

Froth Flotation

- Most common method for separating sulfide minerals from each other and from waste minerals or gangue
- Also used in potash, phosphates
- A stream of air bubbles is passed through the pulp. Being hydrophobic, the particles attach to the bubbles which, of course, are filled with air.
- The bubbles float to the surface and collect in a froth layer that either flows over the top

Chemical additives:

- Frother: a long chain alkyl alcohol, is added to stabilize the froth layer.
- Collector: organic chemical (eg. Xanthates), selectively adsorbs onto the surface of the mineral of interest and renders it hydrophobic (afraid of water) – non-polar head
- Modifier: adjust pH of water
- Activator: cause a mineral to float with a collector when it would otherwise not float.
- Depressant: prevent a mineral from floating. Example: Starch, guar depress flotation of clays in potash

Water – mineral surface chemistry:

Water is a polar molecule. Hydrogen atoms have slightly positive charge, oxygen slightly negative charge.

Thus, pH has a important effect on flotation performance

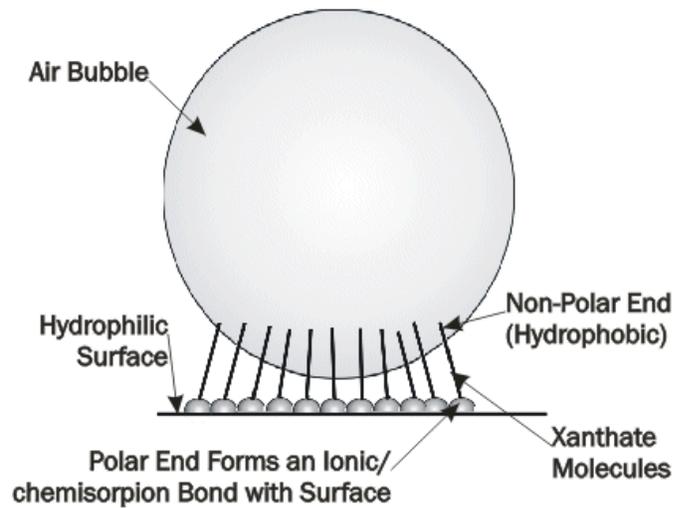
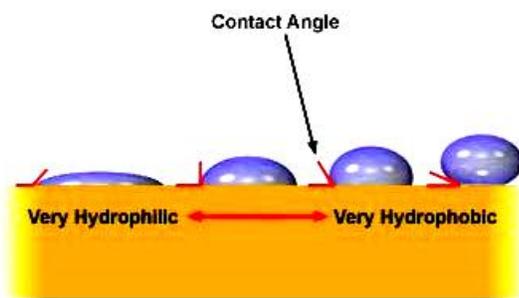
Particles may have an electrical charge on their surface when placed in water.

Sign and magnitude of the charge depends on the atoms on the particle surface and the ions in solution.

Surface will tend to dominate the flotation properties of the mineral

Sulphide minerals can react with oxygen (oxidize) in water used during mining and concentrating processes.

These reactions can change the surface charge usually rendering it hydrophilic, thus non-floating.



Flotation

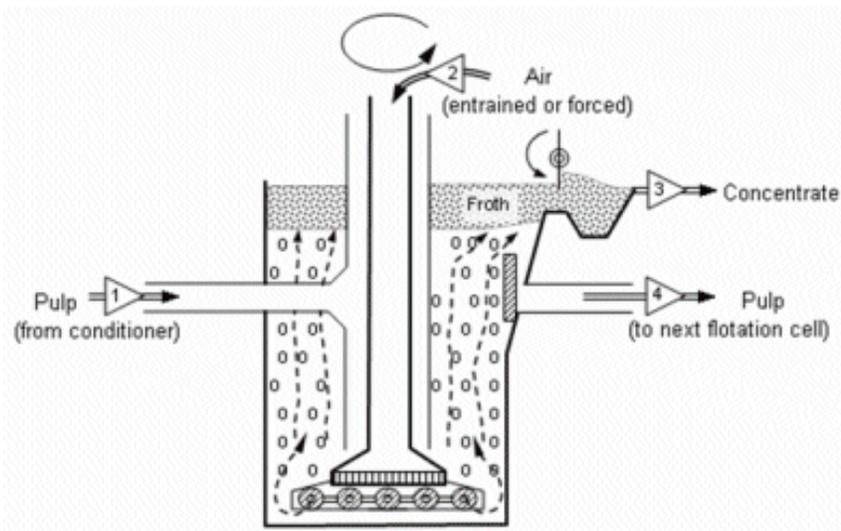
Flotation cell froth, carrying wet concentrate

Color of froth reflects the mineral particles being recovered. High grade material has a distinct color.

More locked particles and gangue will change the color.

If froth is completely barren, it will be clear to white and milky.

Flotation cell flow

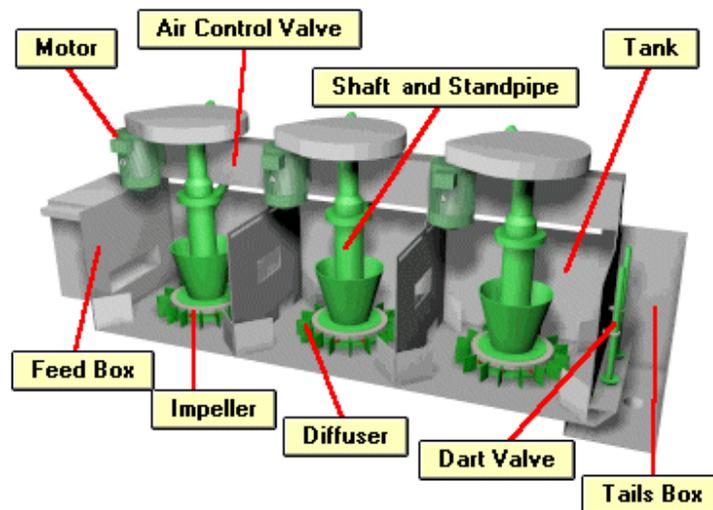


Flotation Process control parameters:

- Feed grade - increase in will result in a higher grade final concentrate at approximately the same recovery (mass balance)
- Feed size distribution - finer will result in higher recovery and grade in the final concentrate (liberation)

- Feed % solids - increase will result in a lower grade and higher recovery to the final concentrate (entrainment)
- Feed tonnage - increase in will result in lower recovery and higher grade in the final concentrate (shorter residence time)
- Air addition rate - increase will raise recovery and lower the grade of the final concentrate (entrainment)
- Froth depth - lowering will increase recovery and lower the grade of the final concentrate (entrainment)

Mechanical flotation cell parts



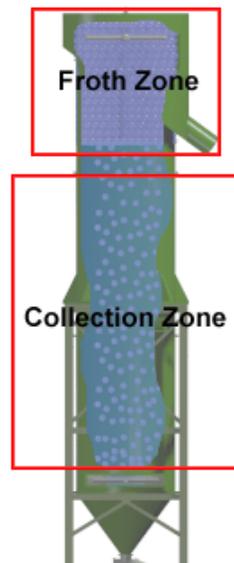
Column flotation cells:

- Do not use mechanical agitation (impellers). Instead, mixing is achieved by the turbulence provided by rising bubbles.
- Mostly used to produce final grade concentrates because they are capable of

great selectivity.

- **Other features:**

- **Tall shape – froth much deeper**
- **bubble generation system - spargers**
- **use of wash water - high degree of cleaning, entrainment virtually eliminated.**



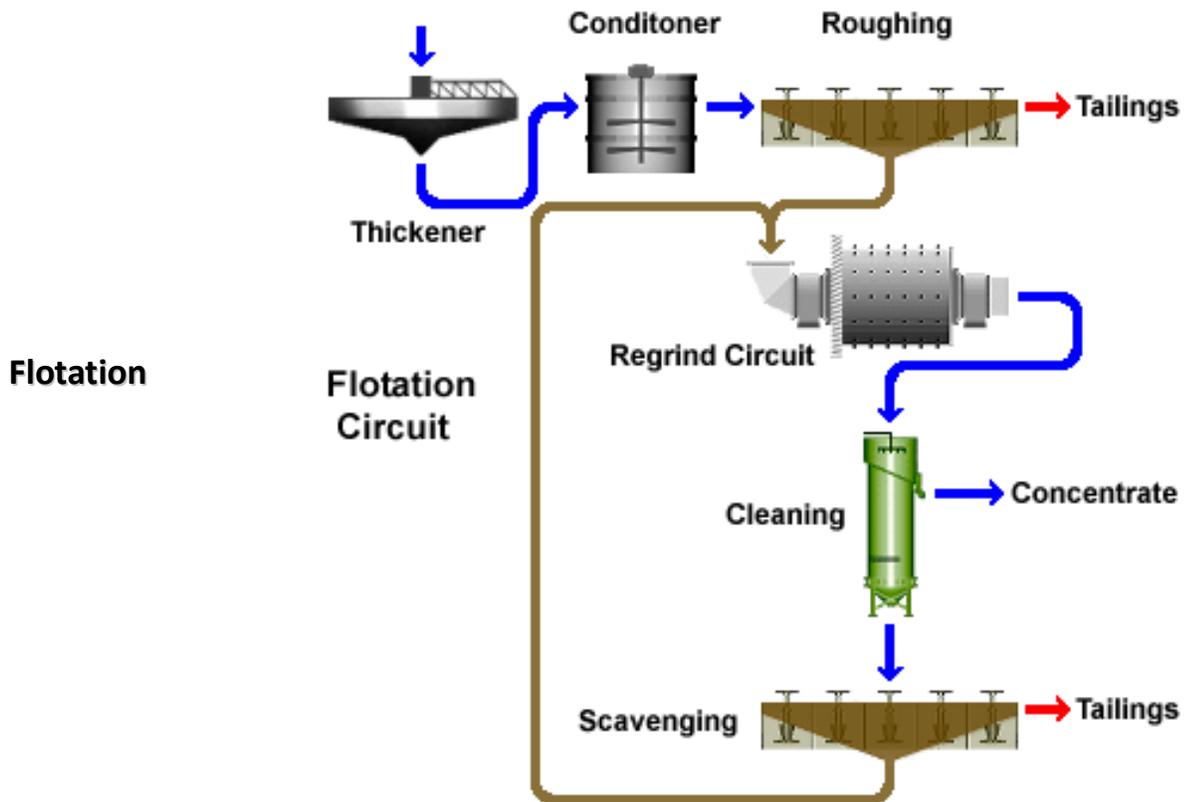
Flotation circuit

Flotation process is broadly divided into rougher, cleaner and scavenger stages, each using many (bank of) flotation cells :

Concentrate from the rougher stage are further concentrated in the cleaner stage.

Tailings from the rougher or cleaner stage are fed to the scavenger stage.

With all the internal recycles, operation of a flotation plant is a somewhat delicate balancing act.



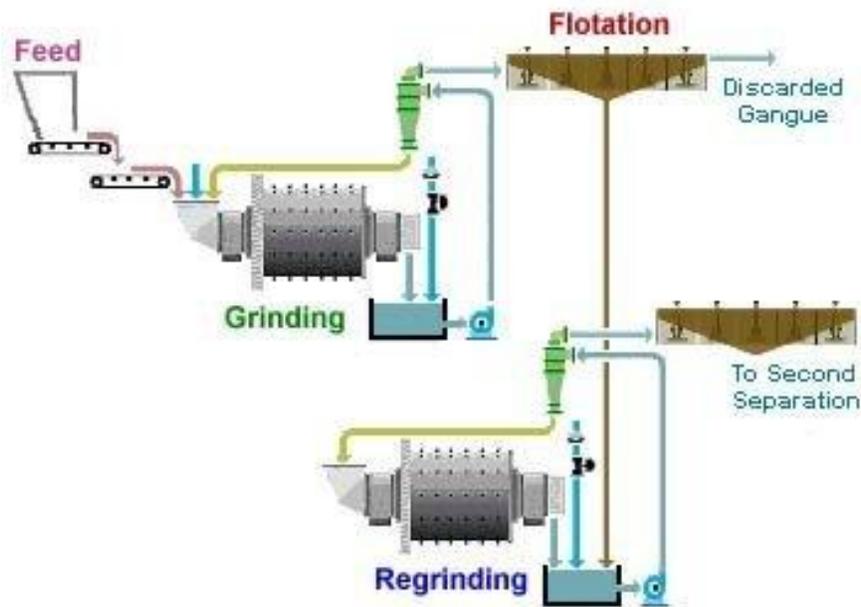
Characteristics:

- Rougher stage:
 - provide sufficient retention time to achieve target recovery.
 - Eliminates a large portion of unwanted material as tailings, thus greatly reducing size of next stages.
- Cleaning stage is to produce the target grade:
 - more than one stage of cleaning. Typically the first cleaners treat rougher concentrate, the second cleaners treat first cleaner concentrate and so on
- Scavenger stage:

- scavenger concentrates usually contain a high proportion of locked middling particles.
- normally sent to regrind.

Regrind:

- First grind fine enough to liberate gangue, but too coarse to liberate valuable minerals.
- Liberated gangue can be discarded in a separation step before regrinding to liberate more of the valuable mineral.
- Avoids grinding liberated gangue unnecessarily, thus saving power.
- Also thought that regrinding "cleans" the particle surface, enhancing the effectiveness of the chemicals used in flotation.



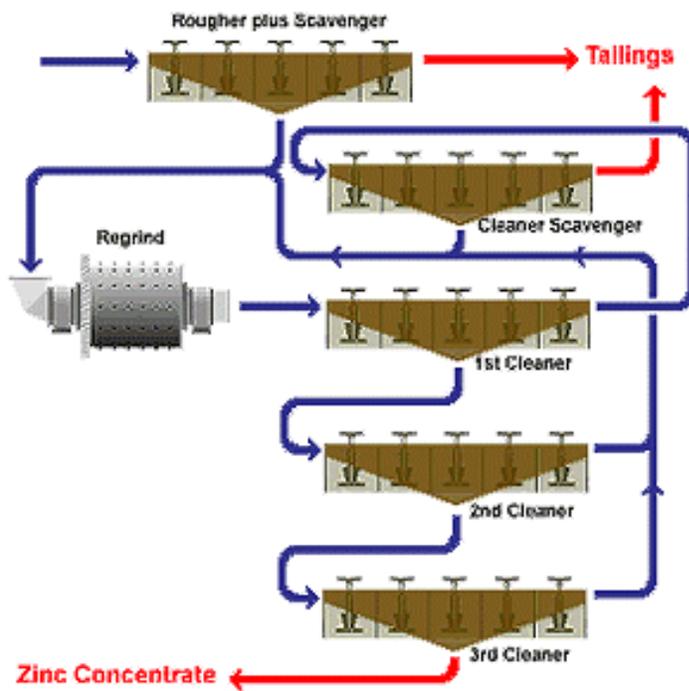
Flotation

- Conditioning - set the correct chemical conditions prior to a flotation stage
- Use a stirred tank
- pH adjustment common conditioning step
- Activator also common, example: copper sulphate for sphalerite flotation
- Aeration – oxidize selected surfaces, example: pyrite

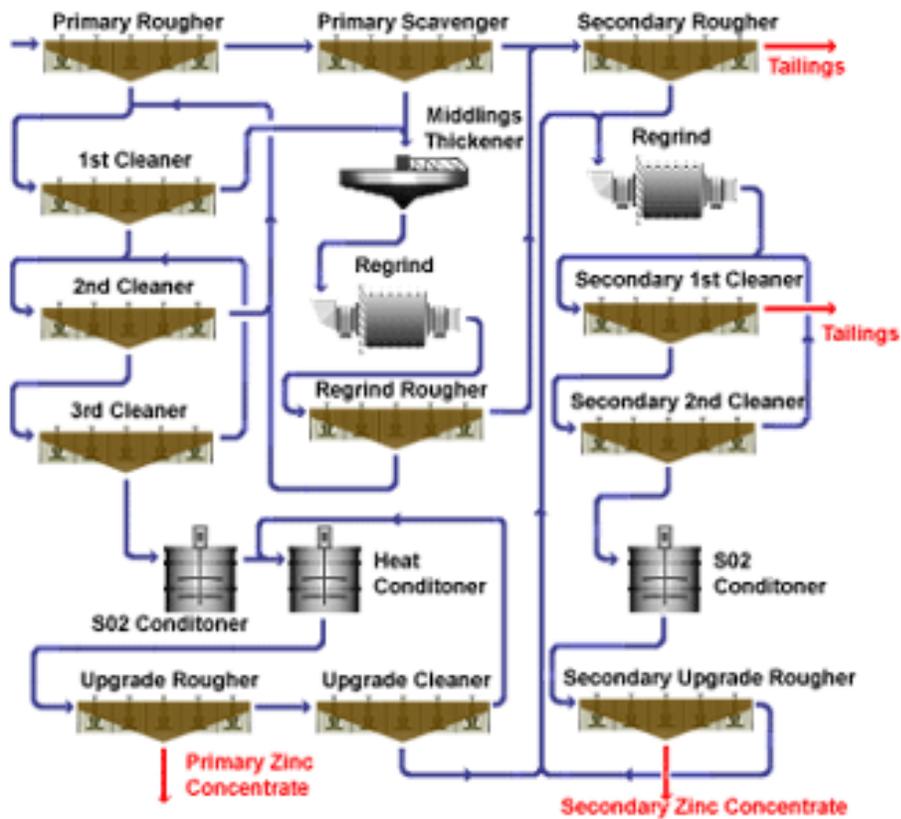
Flotation circuit design philosophy

- Keep it simple:
- Avoid, when possible, unit operation with long time delays, such as thickeners.
- The best circulating load is no circulating load - circulating loads are inherently unstable.
- The more complex the ore, the greater the need for a simple circuit arrangement.
- Deficiencies in liberation or pulp chemistry cannot be corrected by recirculation. In fact the opposite will probably occur.
- In a plant environment, a simple responsive circuit will almost invariably outperform a complicated circuit.
- If a human can't understand, balance, or control a circuit, a computer certainly can't either.
- Flotation

Simplified Zinc Circuit



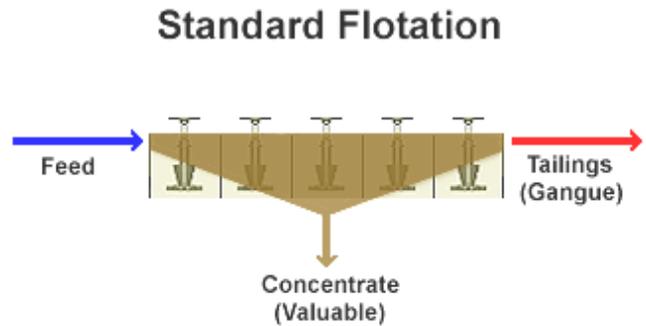
Complicated Zinc Circuit



Flotation Types

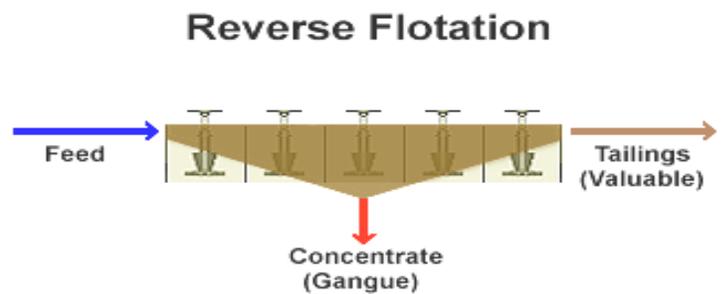
Standard flotation:

- Most common type of circuit
- separates a single valuable mineral from gangue.
- Float the valuable mineral



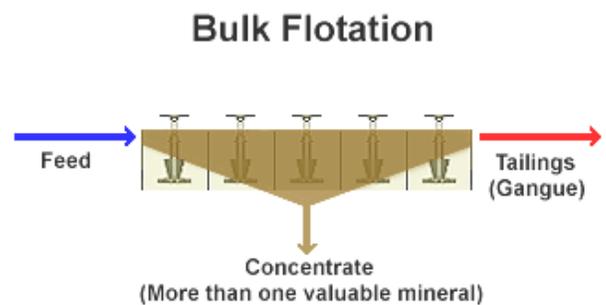
Reverse flotation:

- gangue is floated
- practical if small amount of gangue removed from a large stream.
- example is flotation of pyrite from zinc/lead concentrate



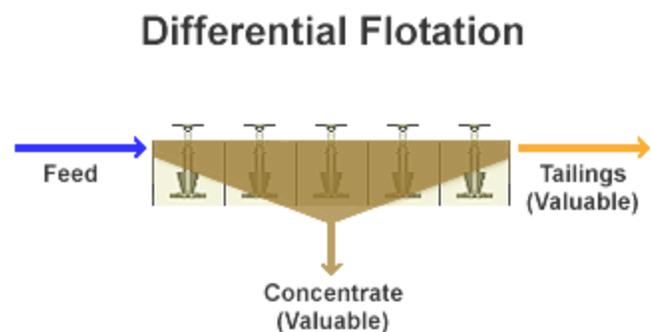
Bulk flotation:

- Two or more values floated together
- one set of conditions
- example is bulk copper / lead flotation



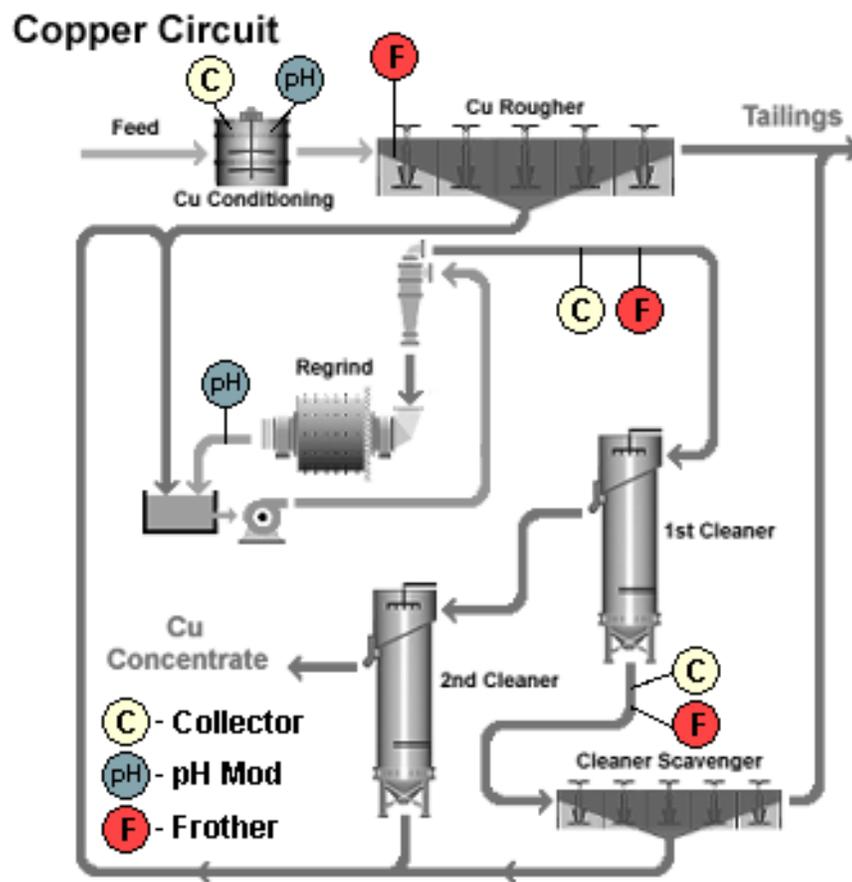
Differential flotation:

- bulk concentrate is separated into two products
- Change chemical conditions
- example is copper / lead concentrate flotation



Flotation Circuit

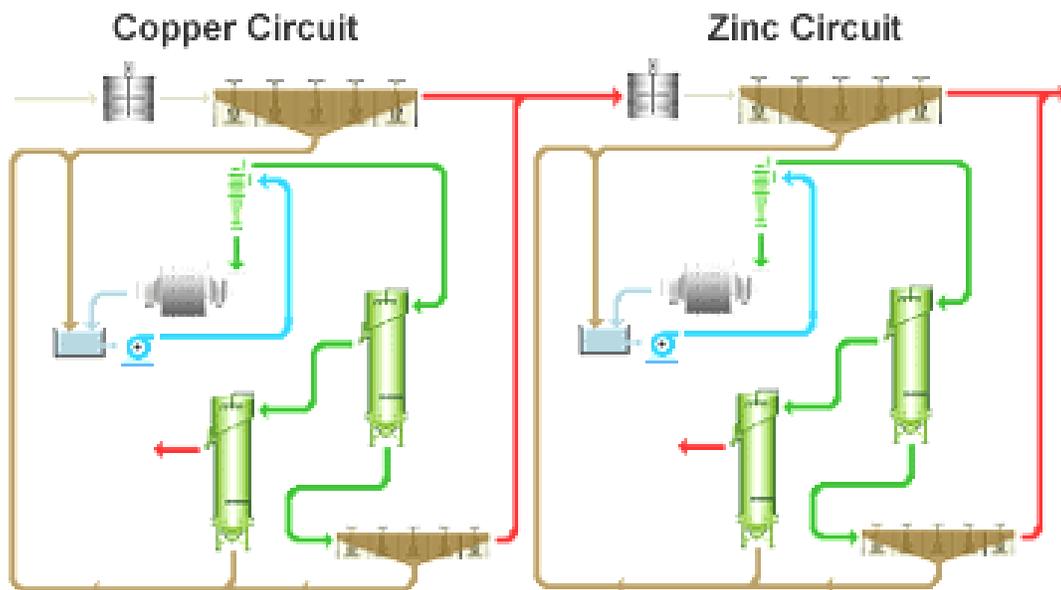
- One basic circuit arrangement has been found to be universally applicable to a wide range of ores and minerals.
- Example:
- Standard rougher-cleaner-scavenger with regrind
- Good for low grade, simple ore such as Cu



Flotation Circuit

- Example:
- Standard rougher-cleaner-scavenger with regrind, times two
- Common for Cu/Zn, Cu/Ni, Pb/Zn

Copper Zinc Circuit



Practice- Some Single-Concentrate Treatments

Small differences in the crystal structure and chemical constitution of minerals of a given species may affect the qualities exploited in flotation.

Plant practice is, therefore, adapted to the specific ore treated, not to the general type of mineral described in mineralogy as galena, bornite or whatever may be the sought value. The requirements for liberation, activation, gangue depression, optimum froth texture, etc. .. follow a general scheme for the separation of a designated metal-sulphide from its associates in the ore.

but specific details are modified for physical, chemical, and economic reasons.

The possible objectives are:

(a) To float one or more valuable minerals simultaneously.

(b) To depress one or more minerals from a bulk float.

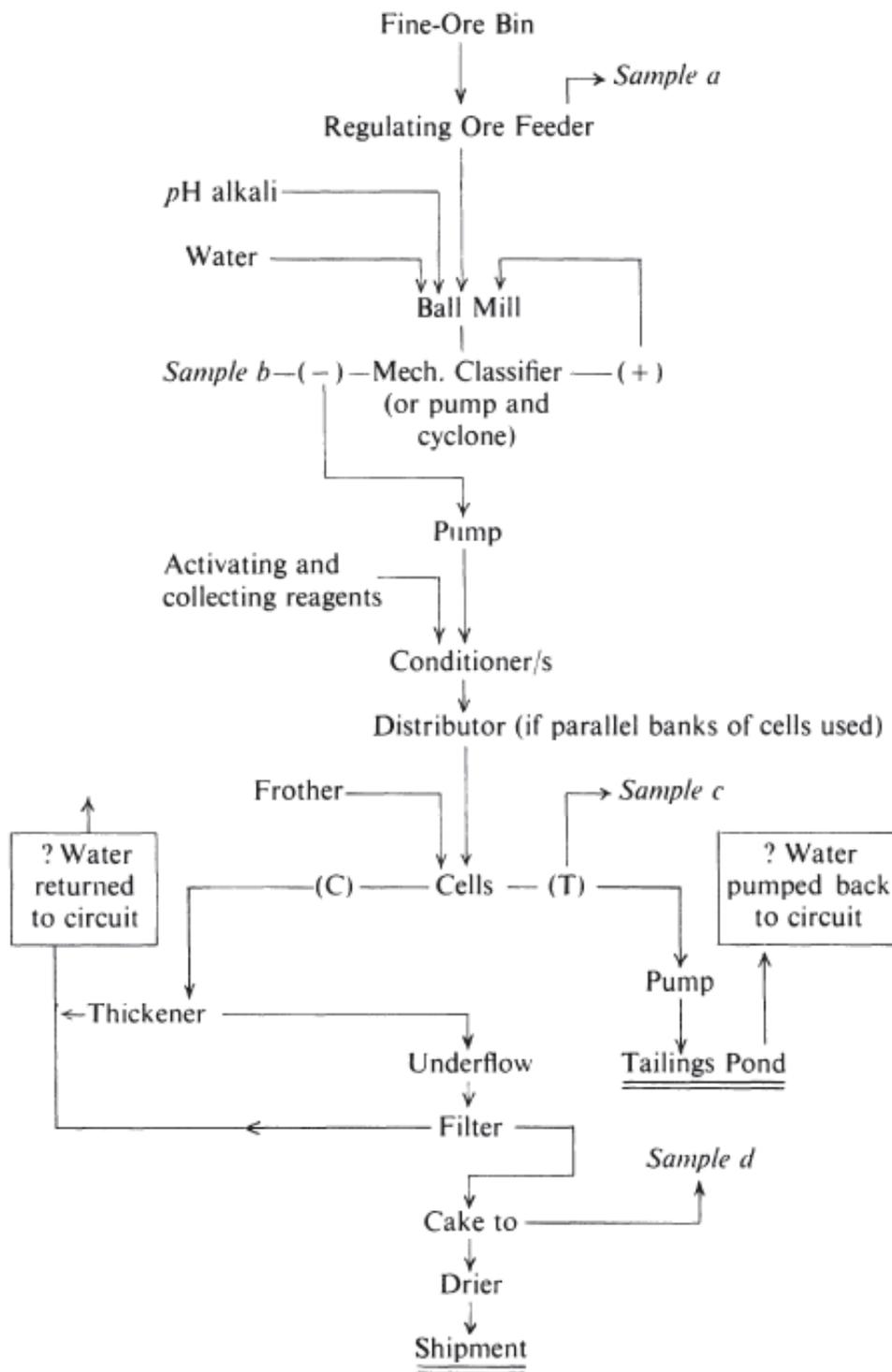
(c) To float one or more minerals in order to concentrate a value intimately associated.

(d) To float one or more gangue minerals.

(a) is the normal procedure. It could be used to make a mixed bulk concentrate of, say, copper minerals which needed no further separation before shipment. Again, when two sulphides readily float together (e.g. the sulphides of copper and lead) they are sometimes bulk-floated, one being depressed in a further treatment.

Treatment *(b)* is used to clean a floated product by depressing undesired constituents (e.g. in removing the last of the lime, silica, and iron from a fluorspar required at "acid" grade) or to separate two values by specific depression of one from the bulk

float. Method (c) is indirect, and is used in such cases as the flotation of auriferous pyrite as a prelude to special treatment of the fraction thus selected, or for upgrading a fraction of an uranium-bearing ore by floating the minerals most closely associated with it. Method (d) is an alternative to (b) used in such cases as the final upgrading of a dirty phosphate float by first destroying its activation and then using amines to remove the silica. Fig. below shows a general flow-sheet for single-product flotation. Possible addition points for reagents are indicated, together with those at which control samples may be taken.



- Sample a* Moisture, size, assay grade.
Sample b pH, % solids, size, assay grade.
Sample c Mesh assay (monthly), assay grade (each shift).
Sample d Assay grade, moisture.

Fig. General flowsheet for flotation for any single mineral concentrate, with discarded of tailing

COLUMN FLOTATION

The column flotation concept has been around for nearly 40 years, but it attracted attention with the copper mining problems of the early 1980s. The column flotation technique uses the countercurrent principle to improve separation by reducing entrapment of particles. A schematic diagram of column flotation cells is shown in Figure -- .

The important operating difference from mechanical flotation cells is the lack of an impeller, or any other agitation mechanism, which reduces energy and maintenance costs. The other major difference is that for most ore-processing applications, wash water is sprayed into the froth at the top of the column, which is impossible to accomplish in a mechanical cell as it can kill the froth. The amount of wash water added is a major factor in determining flotation selectivity and recovery as well as column operation stability.

In column flotation, the ore is fed into the column via a distributor located at about two-thirds of the height of the column; the tails are removed from the bottom; concentrate overflows at the top; and the air bubbles are generated at the bottom of the column by a porous sparger. Three characteristic features are the use of a sparger to generate bubbles near the base, a countercurrent slurry/bubble flow in the collection zone, and a deep froth zone (0.5–2.0 m) coupled with the use of wash water to induce a cleaning action. This design was first patented in Canada in the early 1960s and is sometimes known as the “Canadian” or “conventional” column.

Industrial column equipment has a height of 9 to 14 m and a diameter of not more than 2 m without baffling. Generally, the unit is operated with enough overhead wash water to provide a net downward flow of water, a condition known as a “positive bias.” Positive bias is the norm in column operation, because the froth layer in a column is then stabilized by the wash water. The greater the flow of water down the column, the greater the selectivity, and the thicker the froth layer. The froth depth in a stable operation is a little deeper than one meter. A negative bias eliminates the froth altogether, which is very deleterious for a process where the concentrate is the desired product.

The design of any ore-processing operation with columns must ensure that the rate-controlling flotation mechanism is always bubble capture of mineral particles that have been precoated with collectors in a prior flotation step.

It is customary to describe the operating conditions of flotation columns in terms of superficial velocities (J) in order to normalize the data for different size columns. Typical values (from Crozier 1992) are

- _ Gas velocity, $J_g = 0.5$ to 3.0 cm/s*
- _ Pulp feed velocity, $J_p = 0.7$ to 2.0 cm/s*
- _ Wash water velocity, $J_w = 0.1$ to 0.8 cm/s*
- _ Bias water velocity, $J_b = 0.07$ to 0.3 cm/s*

In addition, in scale-up equations, it is customary to normalize the gas velocity for different column heights by the pressure correction:

$$J_g = \frac{(P_c)(J_g^*)(\ln(P_s/P_c))}{P_s - P_c}$$

Where

J_g^ = gas velocity under standard conditions at the top of the column*

P_c = absolute pressure at the top of the column

P_s = absolute pressure at the sparger

The effect of gas velocity on recovery and grade is dominated by the bubble size, which depends on the pore size of the sparger. The size of bubbles produced is also determined by the type of bubble generation system, frother type, and dosage.

Sparger

Sparging through a porous medium without high external shear is the most common approach for column flotation. Industrial sparging material is made up of either pierced rubber or fabric such as filter cloth. Pierced rubber generally generates smaller gas bubbles, but is more difficult to fabricate.

Rubinstein (1995) examined the effect of filter cloth permeability on gas holdup and suggested an upper permeability level of 6 m³/m²/min. At the laboratory scale, inflexible porous materials such as porous steel, bronze, glass, or plastic are generally used. Early work showed that an inflexible medium would get plugged with solids or precipitate within several hours or days, making it unsuitable for industrial use.

Sparging through a porous medium with high external shear uses a porous sparger placed in a high-velocity slurry or wet line. In this process, bubble generation is controlled by both the nature of the porous medium and the shear action created by the flowing slurry.

Jetting is also used to generate bubbles when either a gas stream is jetted from an orifice into the liquid or when the liquid is jetted from an orifice into the pool.

Bubble Size

Bubble velocity in a flotation column is usually considerably higher than the slurry velocity. Therefore, the major hydrodynamic and flotation characteristics are determined by the airflow rate and the method of sparging. Slurry flow rate mainly influences the particle retention time. Coalescence as well as dispersion of bubbles can occur depending on the hydrodynamic and physicochemical conditions, and this effect can result in marked variation in bubble size distribution. With a limited increase in the column height, bubble size distribution in the upper portion will reach a steady state and will not depend on the sparger parameters; instead, it is determined by the condition of minimum potential energy. The time required to reach a steady-state bubble size distribution depends on aeration rate, surfactants, and solids concentrations as well as material properties. An increase in frother concentration results in lower mobility of the bubble surface and, consequently, in the reduction of the bubble rise velocity (Zhou, Eggeor, and Plitt 1992). The reduction in surface tension significantly decreases coalescence intensity, which in turn causes a reduction in average bubble size. Depending on the rise velocities of small and large bubbles, their retention times in the column differ. The bubble size distribution at the sparger differs from the average distribution in the column, even in the absence of coalescence, breakage, and bubble growth caused by pressure reduction. As a result of the lower retention time of larger bubbles, mean bubble size in the slurry is lower than the initial mean size.

Mixing of Phases

Nonuniform aeration in a flotation apparatus reduces the selection efficiency significantly as a result of large-scale liquid circulation. An increase in the airflow rate results in nonuniform aeration. Such heterogeneous behavior of the column operation is unfavorable, as an increase of the air-lift effect causes particle entrainment in the froth.

Column flotation has the following advantages: low power requirement, low capital investment, large aerated space, a possibility of controlling airflow rate, and dispersion. It allows production of highgrade concentrates, reduction of consumption of depressants, and simplification of process flowsheets.

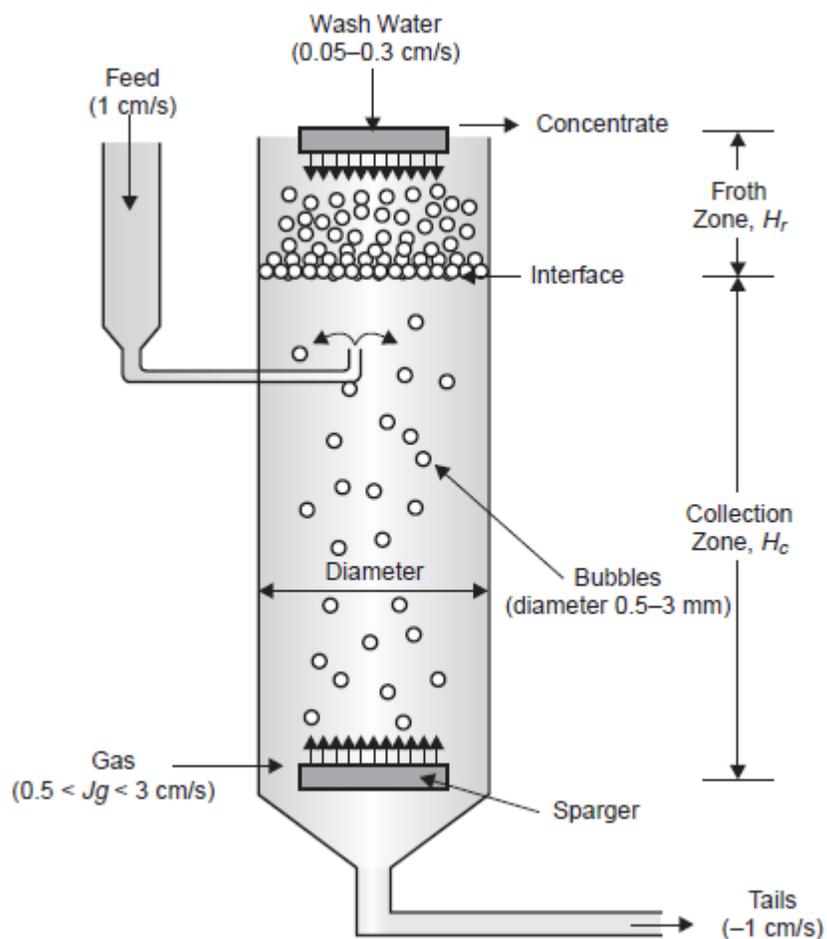


Figure Schematic of a conventional column flotation cell

Flotation Circuits

The elements of flotation circuits, in general, are:

1. *Rougher circuit.* New feed and recycled products (scavenger concentrate and cleaner tailing) are fed to this circuit.
2. *Scavenger circuit.* Rougher tailing is fed to this circuit. Scavenger concentrate and scavenger tailing are produced. Scavenger concentrate may be recycled with or without grinding to the rougher circuit or may be cleaned separately. Scavenger tailing is the final tailing.
3. *Cleaner circuit.* Rougher concentrate is fed to this circuit. Cleaner concentrate and cleaner tailing are produced. Cleaner concentrate may be used directly or cleaned additionally. Cleaner tailing is returned with or without grinding to the rougher circuit.

Cell arrangement can establish either series or parallel flow. Banks of cells are arranged in parallel when flows are too large for a single series line. Cell requirements as a function of feed rate, pulp density, and cell size are presented in

Table 8.16. As can be noted, the use of 500 and 1,000 ft³ cells reduces the number required very dramatically. Cells with volumes of 5,000 ft³ are currently in use.

The complexity of flotation circuits is a function of the complexity of the ore being processed, as Figure 8.55 shows. For single value ores, relatively simple circuits are involved. When concentrate cleaning is not necessary to produce a satisfactory grade, a more elaborate circuit can be employed.

TABLE Variations in cells required with cell size at different tonnages and pulp densities*

Dry Tons per Day, % solids	10,000	25,000	50,000	100,000
100 ft ³ cells				
20	77	192	383	767
30	49	122	245	489
40	32	81	161	322
500 ft ³ cells				
20	16	40	80	160
30	10	25	50	100
40	6	16	32	64
1,000 ft ³ cells				
20	8	20	40	80
30	5	12	24	50
40	3	8	16	32

*8-min flotation time; 3.0 specific-gravity ore.

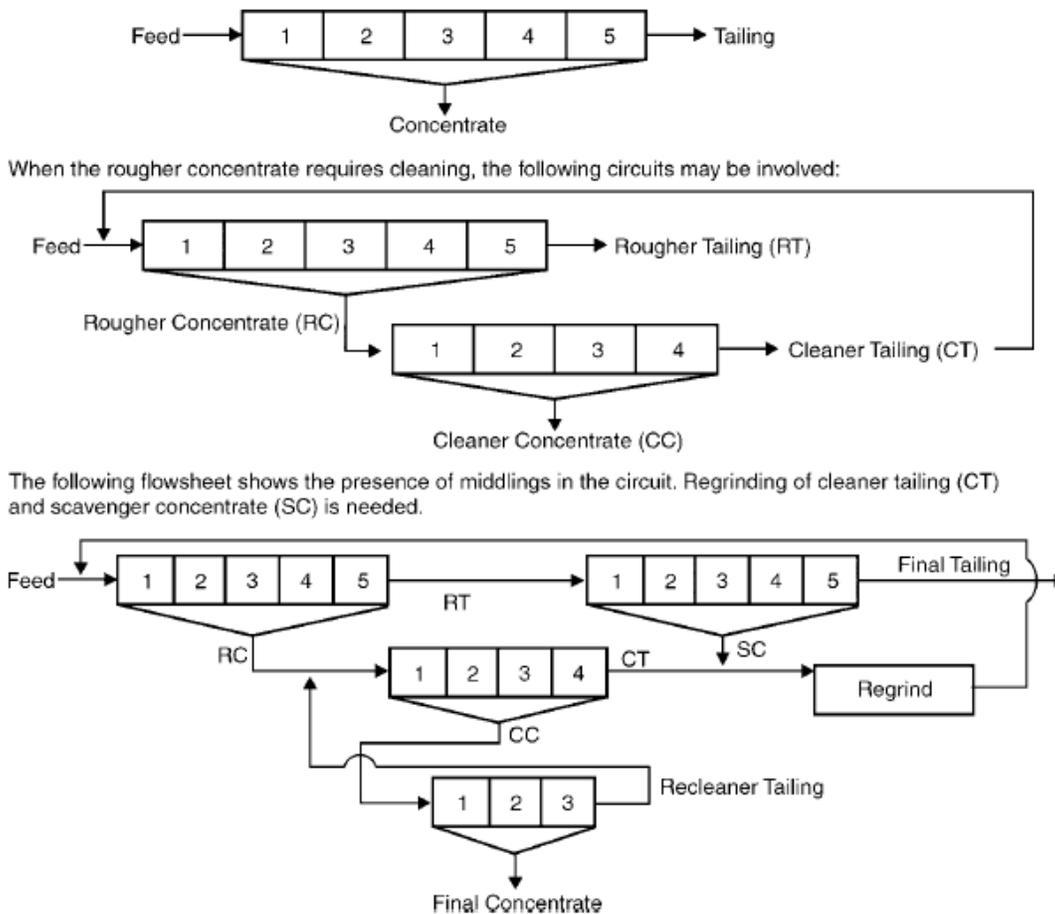


Figure Typical flotation flowsheets