5 – 3.0), which is generally applied based on machine type, ore type, and experience. Various authors (Dengar 1986, Nelson et al. 2000, Wood 2000, Dunne et al. 2010a) have discussed the topic of residence time scale-up, and for further reading Barbery et al. (1986) gives an excellent commentary on this topic. Despite advances in flotation modeling and commercial simulators, to the authors' knowledge none of these have successfully eliminated this scale-up factor from the design of green-field flotation circuits.

The volume required for the flotation bank is typically calculated from the feed slurry flow rate and the required residence time (Nelson et al. 2000, and Wood 2000). As concentrate is removed from each tank in the bank, using the bank feed flow will likely give an over estimation of the required volume. For a typical sulphide rougher or scavenger flotation bank with a small mass recovery to concentrate, the difference is negligible. However, for a cleaning circuit where mass recovery can reach 40-60% of the feed, it is better to use the average flow (feed flow less tails flow) to give a more accurate estimate of the required flotation bank volume, and avoid over sizing the circuit.

When determining the number and size of flotation machines required for a certain flotation bank volume, it is important to take into account the volume taken up by the flotation mechanism, froth depth, and air-holdup in the slurry. Some flotation machine manufacturers quote live tank volumes inclusive of the mechanism and other components located in the slurry, whilst others quote tank volumes with these already removed. It is best to contact the manufacturer to confirm the flotation tank active volume prior to selection.

The air-hold up in a tank is the amount of total tank volume that the bubbles rising through the slurry occupy. Wood (2000) suggests that 15% air hold-up be used for conventional cells and 10% for cylindrical cells. Work from Power et al. (2000) on Australian flotation cells showed air hold up varying from 3-32%, with an average at 14%. This compares well with the figures from Deglon et al. (2000) for flotation cells in the South African platinum industry. Looking at the data from Power et al. (2000) it can be seen that the average rougher cells air-holdup is close to 10% and average cleaner cell closer to 20%.

Number and Size of Cells

Once the volume for a flotation bank has been determined, the number of tanks required then needs to be determined. As a general rule, the most cost effective option from a capital expenditure point of view is to use the fewest number of tank possible, each which the largest volume possible. However there are two important factors that require consideration; they are the number of parallel lines desired, and secondly, the number of cells required to minimize any slurry bypass.

Having parallel banks of flotation tanks can be preferred for maintenance flexibility. It gives the operator the ability to continue to operate a flotation bank and produce product, while another bank is offline for maintenance, and thus can improve overall plant availability. The ability to install and operate parallel banks of flotation tanks will be largely dictated by the scale of the project, capital costs, and available footprint. In high throughput processing plants utilizing the maximum size of available flotation equipment may mean multiple parallel banks of these cells are required.

Early authors such as Arbiter and Weiss (1970) recommended that 12-14 cells are installed per bank to minimize any slurry bypass. Degner (1983) recommended that the minimum number of cells required in an open circuit sulphide flotation application was eight. Bourke (2005) suggests that as a rule when selecting flotation cells, a minimum of five tanks should be used in a sulphide rougher-scavenger flotation bank. This reduction in number can be attributed to improved mixing and gas dispersion in modern tanks. Though this five cell minimum (Bourke 2005) is related to a rougher-scavenger bank it is a good general design rule for any bank in open circuit configuration (i.e. first cleaners). Conversely flotation banks with their tailings returning to elsewhere in the flotation circuit (i.e. closed circuit) may operate with fewer cells as any short circuiting material has a chance to be recovered once again in another part of the flotation circuit.

It is also important to consider the type of tank when considering the minimum number of cells required. Wood (2000) states that fewer modern cylindrical tanks would be required compared to conventional 'hog-trough' mechanical cells, due to modern cylindrical tanks having better hydrodynamics and a more controlled flow between cells ('hog-trough' style with no bulk heads, vs. modern valves and ducting) thus minimizing bypass. To ensure that bypass is minimized when the smaller number of cells are being used, Woods (2000) also notes that the residence time in each cell in the bank should be a minimum of three minutes.

Froth Carry Rate

Due to the inherent nature of froth being made up of water, air and solids and being quite brittle, there is a limit to how much weight of product the froth can transport successfully. Therefore it is important to consider the Froth Carry Rate (FCR) when considering the design of a flotation cell. The FCR is a measure of the froth's ability to support and transport solids from the pulp phase to the lip of the flotation cell. It is a function of solid particle size and specific gravity, and these relationships are discussed further in Espinosa-Gomez et al. (1998).

Mathematically the FCR is the solid product tonnage of a cell (or bank), divided by the froth surface area (FSA) of a cell (or bank), and is expressed in units of $t/m^2.h$.

The FCR has an optimum range where froth phase stability and utilization for transport is maximized. If the FCR is too high the froth may be too heavy (supporting too much weight), lack mobility, and in extreme cases the froth can collapse on itself. This results in reduced froth transport efficiency to the collection launder, and hence reduced stage recovery. Conversely if the FCR is low this usually means that there are insufficient mineral particles in the froth to form and maintain a stable froth this will result in poor froth mobility or even the complete lack of froth. This is because the presence of fine particles in the froth phase plays an important role in the overall froth stability (Moudgil and Gupta 1989). With a low FCR the froth will have low froth stability, appear brittle, and have low overall froth transport efficiency and lower than optimal recovery. Typical FCR ranges for flotation machines can be seen in Table 1, but it should be noted these can vary outside these typical ranges with mineral type and particle size.

Table 1: Typical values for froth carry rate in sulphide flotation applications

Bank	Rougher	Scavenger	Cleaner
Froth Carry Rate ($t/m^2.h$)	0.8 - 1.5	0.3 - 0.8	1.0 - 2.0

As part of flotation cell selection and design, the expected FCR should be calculated from available process design data, and from this the FSA be adjusted to maintain the FCR in the optimal range. The FSA for a given flotation tank size is normally adjusted based on changing the crowding and/or launder configuration on the tank. In a cylindrical flotation tank several launder configurations exist, which provides higher or lower degrees of crowding (and FSA). This can be clearly seen in Figure 3, which shows the FSA cross sectional area for two different collection launder designs.

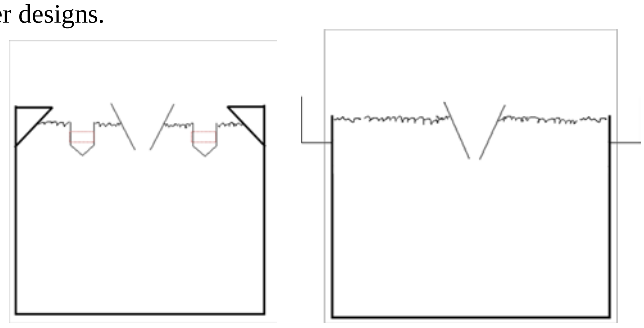

Fig 3: Different cross sectional FSA for two different cell launder configurations, Donut Launder (Left) and External Launder (Right).

Additionally froth crowders in the tank itself can be adjusted as required for a given launder configuration. For example, the central froth crowder (booster cone) diameter, and the exterior tank wall crowding angle can be adjusted to increase or decrease the available FSA. Conventional cells are a little more limited with crowding options however froth crowders are available to reduce the FSA.

In extreme cases where the FCR is too high and there is no design capacity left to reduce crowding (increase FSA), it may become the driving force behind the number of flotation tanks in a flotation circuit. Due to equipment manufacturers having fixed tank aspect ratios, additional tanks may need to be added to the bank to ensure sufficient froth surface area. This is best discussed and addressed in conjunction with technical personnel from the equipment supplier.

Another consideration of launder design and froth crowding is froth transport distance. This is the average distance that a particle travels in the froth phase before it passes over the launder lip to the collection launder. As the transport distance increases, the probability of particle drop back also increases (especially for coarse and poorly liberated particles), and increased particle drop back has a negative effect on flotation cell recovery. Hence there is a desire to keep the transport distance as low as possible whilst maintaining an adequate FSA and FCR. As can be seen in Figure 3, the froth surface area and launder design significantly affects the transport distance, and this should be taken into consideration when conducting flotation tank design selections.

Lip Loading

Similarly to FCR, lip loading relates to the transport of froth from the cell to the collection launder. Mathematically it is an expression of mass transfer of concentrate from the froth phase of the cell to the launder, and is calculated by dividing the solids product tonnage from the cell (or bank), by the lip length of the cell (or bank) and is expressed as t/m.h.

It is recommended that lip loading should not exceed 1.5 t/m.h for typical sulphide applications (Bourke, 2005). Exceeding this value can limit froth transport from the cell and result in reduced froth transport efficiency and hence reduced stage recovery. In most cases the launder configuration on a tank can be adjusted to increase launder lip length and get the lip loading into the required range. A specific type of launder to achieve this, is known as a radial launder (see Figure 4). In the author's experience low lip loadings do not cause a problem with cell operation where as low FCR do.

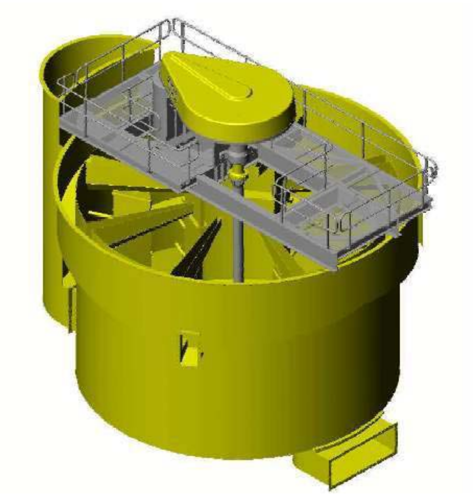

Fig 4: Example flotation tank cell with radial launders.

Energy Consumption

Electrical energy is normally the largest operational cost associated with mechanical flotation equipment. It is thus imperative that during flotation circuit selection, the energy efficiency of the proposed equipment is considered. For a forced air flotation machine the energy consumed should also include the power required to operate the air blower. This will ensure that a comparison made to self aspirating flotation machines is on the same basis (total power consumed). Even including the power consumed by the air blower, it has been noted in the literature (Nelson et al. 2000) that forced air flotation machines (including blower), typically have lower energy consumption than the equivalent self aspirated machine.

Energy consumption comparisons are typically made on the basis of specific energy (kW/m^3), which is the operational power input divided by the active tank volume for a given pulp density. If using this metric, care should be taken to ensure that the power used is the operational power of the flotation equipment (operating with air), and not just the installed motor power, as these can differ greatly (Murphy 2013). An alternative and preferred metric to measure energy efficiency, is the power consumed per quantity of product produced (i.e. $kW/t_{product}$). This takes into account the actual efficiency of the flotation machine at producing the desired product, and provides a better measure of the energy efficiency.

FLOTATION CIRCUIT LAYOUT CONSIDERATIONS

Tank Configuration

The configuration of tanks in a flotation circuit is an important consideration during equipment selection and circuit design, as this has several implications on the capital cost. First and foremost is the consideration of the number of flotation tanks on the same reduced level (RL) in a flotation bank. As gravity is the driving force for slurry passing through a flotation tank, there are limitations to how many tanks can be installed on the same level whilst still maintaining an acceptable slurry static head. Generally the larger the flotation tank, the less that can be installed on the same level (see Table 2). Note this has been modified from earlier tables that can be found in Bourke (2005) and Lane et al. (2005), where the maximum number of the smaller cells were 5-6. This is due to author observations of level control problems when these cells are in banks longer than four cells, especially in high mass pull applications.

Table 2: Recommended maximum number of flotation tanks on the same level.

Tank Size	TC500 - TC200	TC150 - TC10	OK38 - OK8	OK8 - OK1.5
Number Per Step	1	2	4	4

The number of cells installed on the same level also has implications on the slurry level control. As level control is conducted against the slurry static driving head, when multiple cells are installed only a single level control valve is used (on the final cell in that level) to control the overall level in all the cells on that level. This means capital costs can be reduced by installing multiple cells on the same level rather than one cell per level. It is worth noting that the saving in capital cost does come at the expense of a reduced degree of slurry level control. Additionally, installing multiple flotation tanks on the same level means that the overall height of the flotation support structure is reduced (i.e. flotation circuit installed volume is reduced), thereby reducing capital costs especially if the flotation circuit must be enclosed in a building.

Another factor which affects the overall installed footprint and volume, is the slurry level control valve type and location. Dart valves can be installed either internally or externally to the tank. If installed internally they will occupy a small portion of the active cell volume, however there is no increase in the flotation circuit footprint that occurs if the dart valves are installed externally to the tank (see Figure 5). In the same way, pinch valves usually result in a larger flotation bank footprint as they must be installed externally to the tank.

Fig 5: Example flotation bank with external dart valves (Top) and internal dart valves (Bottom)

Equipment Maintenance

As with any other mechanical equipment, flotation machines require routine maintenance to remain operating at optimal performance. Life time maintenance costs of flotation equipment can be substantial, with one study attributing approximately 10% of the total equipment expenditure over a 25 year life span to maintenance of that equipment (Rinne and Peltola 2007).

One method to keep maintenance costs to a minimum is to keep the number of different flotation equipment types to a minimum. This means that flotation tanks of the same size and using the same components should be selected where possible (i.e. if it does not cause decreased metallurgical performance). Doing this there are more common spare parts for the complete flotation circuit, and therefore it is possible to keep a smaller inventory of spare parts on hand. It should also be possible to negotiate improved spare parts prices with the equipment supplier, due to the site purchasing a higher volume of a smaller number of spare parts (i.e. economies of scale). It is even possible to take this concept one step further by ensuring that flotation equipment selected is common with other flotation circuits in the local area, with which spare parts could be shared.

Some manufacturers advocate installing mixed flotation equipment, for example a flotation bank that has both forced air and self aspirating flotation cells (McNamara 2007). This arrangement may have benefits from a metallurgical point of view, however this should be quantified and compared to the higher maintenance cost that will occur from having different types of flotation equipment in the same flotation bank. Also it is worth noting that maintenance personnel will become more familiar with the equipment if a smaller number of flotation cell types are installed, and hence will require less time to complete maintenance. If there are many different types of flotation cells in a flotation circuit this will mean that the maintenance personnel will take longer to perform maintenance on a given flotation cell type due to unfamiliarity, or indeed skip over some critical maintenance items on one flotation cell type that is not required on another flotation cell type in the same flotation circuit. This is another reason for rationalizing flotation equipment as much as possible during the equipment design and selection phase of a project.

When laying out a flotation plant consideration should be given to how maintenance will be performed in and around the circuit. Provision should be made for safely accessing all areas where frequent tasks need to be performed. Consideration should be given to location and access of crane for lifting flotation cell components for maintenance (Lane et al. 2005). Most manufacturers also have certified lifting and support devices that can be used to perform maintenance on the mechanism quickly and safely.

DATA REQUIRED FOR FLOTATION CELL SELECTION

The trend in industry today is that most flotation cell selection is done by equipment manufacturers. Many manufactures employ flotation specialists who use many of the rules defined above, along with operational experience, to select the option that most suits the client's needs for a specific project. As a general rule the more information provided to the manufacture, the better the equipment selection.

The minimum data required for cell selection is;

- Mineral(s) to be floated
- Required Duty (e.g. rougher, cleaner, recleaner, etc)
- Particle Size (P80)
- Feed tonnage, solids specific gravity and percent solids
- Concentrate tonnage, solids specific gravity and percent solids
- Residence time (actual laboratory or plant design)

Other useful data that helps to get the optimum outcome when selecting flotation cells;

- Plant flow sheet
- Abrasive index (Ai) of ore
- Feed particle size distribution (PSD)
- Reagents used and pulp chemistry conditions
- Flotation test work data (particularly kinetics)
- Site data (location, elevation, seismic conditions, electrical supply, plant air pressure)
- Other site constraints

With the above information the engineer designing the flotation equipment should be able to provide a very good solution for the duty at hand. One final factor that requires discussion is that of design factors. Normally during pre-feasibility and bankable feasibility studies it is commonplace for engineers to add safety factors to data, to provide safety against underestimating the size of the required equipment. In the context of flotation, overestimating can also be detrimental and so if a safety factor (design margin) is included this should be clearly stated to the engineer selecting flotation equipment. A good example of where too much safety margin can be detrimental is if the FSA is overestimated then the FCR may be lower than the optimum range, which can lead to froth stability issues and/or higher operating costs during operation.

CONCLUSION

Flotation equipment selection is an important part in designing a new mineral processing plant to ensure that the performance will meet expectations. Taking into account residence time only is a simplistic strategy for equipment selection. It is critical that other factors be taken into consideration, including;

- Froth carry rate
- Lip loading
- Energy consumption
- Plant layout
- Maintenance considerations

Equipment selection completed taking into account all the recommended factors will not only lead to the optimal selection to meet performance expectations, but often exceed them as well.

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