A BRIEF GUIDE TO FLOTATION TECHNOLOGY

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Abstract: The ability to separate small particles of ore from gangue by froth flotation was first noted at the beginning of the 20th century. It has since grown into an essential tool in the Mineral Processing profession. There has been development of many different types of flotation machine to suit every eventuality.

INTRODUCTION

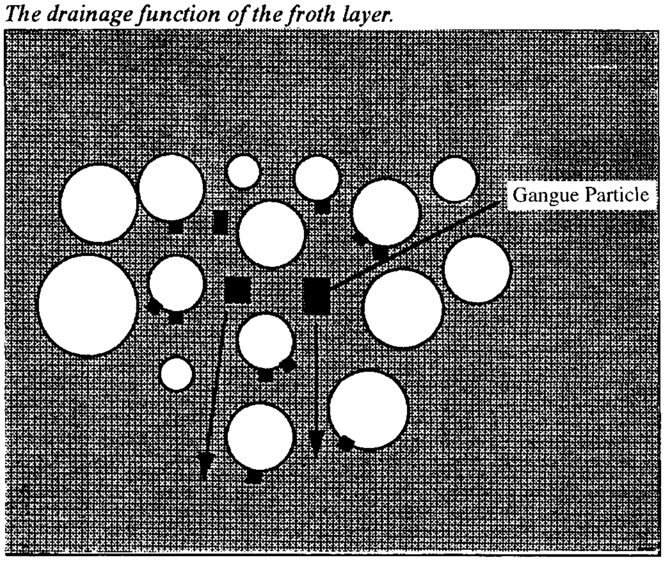
Flotation is arguably the most important technique of mineral processing. Originally patented in 1906 (Wills 1988), it is applicable to almost any type of mineral from precious metals such as gold, base metals such as lead to industrial minerals such as fluorspar, the main product of Laporte Minerals' Cavendish Mill near Stoney Middleton, Derbyshire. A brief description of the process itself will be given before moving on to the technology used to implement it.

FLOTATION TECHNIQUE

The basic idea is that a separation of valuable mineral from gangue is made on the basis of the differing surface properties of the two when contained as a finely ground suspension of the minerals in water - known as *pulp*. This may be a natural difference between the minerals or, as is normal, a difference created by the use of flotation reagents. Two types of flotation exist: *direct flotation* and *reverse flotation*, depending on whether it is the valuable mineral or the gangue that is being floated. For the purpose of this talk "flotation" will refer to direct flotation where it is the valued mineral that is floated off.

For a mineral particle to float its surface must be *hydrophobic*. This causes it to stick preferentially to a bubble of gas, usually air, rather than stay in the pulp. The surface of the mineral has to be attracted strongly enough to the bubble to overcome the force of gravity trying to pull it off and this is not normally the case for minerals in their natural state. To this end a reagent known as a *collector* is normally added to the pulp to raise the level of attraction between the bubble and the particle by adsorbing on to the mineral surface. For the particle to be floated successfully it is not enough that it merely sticks to a bubble, it must stay in that state stably for the build up of a froth layer. This is aided by the use of a further reagent known as a *frother*. With these two reagents a good mineral laden froth can be achieved, However, to try and effect a good separation further reagents are generally added known as *regulators*. These can be *activators*, *depressants* or *pH modifiers*. To use fluorspar flotation as an example one collector, Oleic Acid is used (which acts as a frother) as well as three depressants and one pH modifier. Soda Ash is used for pH control and there is a fully automatic bulk reagent and closed circuit system due to the sensitivity of the circuit. The other reagents are fed from troughs through rotating disc and cup feeders and then by gravity into the conditioning tanks (Bramley, 1991). Dextrine and quebracho/mimosa are used as barytes/silica and carbonate depressants respectively and occasionally sodium metasilicate is used as a slimes dispersant/silica depressant.

The drainage function of the froth layer.



The necessity for a stable froth layer is due to the requirement for froth drainage i.e. the drainage of entrained gangue particles out of the layer of valued mineral and bubbles. In general the higher the froth depth the better the separation of the value from waste and therefore the better the grade.

As is now apparent the technique of froth flotation can be a fairly complicated one and the answers to process obstacles are rarely straight forward. What must always be kept in mind is the trade-off between grade and recovery that exists. It depends on which of the two is more important as to which you place higher priority. If a further process step is carried out after flotation such as smelting then recovery would be the highest priority, or if, as is the case for many operations, the flotation is the only separation step then obviously grade is more important.

FLOTATION TECHNOLOGY

Prior to flotation, gravity techniques were much more widely used in processes such as *jigging* and *buddling*. Jigging is still used today although in a more sophisticated way, as would be expected. This technique separates ore from the gangue by means of shaking

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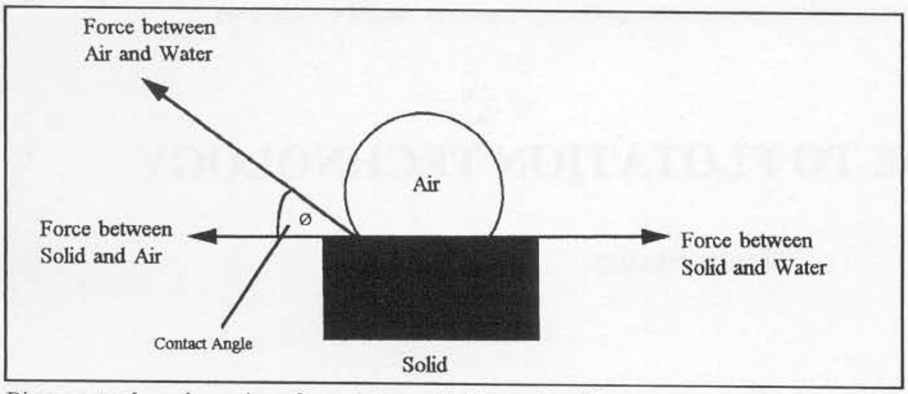


Diagram to show the various forces between bubble and solid.

complete fiction but when demonstrated it becomes wholly believable. It is certain, however, that the chemical flotation we know today came about as a development of what was known as Oil Flotation. Now obsolete, oil flotation was used in the period 1860 to 1920 (American Cyanamid Co. 1955), although the first commercial success was about 1896 at the Glasdir Mill in North Wales by William Elmore (Williams 1980). It was realised that the wettability of sulphide and some oxide ore was altered by agitation with large quantities of fatty and oily materials, the mineral would

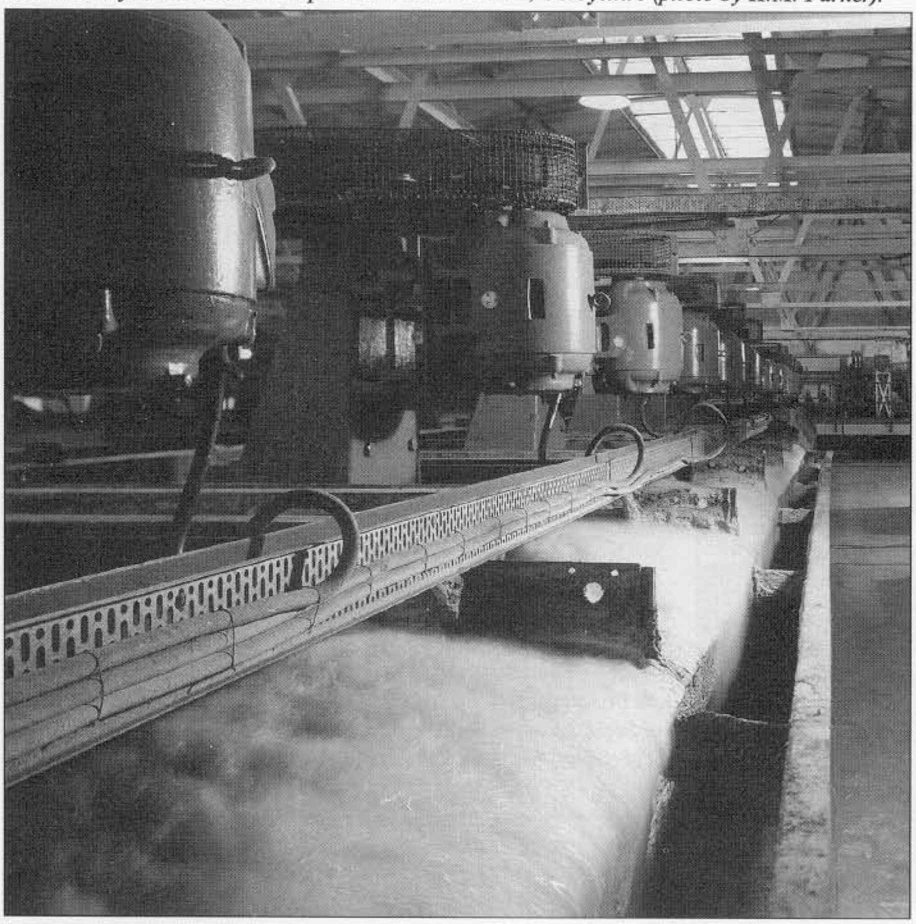
a mixture of the two in a water medium and allowing the differential settling rates to cause the heavy mineral to sink to the bottom first and the lighter to form a layer on top that can be scraped off. Buddling again exploits the difference in specific gravity but is used on the smaller size fraction that was washed out of the jig. The finer ore was introduced to the buddling machine gradually by means of someone effectively raking it into gently flowing stream of water slightly against and across the flow (Stokes 1980). The water disperses it and the heavy fraction settles first with the lighter sand fraction washed further away. These were useful techniques for high quality ore where high loss in tails could be afforded, but were not very good for poorer quality ores, particularly those containing a lot of finely differentiated mineral. Here increased crushing and grinding were required for liberation.

According to legend the idea for flotation came about when a lead miner, watching his wife scrub his clothes, saw the dark lead fines coating the foam caused by the soap she used. This may be

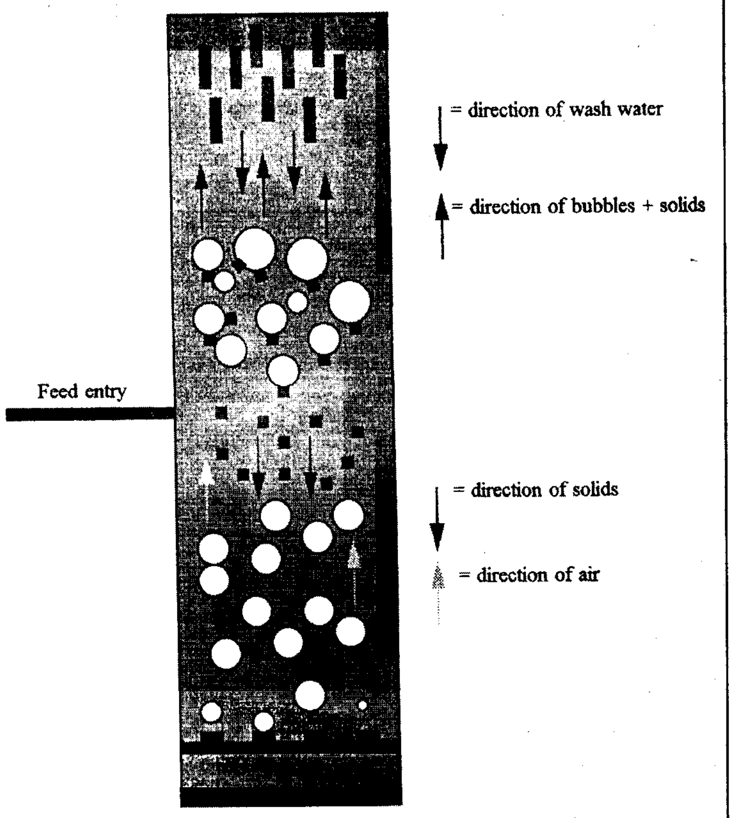
therefore stay in the oil layer and could be separated from the water and gangue. The next development of this was the supplementation of the oils' buoyancy effects with the introduction of gases by all sorts of means including reactions of the ore with acid, electrolysis of the water and, most importantly, by the introduction of air with agitators and submerged pipes. This dropped the oil consumption from 10-20% to about 1% and focused attention on what exactly it was that the oil was doing. From this further development of the chemical reagents added lead to the frothers, collectors and modifiers that we still use today.

Although the original patent for flotation was in 1906 the actual use as a mineral separation technique has only really been since about the 1930s. In this time it could be forgiven for thinking that one machine capable of treating all the different ores requiring flotation would have been developed as there is only one basic principle, that of a particle sticking to a bubble, that is used in all flotation. This, to an extent is probably true: any one machine could certainly float most types of ore but the unique requirements of every process plant make a number of types of machine very popular. Despite being completely different when looked at superficially, most machines have a lot of basic design features in common. All, obviously, have to have a method of introducing the air, a volume in which the pulp and air can mix thoroughly and all must have what is termed a quiescent zone, a volume in which agitation is minimal so that the bubbles can rise above the rest of the pulp.

Mechanical flotation cells at Laporte's Cavendish Mill, Derbyshire (photo by H.M. Parker).



Without doubt the most common type of flotation device is the *mechanical cell* (Young 1982), so-called because of the mechanically driven impeller which has the dual purpose of agitating the pulp and dispersing the air. Probably the best example of this type of cell is the *Denver Sub-Aeration cell*. There are lot of choices of mechanical cell such as *Open Flow* or *Cell to Cell*, *Supercharged* or *Self Aeration* which all have slightly different features but the Denver Sub-A type is a good example due to its simplicity. Each flotation mechanism has its own square cell with the feed pipe conducting the flow of pulp from an adjustable weir in the previous cell. The suction created by the impeller draws air down a hollow stand pipe surrounding the shaft (Wills 1988). The impeller breaks up the air stream into small bubbles, at the same time producing intimate mixing with the pulp which is fed on to the top of the impeller. Baffles are used in the cell to prevent swilling of the pulp and to reduce the agitation in the quiescent zone. The bubbles rise through the quiescent zone to the froth layer where their arrival pushes the froth near the edge over the weirs into the froth launders. Most of the tailings leave the cell through the adjustable weir with the material that is too heavy being allowed through a sand relief port. A supercharged mechanical cell is very similar to a self-aerating cell but instead of the air being sucked in by the impeller it is blown in under pressure. These are generally used in higher throughput circuits in conjunction with the open flow cell design where the weirs are eliminated in favour of allowing the pulp free transition through the cells. The most popular type of mechanical cell is the Wemco Fagergren which foregoes the impeller in favour of a rotor/disperser assembly with the rotor providing much the same action as the impeller apart from breaking up the airstream which is done by the motion of the pulp/air mixture through the disperser.



The two counter-current flows in a column cell.

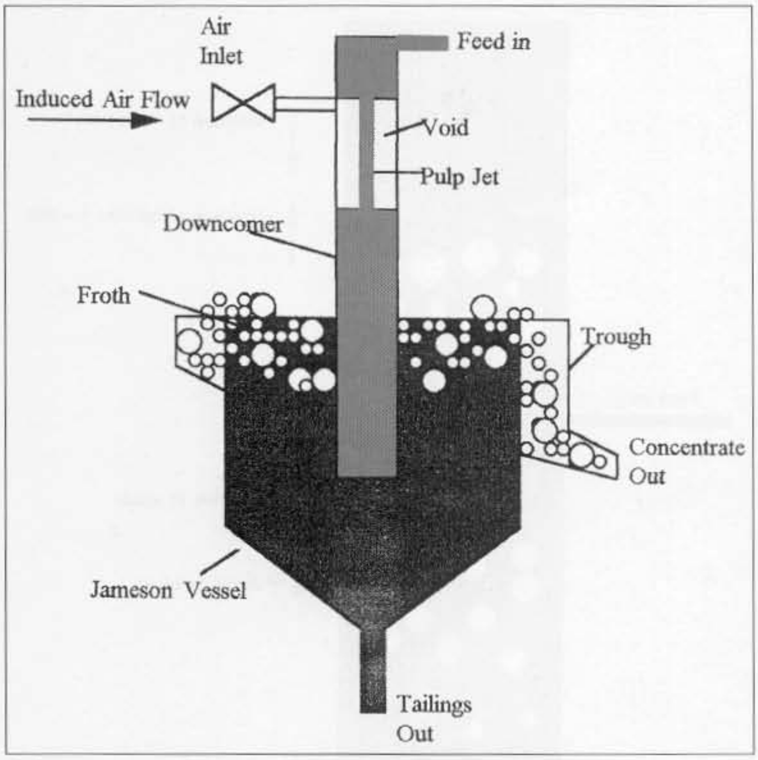
The mechanical cell as stated previously is the most popular type of flotation device, however, a type that is gaining in popularity all the time is the *column cell.* The first column cell was invented by two Canadians, Boutin and Tremblay in 1961 (Young 1982). The design is based around the principle of two *counter-current* flows in two zones of a tall column. The first set of flows is the rising stream of bubbles from a diffuser at the base against the downward flow of ore particles. In the upper zone the bubbles, now with mineral attached, flow upwards with the wash water flowing downward from the top of the cell; this prevents the bulk flow of material to the concentrate. The height of the lower zone allows increased contact time between the bubbles and the mineral particles giving them a better chance of successful collision. The separate upper zone allows better washing of the froth and therefore less material is entrained between the bubbles. The first two commercial units were installed at Mines Gaspé in Canada in 1980 with much success. Since then many more machines have been installed and produced wider acceptance of the column cell as an alternative to the mechanical cell. The advantage of column flotation is the increased froth washing capability, which makes it very good for treating ores that need much finer grinding than normal followed by a lot of desliming and cleaning. The froth washing can be so effective that in the Canadian columns the froth bed is dispensed with, instead allowing the bubbles to fall straight over the discharge weir. As with the mechanical version there are now many different types of column cell each with a slight adaptation to give better performance in one area than the others.

The last main category of flotation device at the moment is the *froth separator*. This is a markedly different machine and was being invented in the former U.S.S.R. at the same time as the column was being invented in Canada. Originally the froth separator took off a lot more quickly than the column although the latter is now probably more popular. In fact they treat materials at completely different ends of the size range with the froth separators treating much coarser particles effectively. The feed is introduced on top of the cell descending over baffles before flowing over the froth bed maintained by horizontal aerators. The resultant tails continue downwards into a cone and are discharged at the bottom by gravity. The usual type of froth drainage would take too long in this type of cell and therefore fine gangue particles must be removed prior to the separator. Typical feed size is from 75μm up to 2 mm: for conventional flotation the ideal size is normally between 53μm and 150 μm.

The introduction of feed at the top along horizontal baffles creates extremely good bubble/particle contact. It also has the effect of enabling the particles to stick to more than one bubble which is how it can float very coarse material up to ten times the size of the mechanical machines (Young 1982). Obviously the benefits of this are that the grinding prior to the flotation circuit can be reduced, resulting in lower costs; also the power consumption per tonne is reduced as the residence time required for good recovery is much less: in fact the relationship between time and recovery is the reverse of other flotation machines with recovery falling and grade increasing as retention time increases.

That is main present day technology covered. Although completely different machines to those mentioned do exist, they are at present a very small minority. A couple of new machines are starting to take a significant share of the market although, most again are really variations on a theme.

The *Jameson Cell* is definitely in a class of its own. The first commercial installation for industrial minerals was the 6th September 1994 (Hall and Harrison 1995) which gives an impression of how new the technology is compared to the previous examples. Instead of a very tall column with air being introduced at the bottom, the Jameson Cell introduces the air with the feed by causing a vacuum in the top of what is known as the *downcomer.* The downcomer is what makes the Jameson Cell so unique. It is a very simple static device with a nozzle joined to an outer pipe. Feed is pumped through the nozzle and forms a crude jet shooting straight down into the cell. Once full the cell is set up so that a liquid seal is created at the bottom of the downcomer and this then fills with pulp. Once air is allowed in the rate at which it is set regulates the height of the pulp in the downcomer, because



Schematic diagram showing the main features of the Jameson Cell

the jet carries so much force that high shear and mixing conditions are caused as it hits the pulp surface. This causes an enormous amount of fine bubbles which are forced to travel downwards for about 8-10 seconds into the main vessel. Once there they are free to travel up to the froth layer where they overflow the discharge weir. The total residence time for the slurry is only about 2 or 3 minutes and therefore throughput is high. This mode of operation has many advantages over conventional cells with the main one being energy savings as a result of less cells being needed and no impeller to run. It is also very compact compared to columns and has no moving parts to breakdown.

The "*Turbo*" *Column* is, as the name implies, a variation of the conventional column cell and has a downcomer which is similar to, although a lot cruder, than the Jameson Cell. In addition to drawing air through the downcomer it has a sparger at the bottom which releases bubbles into the column thereby giving it the "Turbo" effect. The advantage of this is primarily the increased particle/bubble interaction but the way the column is set up also has great benefit: it works with a feed sump to which the tails are recirculated with two helpful results. The first is that a portion of the tails are recycled so recovery is very good, the second is that the presence of the sump allows a constant level in the column even when there is a problem that causes the feed to stop. This means the time required to get back to ideal operating conditions is much less, resulting in much reduced quantities (less than 30%) of off-specification material during start-up periods and the occasions when there are problems with the feed supply.

Looking to the future very briefly, one area of flotation research is ultra-sonics. Flotation is dependent on the surface of the mineral particles. It is extremely beneficial if the surface can be free from attached fine particles of gangue. Exposure to ultrasonic radiation can have the effect of shaking the rogue particle from the surface thus creating a clean mineral particle.

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Cavendish Mill. Bucket elevator on left. The mill was visited by members of the 1997 NAMHO Conference (photo by H.M. Parker.