

FLOTATION

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Flotation is a method of separating one mineral species from others present in a mixture based on its hydrophobic nature—either natural or induced on the surface—when present as a suspension in water along with gas bubbles. Because of the surface hydrophobicity, the mineral particles gets attached to gas bubbles and get separated due to buoyant forces. Mineral separation by flotation became a reality at the beginning of the century when the first plant to produce 80,000 tpy zinc concentrate came into existence in Australia. Since then, the technique has gained industrial importance at a rapid stride and today no less than 33 minerals, involving two billion tonnes of ore, are recovered all over the world and the information available in literature holds promise to many more. The reasons for such a widely acclaimed success are the flexibility of the process to suit a given system and its applicability to finer sizes. In fact, theoretically, any two given mineral system can be separated by flotation by suitably manipulating the conditions.

Industrial flotation of metallic and non-metallic minerals in India as practiced and the potential that exists for them are summarised in Tables 1 and 2.

The steps involved in flotation, on a macro level can be classified into three broad categories of (i) preparation of solids, (ii) creation of gas bubbles and (iii) separation of solid/solid and solid/liquid components. Each of these steps involve a number of micro processes and to effectively carry them out in practice for ore separation require knowledge of mineralogy, grain size and its distribution, surface morphology, size and size distribution of gas bubbles, flotation kinetics, settling rates etc., based on which reagent system is selected and different machinery required are designed. Figure 1 graphically depicts the three macro steps involved. The status of the knowledge with respect to each of these three aspects are discussed.

1. PREPARATION OF SOLIDS

1.1 **Grinding and classification.:** An essential pre-requisite for any mineral separation is that the required mineral is in sufficiently liberated form. At the same time since separation by flotation is through apparent reduction of specific gravity of gas solid conglomerate and separation of gas-solid mixture by buoyant forces in theory an upper limit on the particle size is imposed. Generally speaking, maximum size of a mineral particle that can effectively be floated should have an inverse relation to its specific gravity but in practice there are other considerations that alter this balance to a great extent. This aspect is seen in Fig.2. On the other hand, flotation being a process in which the required particles get attached to air bubbles, efficiency of separation depends upon the efficiency of collision and as the particle size decreases chances of successful collision decreases. Thus for a

given mineral there is a range of size within which flotation becomes effective and in this context preparation of solids on the basis of grain size and its distribution in the parent rock assumes a great significance. When the natural grain size distribution of the mineral is within that suitable for flotation, size reduction system, particularly grinding stage, is to be designed in such a way that excessive grinding of the desired mineral does not take place. Efficient grinding and closed circuit classification (involving hydrocyclones) play an important role here. Recent trends are to incorporate flash flotation unit (Fig.3) in the circuit to prevent excessive grinding of fully liberated coarse grains. If on the other hand, the natural grain size is much finer than what meets the requirements of flotation, either the flotation system needs to be modified to recover finer particles or prior treatment of fine particles to build up in size to bring it within the size range acceptable for flotation.

Modifications to flotation system includes change over from conventional stirred-tank mechanical cells to counter current type pneumatic flotation units which will be discussed in more detail in chapter-2. Modifications to flotation system can also be brought about with classified flotation by fine tuning the reagent system particularly frother combination to treat finer fractions as against bulk flotation. Fig.4. gives a typical example of four such cases where classified flotation is more efficient compared to bulk flotation. Precipitate flotation and electro flotation are other techniques being developed to handle finer particles.

Selective flocculation prior to conventional flotation is another way to handle fine grained minerals. Practice followed to recover iron ore at Tilden mines in USA and oleo flotation for coal recovery being tried out by Central Fuel Research Institute, Dhanbad (CFRI) is another example. One of the important aspect of development that has helped flotation is the availability of large size grinding unit and the associated developments in classification besides large size unit cells.

1.2 **Conditioning:** Only coal, graphite, molybdenite and sulphur are naturally flotable. But in practice, even these in addition to others need conditioning to render the surface effectively hydrophobic in order to selectively remove them by flotation. Conditioning, essentially, means coating the surface of the mineral with a thin (molecular) layer of certain chemicals to transform the surface effectively hydrophobic.

Much of the voluminous research work that has been carried out over the century lie in the area of understanding the physical chemistry, thermodynamics of reagent interaction with mineral surfaces and inspite of the knowledge gained still much needs to be known. A simple xanthate was virtually the only collector known in the beginning. Flotation started with sulphide ores - and today we have a choice among 17 xanthates, 19 di-thiophosphates 6 xanthogen formates and 5 thio-carbonate, as collector and this spurt in the number of reagents available has made the situation more complicated. At the same time, simple addition of any collector does not suffice, and other conditions

prevailing like pH of the solution, electrophoretic mobility of the particles in the system, and need to add additional reagent either to promote the coating of the collector on the mineral or prevent its deposition on minerals not wanted all play a vital role. As a result neither there is an uniform prescription for a given system nor there is a well laid out procedure to arrive at reagent system required with respect to the type, dosage of the collector, promoters, depressants etc. These need to be worked out through experiment on the basis of past experience with similar minerals. The surface morphology, and point defects known to differ from one deposit to the other of the same mineral, and the nature of the associated mineral is the cause of this complexity. At the same time, a knowledge of the electrophoretic mobility of the minerals is of help since any condition that renders the zeta potential negative makes the mechanism shift from physisorption to one of chemisorption which is more effective. Figs. 5 and 6 show zeta potential values (in air) and without any addition. Absence of oxygen or presence of chemical drastically change this picture. There is no theory that predicts them.

However, the known collectors are classified into two groups of non-ionising and ionising which has further sub-groups of anionic and cationic types. Anionic collectors are both oxyhydril and sulphhydril. Fig. 7 shows the classification.

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At the same time, minerals are also classified into six groups on the basis of increase in the surface polarity the details of which

are shown in Fig. 8. Collector action is essentially to reduce the polarity and therefore all collector need to be a hydrocarbon or must atleast possess in part a hydrocarbon group. But all hydrocarbons do not selectively perform the required function. To achieve this the hydrocarbon must have a polar group.

1.2.1 Depressants, Activators and Dispersants:

Besides collector and more important frother (being discussed in the next Chapter) there are other reagents known to be modifiers and classed as depressants, activators and dispersants that are essential in flotation practice unless the mineral is naturally floatable like molybdenite or talc for which frother alone is sufficient.

Depressants are essential to prevent collector coating on mineral surface for which pH control is very important. The selectivity in sulphide mineral system is effected by the differential tendencies of the mineral cations to form surface hydroxy complexes that block collector absorption. The sensitivity of sulphide minerals to OH^- ions decreases in the order of pyrite, pyrohotite, galena, activated sphalerite, chalcopryrite and chalcocite. Besides, Cu^{++} (lime) CN^- , So_2^- , Cr_2O_7^- , S^- and $\text{Fe}(\text{CN})_6^{4-}$ are ions used as depressants in sulphide system.

For non-sulphide minerals the range of depressants is wide and their role less understood. pH and hydroxy complex formation with cations play important role. Most collectors being weak acid/base ions play leading role compared to molecules. Silicates, phosphates,

Flouride and silico-flouride are inorganic depressants whereas lignin, sulphonates, tannic acid, dextrin are organic depressants used in non-sulphide minerals. Activators are ions which on adsorption on mineral surface permit collector adsorption. Copper sulphate for sphalerite, Ca^{++} ions for quartz and $\text{Na}_2\text{S}/\text{NaHS}$ for oxidised copper are examples.

In addition to these at times, dispersion (gangue) or flocculation (wanted mineral) - particularly selective - is desirable to deal with very fine particles.

1.3 **Conditioners:** The induction of necessary surface characteristics in presence of reagents is brought about in conditioning attritioning equipment. At instances, the temperature is also adjusted in the conditioners. These are simply mixes/agitators but the design aspect interms of power intensity required is related to the duty called for. The order for these in the order of increasing power intensity residence time to carry out the desired function is indicated in Table 3.

2. CREATION OF GAS BUBBLES

Creation and use of swarm of gas bubbles forms the heart of flotation. Practically air is used for the purpose eventhough literature has shown evidence of advantage of using other gases for specific purposes.

For the flotation to be effective, sufficient surface area of the gas bubbles need to be provided to carry off the required

mineral species. The other important aspects is the size of these bubbles in relation to the size of the particles being floated and its specific gravity. From the consideration of the surface area to be provided for flotation, it is always advantageous to make the minor minerals float to increase specific (volume) capacity of the given flotation unit.

Reagents on one hand, and the machinery/mechanism on the other play an important role relating to creation of gas bubbles. The entire development of flotation machinery over the last 9 decades centres around this aspect.

Since the beginning of the century, when flotation was established as a commercial operation, hundreds of patents sprang up for equipments in which flotation could potentially be carried out. But none except a dozen had any glimpse of success. What lasted through the years belong to two generic families (i) mechanical type in which air is dispersed into the pulp through impeller action and (ii) pneumatic cells in which air is supplied from an external source keeps the pulp in agitation, made and marketed by a few companies each claiming the own design secrets. Subsequently, even the pneumatic cell reminiscent of which is still operating at South Bank Concentrator in Ghatsila, in the then original form disappeared. But the real developments with regard to flotation machinery have taken place during the last 2 to 3 decades.

One significant development is the appearance of large volume unit cells, which are more or less enlarged versions of the established designs of the respective manufacturers. These larger cells give the advantage of reducing the specific energy consumption and the capital cost and paved way to harness lower grade ores with the attendant economic advantage of scale of operation.

Similarly, developments took place in the evolution of pneumatic cells with external air supply with counter current flow of air and feed solids from the cross flow pattern prevailing in the sub-aeration machines. Besides, flow regime in the pneumatic cells is closer to streamlined conditions in contrast to intense turbulence in the impeller agitated sub-aeration type. With the streamlined flow and additional wash water spray flowing down counter current to rising froth gangue entrapment is decreased and higher grade products has been possible from the same feed in pneumatic cells. Many other advantages of such a pneumatic cell which resemble counter current reactors in contrast to stirred tank type sub-aeration machines are given in Table 4. Schematic diagram of a few pneumatic cells are shown in Fig. 9. Their applications are shown in Table 5. Comparison of well known flotation machines are made in Figs. 10 & 11 with regard to the specific capacity, power consumption.

One distinct type of sub-aeration machine, marketed by Ottokumpu of Finland is the flash flotation cell with the ability to handle coarser feed. This finds application in recovering naturally

floatable coarse grain product without any collector from the hydro-cyclone underflow before returning to the grinding mill.

Thus, with the overall improvements in the flotation equipment design, in the sub-aeration type cells on one hand and the appearance of pneumatic cells on the other, the range of particle size recoverable through flotation has widened, the efficiency of separation has improved and economics have become favourable.

However, the hydrodynamics of bubble formation, its size and size distribution on one hand and the relation between them with the size and size distribution of particles being floated on the other, are not totally understood. Research is limited to two phase gas/liquid systems.

The available literature information is compiled in Fig.12 which shows the frequency of air bubbles size in mechanical type cells and that of the modern pneumatic cells. Figure 13 shows the relation between flotation efficiency and the ratio of particle to bubble size. It therefore, becomes evident that to have higher flotation efficiency, as fine a bubble as possible needs to be created more so if larger particles or particles of higher specific gravity need to be floated. Some of the recent patents with respect to flotation machinery centre around the claims on the ability to produce finer and more uniform bubbles.

Irrespective of all these considerations, flotation could not have been a commercial success as of to-day but for the role of the reagents; frother in this context

Reagents used as frother in controlling the size of air bubbles generally fall into two categories the one which has least or no collector effect and the other where collector also acts as a frother.

It is difficult to explain the beneficial effect of one frother from the other or a mixture of them by its mere effect on the reduction of surface tension and the slope of the surface tension and the slope of the surface tension concentration which is generally claimed. The synergistic effect of a mixture of frother particularly for fine size particles and the beneficial effect of one frother over the other as a function of particle size and the need to change the frother system with the sample itself as revealed during the investigations with different coal samples support this gap in the knowledge.

While the tenacity and the stability of the frother - a function of frother - is desirable within the flotation machines, for subsequent operation of dewatering the same properties are undesirable. In mechanically operated cells as the height of froth bed increases, for the same system, water retained in the froth and the resultant carry over of gangue particularly slimes decreases. The mechanism of particles carry over around 20 micron changes from one of attachment to that of entrapment. However, concepts in modern pneumatic cells is different where wash water spray improves the froth stability with in and prevent gangue entrapment.

3. SEPARATION

Having prepared the ore for effective separation of the desired mineral and created conditions for separation, the actual processing of particles attachment to air bubbles with the flotation machinery is dependent on the kinetics.

The process of flotation is the net effect of attachment and detachment of particles to air bubbles and collision efficiency is a function of bubble and particle concentration, their size and size distribution.

An ideally designed flotation circuit is to recover most of the wanted species in the size in which it is present in the host rock with least cost. However, limited by a variety of factors, beginning from the lack of knowledge of accurate natural grain size distribution of material to be recovered from the host rock and its surface behaviour controlling the rate of flotation in the presence of other associated minerals, in practice the position becomes far from ideal and the circuits designed for each case differ widely depending on the situation. However, in general barring for special reasons, the approach is to (i) float the minor constituent and/or take advantage of difference in specific gravity wherever possible (ii) generate a disposable tailings in the first stage to reduce the bulk to be processed in the subsequent stages and (iii) resort to stage grinding where the wanted mineral is fine grained and locked in pockets in the host rock.

The circuits involved range from simple single stage operation where single natural floatable mineral like coal is involved to multistage comprising of roughing, scavenging and cleaning upto 10 stages in instances like molybdenum recovery, to recover a valuable fine grain material present in low concentrations.

Design of flotation cells for each of the stages required is governed by

$$NV = QTEX/24$$

where

| | | |
|---|---|--|
| N | = | the number of cells |
| V | = | effective volume of each m |
| Q | = | dry ore throughput per 24 hours, tonnes |
| T | = | circuit retention time, hr |
| E | = | pulp expansion factor due to aeration |
| X | = | pulp flow rate, ft/min. per ton dry ore per hr $0.54 (1/s + 100/P-1)$ |
| S | = | specific gravity of solids |
| P | = | solids concentration in pulp, % |

Therefore, the volume and number of cells involved depends upon T, the rate of flotation apart from X which is both a function of cell design and an effect of frother used.

It is gratifying to note that an analogy between flotation as a process, as much as for grinding, and chemical reaction is commonly accepted and mostly found to behave as a first order reaction and in some rare cases a second order one.

The modified recovery equation evaluated for a first order flotation

$R = RI (1 - \text{Exp}(-Kl))$
 where R = actual recovery
 and RI = maximum recovery possible
 K = first order rate constant

However, K, the first order rate constant in flotation unlike in a chemical reaction which is essentially temperature dependent, is a function of variety of factors like particle size, impeller speed, aeration rate and surface characteristics. Fig 14 represents the variation in the value of K for a selected number of minerals. The variation with particle size, impeller speed and sample to sample of the same mineral is apparent, besides being highly sensitive to size with an optimum between 50 and 80 microns and rapidly decreasing below 20 microns. It is also seen that there could be instances where rate constant could be five times over the normal range giving 1/5th advantage in required specific volume of cells.

The variation of flotation rate constant with size, as predicted by Sutherland and Woodburn would however be extremely useful in the assumption of a specific flotation rate (of one per min. ideally) in obtaining a predesign estimations of a flotation circuit based on the knowledge of liberated product size.

Subsequent to froth separation, dewatering, recirculation of water, the effect of recirculated water containing reagents carried with throughout the process is another aspect which is byproduct in commercial flotation.

SUMMARY:

On the basis of present day knowledge of flotation and eight decades of flotation plant practice if one has to think of a green field concentrator based on flotation adequate thought should be given for a flow sheet consisting of a primary grinding with closed circuit, incorporating a fresh flotation unit to recover naturally floatable large grains, secondary grinding with rougher cells (sub-aeration) and cleaner and scavenging involving modern pneumatic cells with proper choice of reagents.

Under Indian conditions, improvements in the existing plants through the use of modern pneumatic cells and proper reagents system needs to be examined for minerals where scope and potential exists. These need to be examined in detail.

TABLE 1

INDUSTRIAL FLOTATION OF MINERALS
(Practice and potential in India)

A. METALLIC MINERALS

| Mineral | Life expectancy in years | | Present status and scope in future |
|----------------------|--------------------------|-------|--|
| | World | India | |
| 1. Copper | 5 0-99 | 71 | Practiced, no expansion envisaged but scope for improvements in the existing plants. |
| 2. Molybdenum | 5 0-99 | - | No known primary source |
| 3. Mercury | < 30 | - | No known source |
| 4. Nickel | 5 0-99 | n.e. | No primary sulphide sources, scope exists for enrichment of oxide nickel in laterites for metal extraction. |
| 5. Copper-molybdenum | | | Potential exists for by-product recovery from copper concentrates - Rakha to supplement the by-product recovered at uranium plant, Jaduguda. |
| 6. Copper-nickel | | - | |
| 7. Copper-lead-zinc | | n.e. | One plant operating at Sikkim but needs improvement, scope exists for additional plants viable on small scale operation. |
| 8. Gold | < 30 | 10 | Scope exists for improving the recovery of existing operation by replacing cyanide treatment by flotation-cum-carbon in pulp process. |
| 9. Lead | 30-49 | 66 | Practiced |
| 10. Lead-zinc | | | Practiced, scope exists for improvement in the existing plant in addition to envisaged plants for expansion. |
| 11. Pyrite | >100 | 1419 | |
| 12. Lithium | | | |
| 13. Tin | 30-49 | 12 | |
| 14. Tungsten | 30-49 | 196 | Scope for by-product recovery from gold plant tailings. |
| 15. Zinc | < 30 | 72 | Please see item 10. |

TABLE 2

INDUSTRIAL FLOTATION OF MINERALS
(Practice and potential in India)

B. NON-METALLIC MINERALS

| Mineral | Life expectancy in years | | Present status and scope in future |
|----------------|-----------------------------|------------------------|--|
| | World | India | |
| 1. Barite | < 30 | 101 | Not practiced but scope exists as export potential particularly in view of relative abundance over world known reserves. |
| 2. Bastnaesite | | | Not known |
| 3. Coal | 100 | 30-49 (Coking coal) | Recovery of coking coal fines practiced in some washeries, incorporation contemplated in other existing and new washeries, scope also exists for thermal coal beneficiation for the preparation of high concentration coal slurry for direct combustion in power plants. |
| 4. Feldspar | n.e. | 46 | |
| 5. Fluorspar | 30-49 | 73 | Practiced and additional plants envisaged, scope exists in improvements of product quality for acid grade and special applications. |
| 6. Graphite | | 103 | Practiced on small scale; scope for improvements. |
| 7. Ilmenite | | 417 | Flotation not practiced from any scope. |
| 8. Iron ores | | 132 | Scope exists for additional recovery from the tailings of Kudremukh plants and also from other hematite washing plants tailings for low alumina product. |
| 9. Kyanite | n.e. | 26 | Immense potential exists. |

| | | | |
|-----------------|------|------|--|
| 10. Limestone | >100 | 398 | Practiced in a few cement plants, limited scope exists for additional processing depending upon local economics. |
| 11. Magnesite | n.e. | 305 | Scope exists for improving overall mining recovery in Salem area. |
| 12. Mica | n.e. | | |
| 13. Phosphate | | 87 | Scope exists for recovery from gold plant tailings. |
| 14. Talc | | 46 | |
| 15. Potash | | | |
| 16. Quartz | | 177 | Scope exists for recovery from gold plant tailings. |
| 17. Sillimanite | >100 | 5292 | being practiced. |
| 18. Vermiculate | | 25 | |

TABLE 4

ADVANTAGES OF FLOTATION COLUMN

- * A BETTER GRADE FOR THE SAME RECOVERY OR INCREASED RECOVERY FOR THE SAME GRADE OF PRODUCT
- * A REDUCTION IN THE NUMBER OF STAGES OF OPERATION
- * ABILITY TO HANDLE A FINER FEED
- * SAVINGS IN REAGENTS REQUIREMENT
- * SIMPLICITY IN DESIGN & FABRICATION WITH NO MOVING PARTS
- * REDUCTION IN SPECIFIC ENERGY CONSUMPTION AND FLOOR SPACE REQUIREMENT
- * USE OF GASES OTHER THAN AIR TO DERIVE PROCESS ADVANTAGES SUCH AS PREVENTION OF MINERAL OXIDATION REAGENT DEGRADATION ETC.
- * BETTER AMENABILITY FOR AUTOMATIC CONTROL AND SCALE UP
- * POSSIBLE ELIMINATION OF DESLIMING OPERATION AND
- * RECOVERY OF FINER PARTICLES.

Salient features of different designs of pneumatic flotation columns

| Type | Design details | Special features | Performance | Item in Fig.: 1 |
|---------------------------------|---|---|--|-----------------|
| Boutin and Trembly, Canada | (0.5 m square column, 12 m height) | Conical air diffuser, column enlarged around diffuser | Recovery less for copper ores (0.174 mm), recovery high for molybdenum (0.074 mm) | 1 |
| Ph PPM, Soviet Union | | Distinct input feed discharging section and cleaning section: aeration into individual cells | Substantial rise in anti-mony level from 32% to 40% without sacrifice in recovery | 2 |
| KFP type, Poland | Cell volume 5 m ³ , air input 1.3 to 1.5 m ³ /min, 1.5 to 2.5 m ³ /min pulp. | Multiple porous plate air diffuser with 30- to 40-micron pores: variation in cross-section along length, height froth layer and no wash water | 7% to 8% increase in grade without sacrifice in recovery in the concentration of sulphates | 3 |
| Ph PPM-7, Soviet Union | Diameter 1.4 m, height 4.6 m, volume 7 m ³ , capacity 2 t h ⁻¹ m ⁻³ | Squirrel gauge type air diffuser; annular distribution of feed; slide valve arrangement for level control | Recovery of -0.16-mm coal from sludge without frother; kerosene requirement 120 g/t ash 5.5 to 6.8%; solids (g/l) feed 68; product 236; 40% reagent recycle; also for saving of tungsten | 4 |
| Gosgor Khimproekl, Soviet Union | 3 chambers of 9 m ² , height 5.5 m | Horizontal pipes for aeration; cascade system; deep chamber frother separator | Desludging of KCl | 5 |
| Ginstsvetmet, Soviet Union | | Includes a mixing chamber to allow mineralisation particles with jet ejectors; has a fluid bed chamber | | 6 |

TABLE 6
REQUIREMENTS OF CONDITIONERS

| | Power intensity HP/ft ³ | Residence time Sec. |
|---|---------------------------------------|------------------------|
| 1. Reaction with soluble reagents, pH adjustment | 0.4 - 0.5 | few seconds |
| 2. Reaction with partly soluble reagents, precipitates/emulsions fatty acids/fuel oil sphalerite activation | 0.003-0.03 | 300-600 |
| 3. Desorption of already coated reagents, finer feed/partly oxidised ore | 0.3 - 0.6 | 1500 |
| 4. Displacement of already existing non-selective collectors. Oxide systems/fatty acid high solids concentrates removal of coated mineral | 0.6 | 1800-3600 |

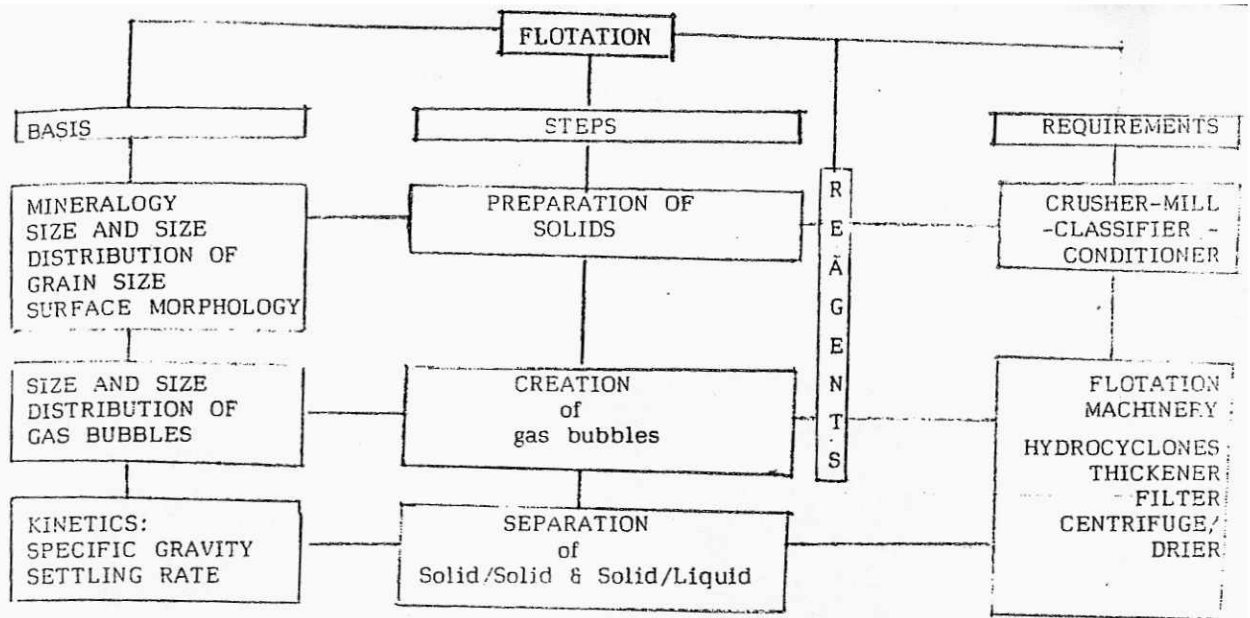
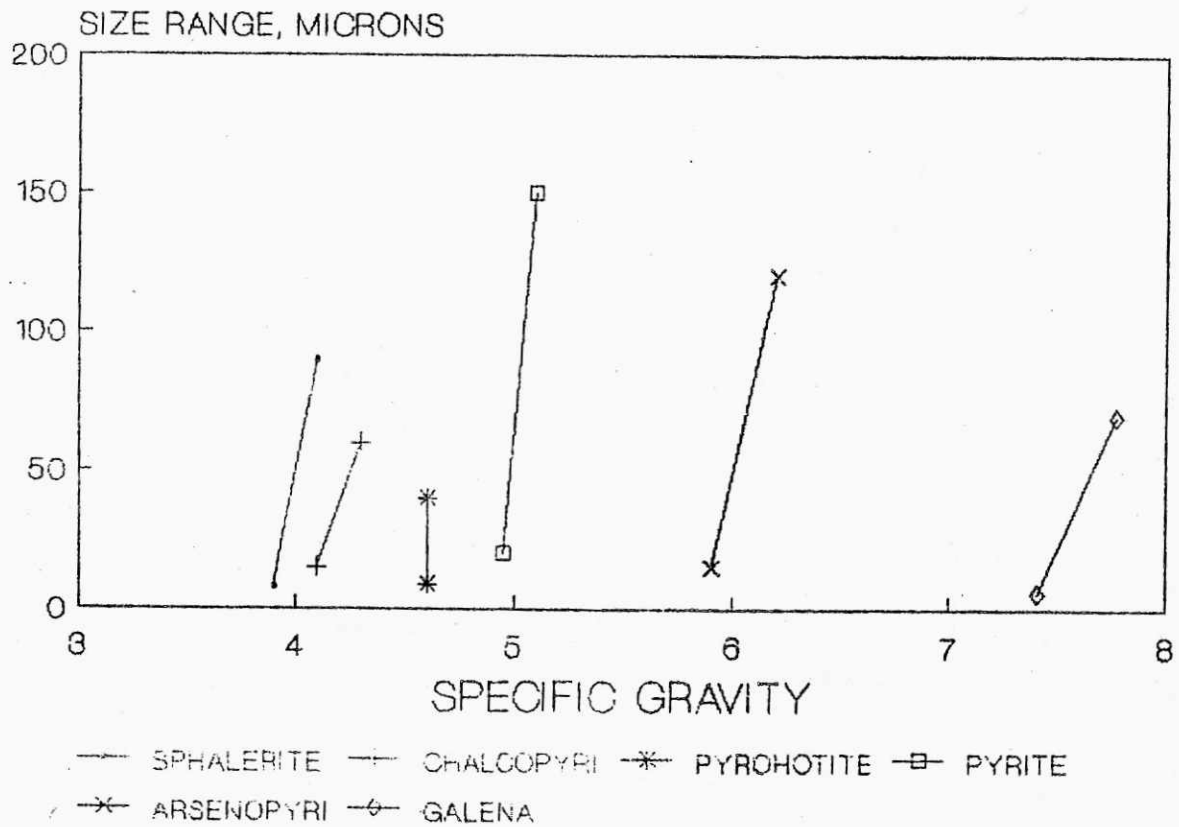


FIG. 1 : DIFFERENT ASPECTS OF FLOTATION

FIG. 2
FLOTATION SIZE RANGE
RELATED TO SPECIFIC GRAVITY



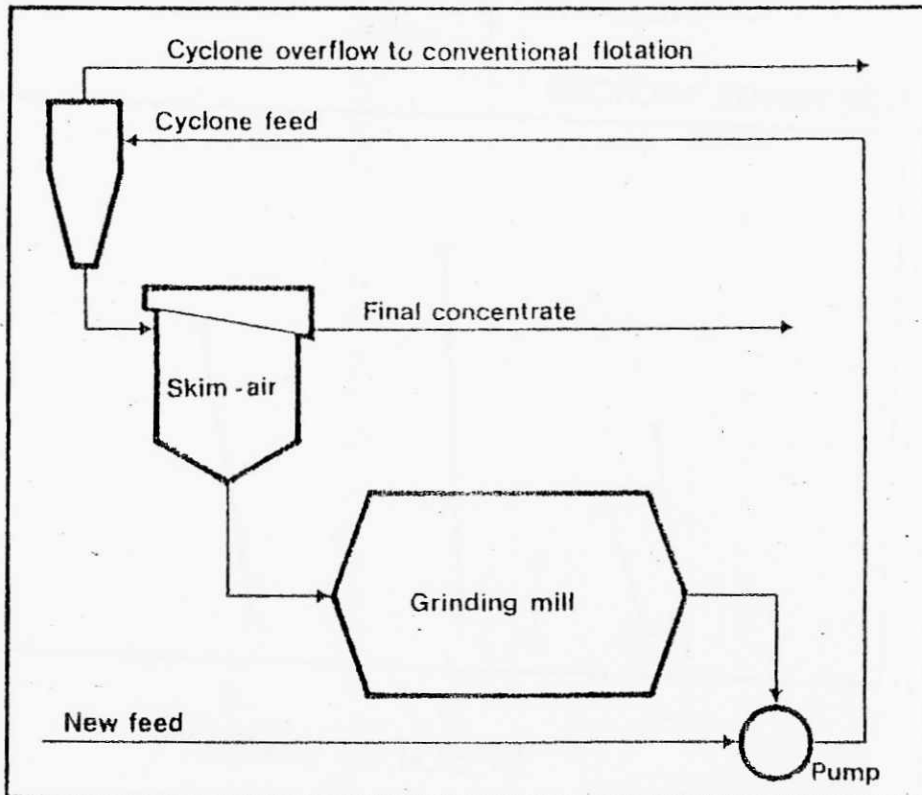
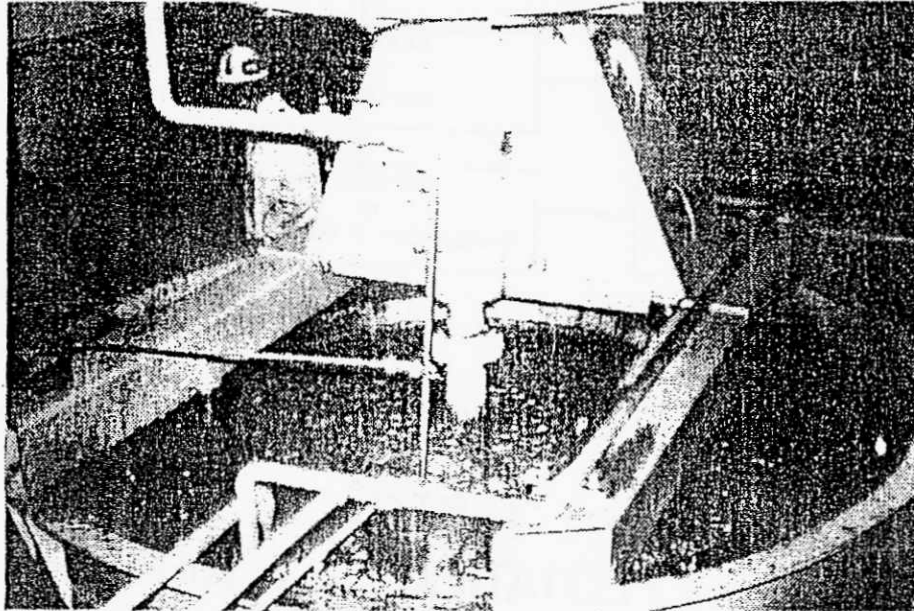
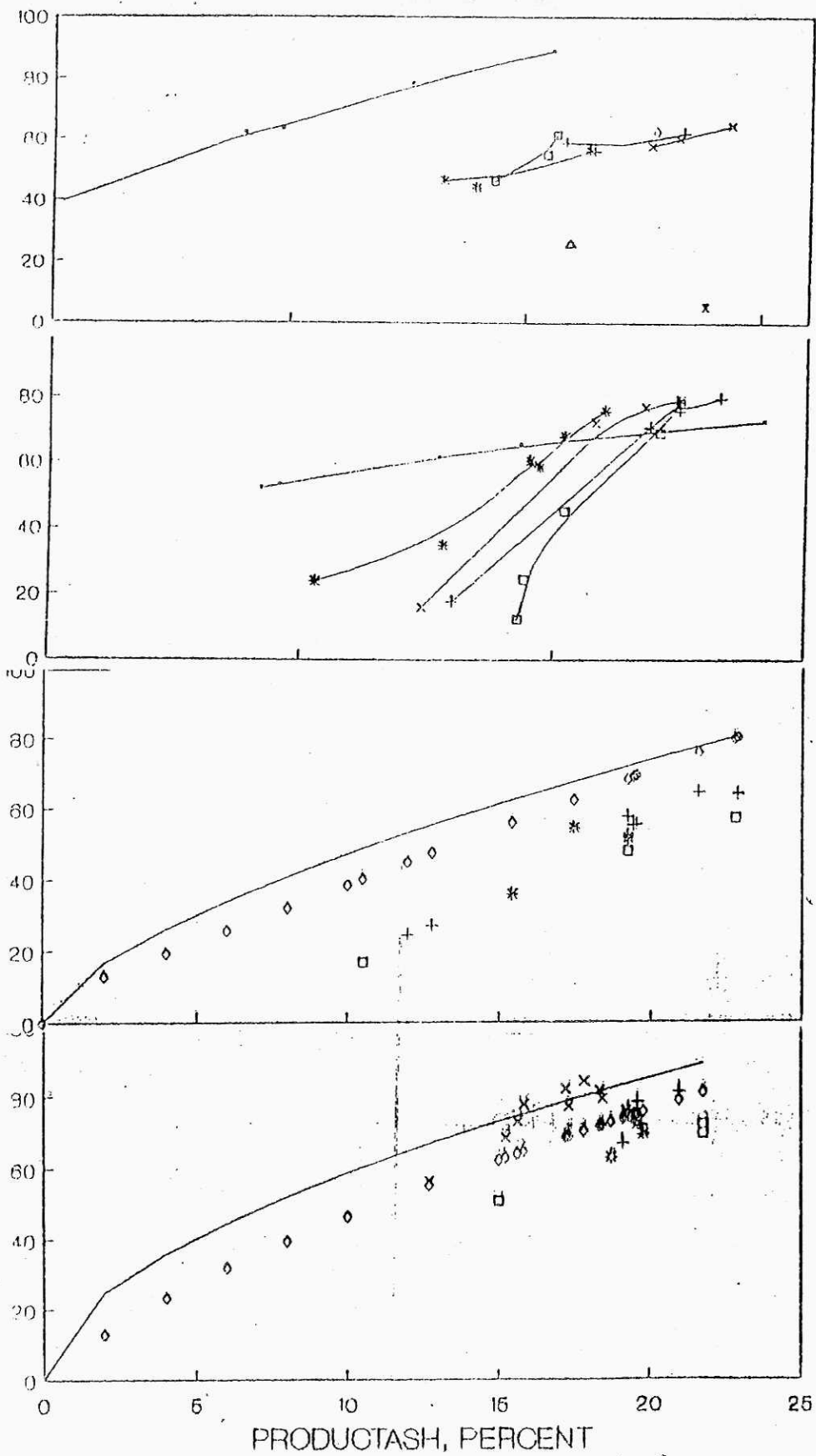


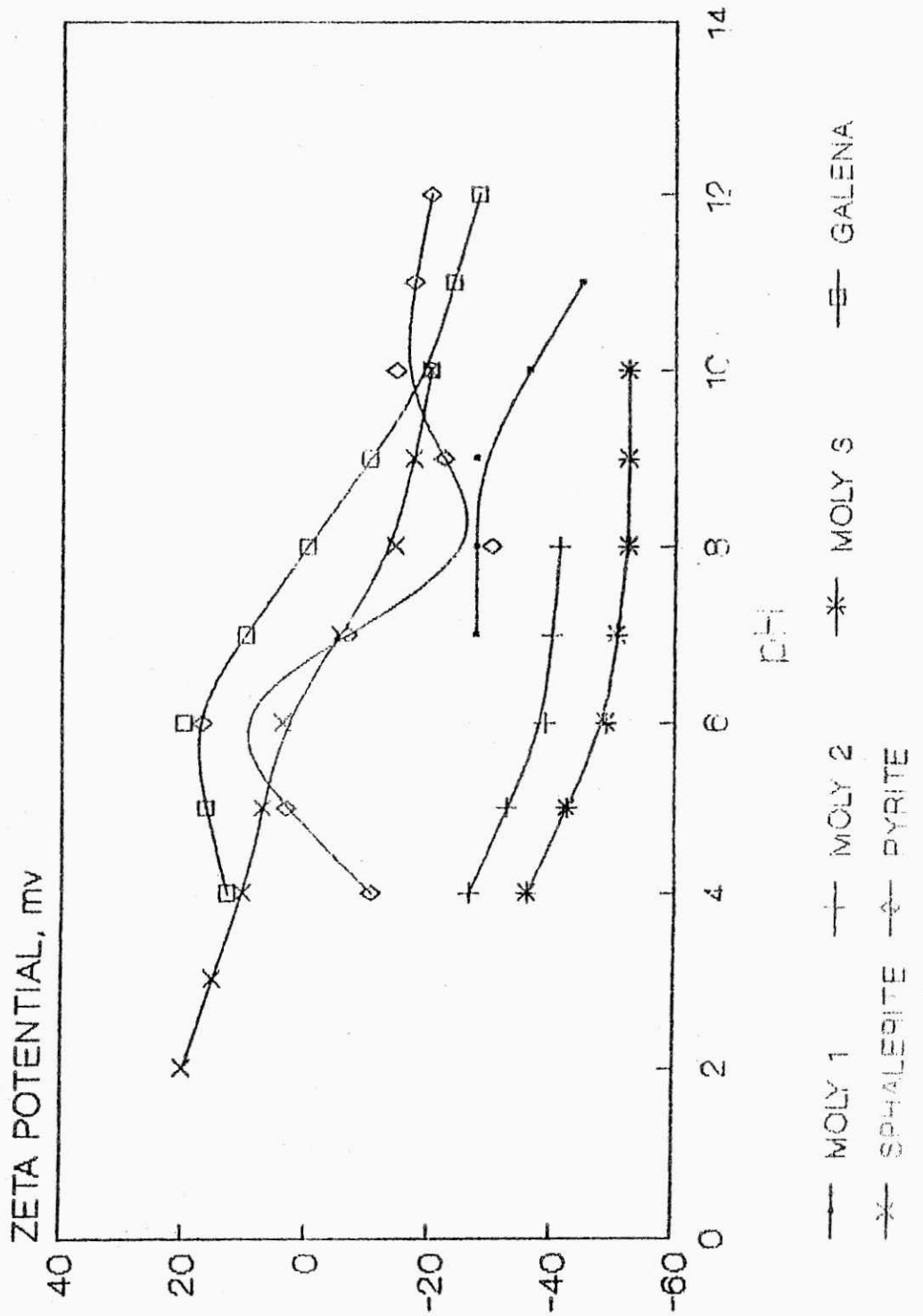
FIG. 3 : SCHEMATIC DIAGRAM OF THE FLASH FLOTATION PROCESS.

FIG. 4 BULK AND CLASSIFIED FLOTATION



— WASHABILITY + BULK(CELL/PO) *BULK(CELL/MIBC) □ BULK(CELL/G.ACID)
 × BULK(COLUMN) ◇ CLASSIFIED (CELL)

FIG. 5
 SULPHIDE MINERALS
 ZETA POTENTIAL



Non-toxic liquid, non-water

Group

(Carbox)

FIG. 6
OXIDE MINERALS
ZETA POTENTIAL

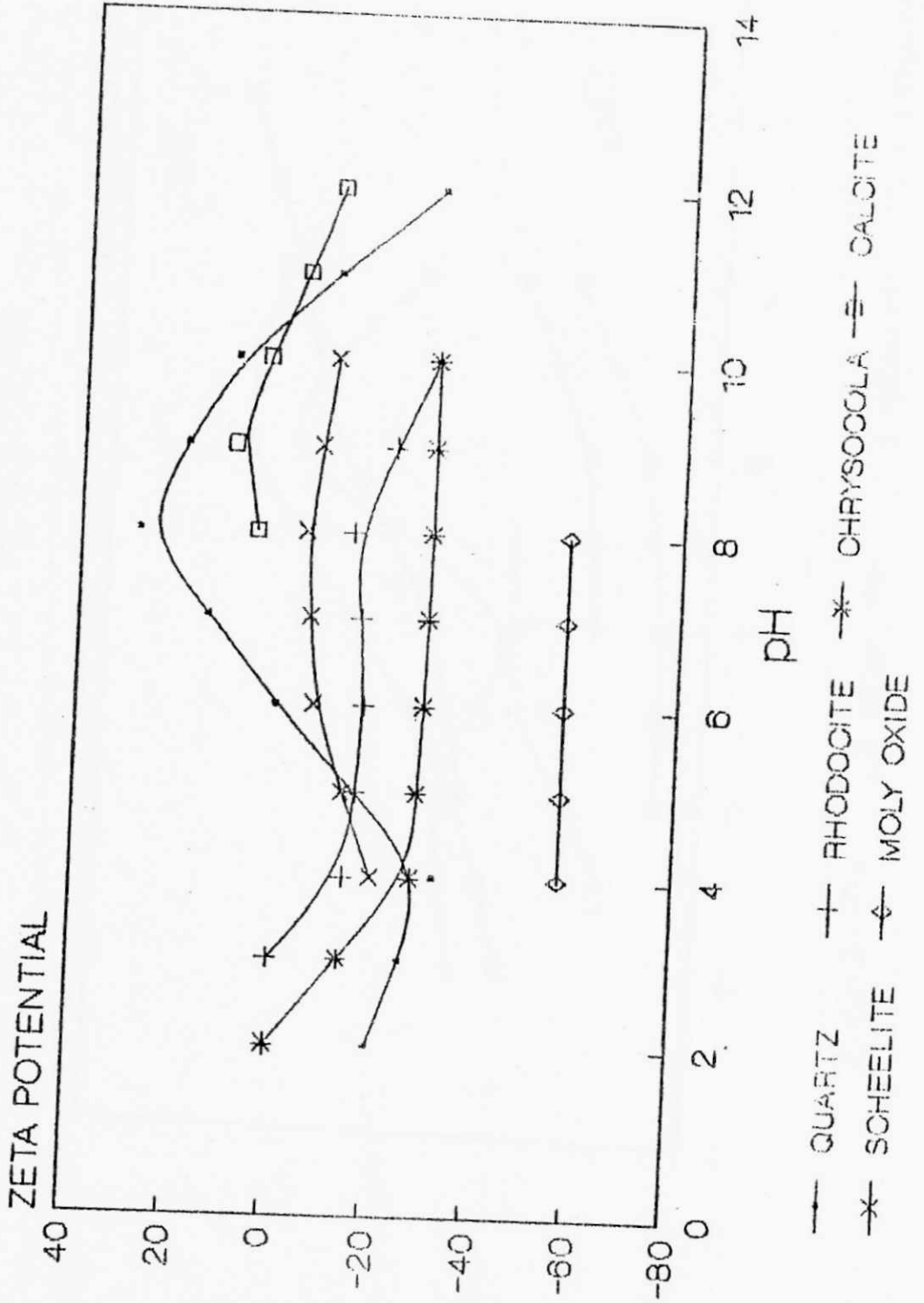
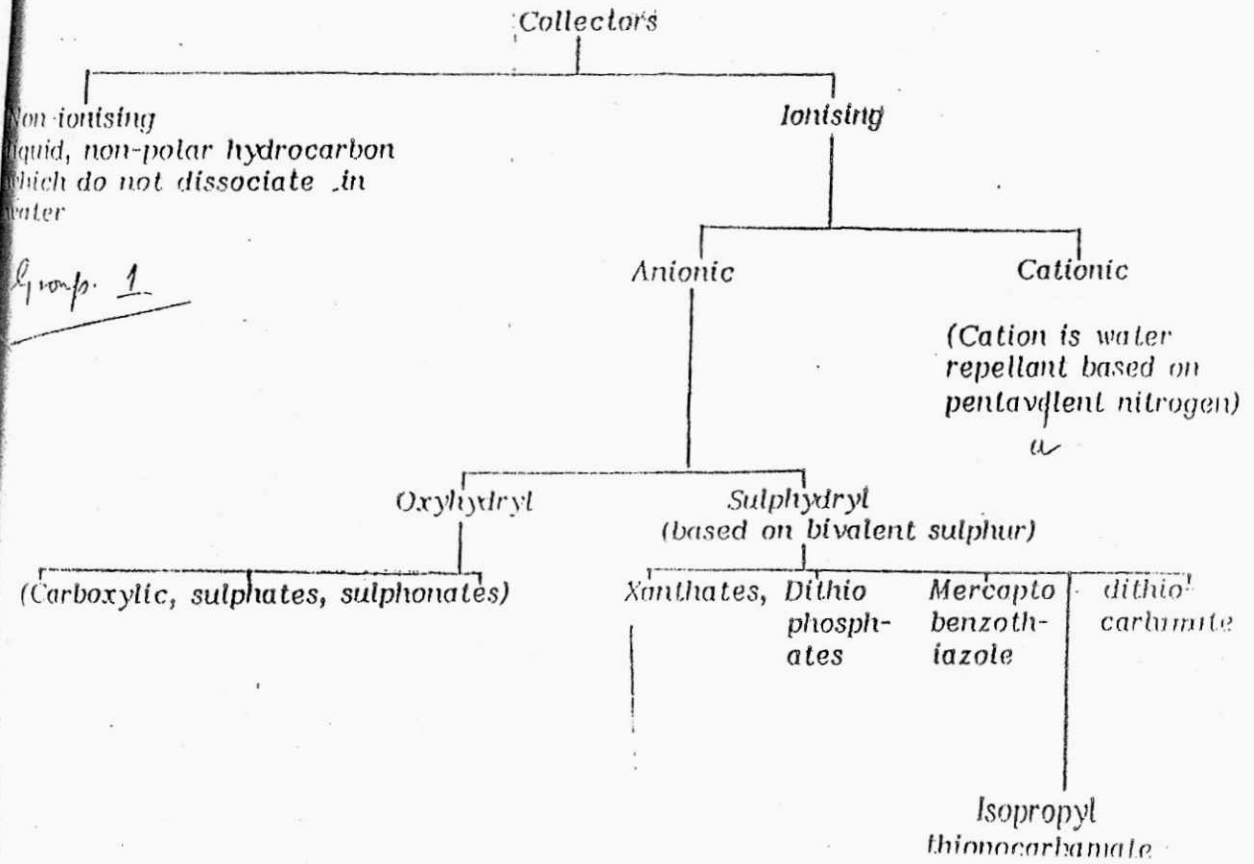


Fig. 7

CLASSIFICATION OF COLLECTORS



Group 1

OXIDE MINERALS
FIG. 6

Fig. 8

CLASSIFICATION OF POLAR MINERALS

| Group 1 | Group 2 | Group 3 | Group 4 (a) | Group 4 (b) | Group 5 | Group 6 |
|-------------------------------------|---|-------------------------------|-----------------------------------|--|--|--|
| Graphite sulphur coal | Galena Covelite Bornite | Barite Anhydrite Gypsum | Cerussite Melachite Azurite | | Hematite Magnetite Goethite | Zircon Willemite Hemimorphite |
| Talc Pyrophyllite Molybdenite | Chalcocite Chalcopyrite Argentite cobaltite Arsenopyrite Pyrite Sphalerite Orpiment Pentalandite Realgar | Anglesite | Wulfenite | Fluorite Calcite Witherite Magnesite Dolomite Apatite Scheelite Smithsonite | Chromite Ilmenite Corundum Pyrolusite Linonite Borax Wolframite Columbite Tantalite Rutile Casselerite | Beryl Feldspar Sillimanite Garnet Quartz |
| | Native Au, Pt, Ag, Cu | | | Rhodochrosite Siderite Monazite | | |

5 Group 6
 Zircon
 Willemite
 Hemimorphite
 Beryl
 Feldspar
 Sillimanite
 Garnet
 Quartz

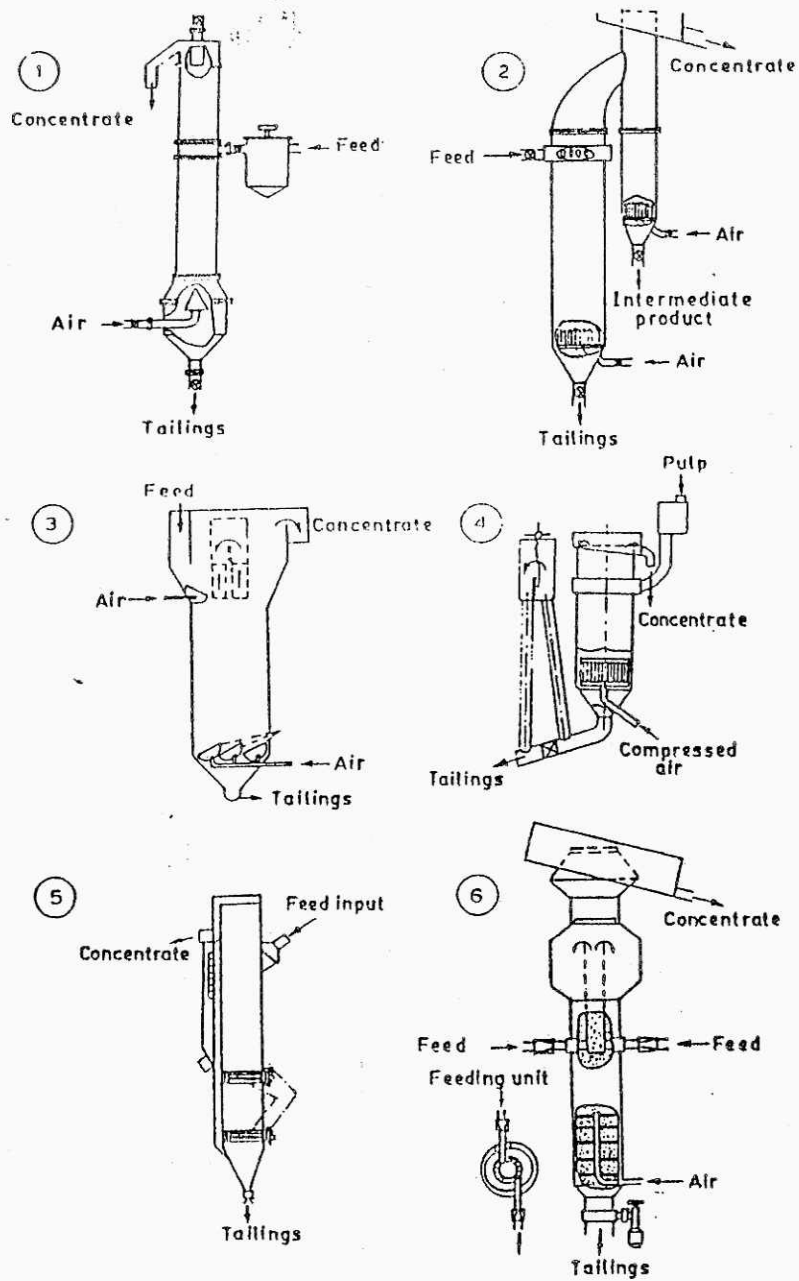


Fig. 9 : Different designs of flotation column.

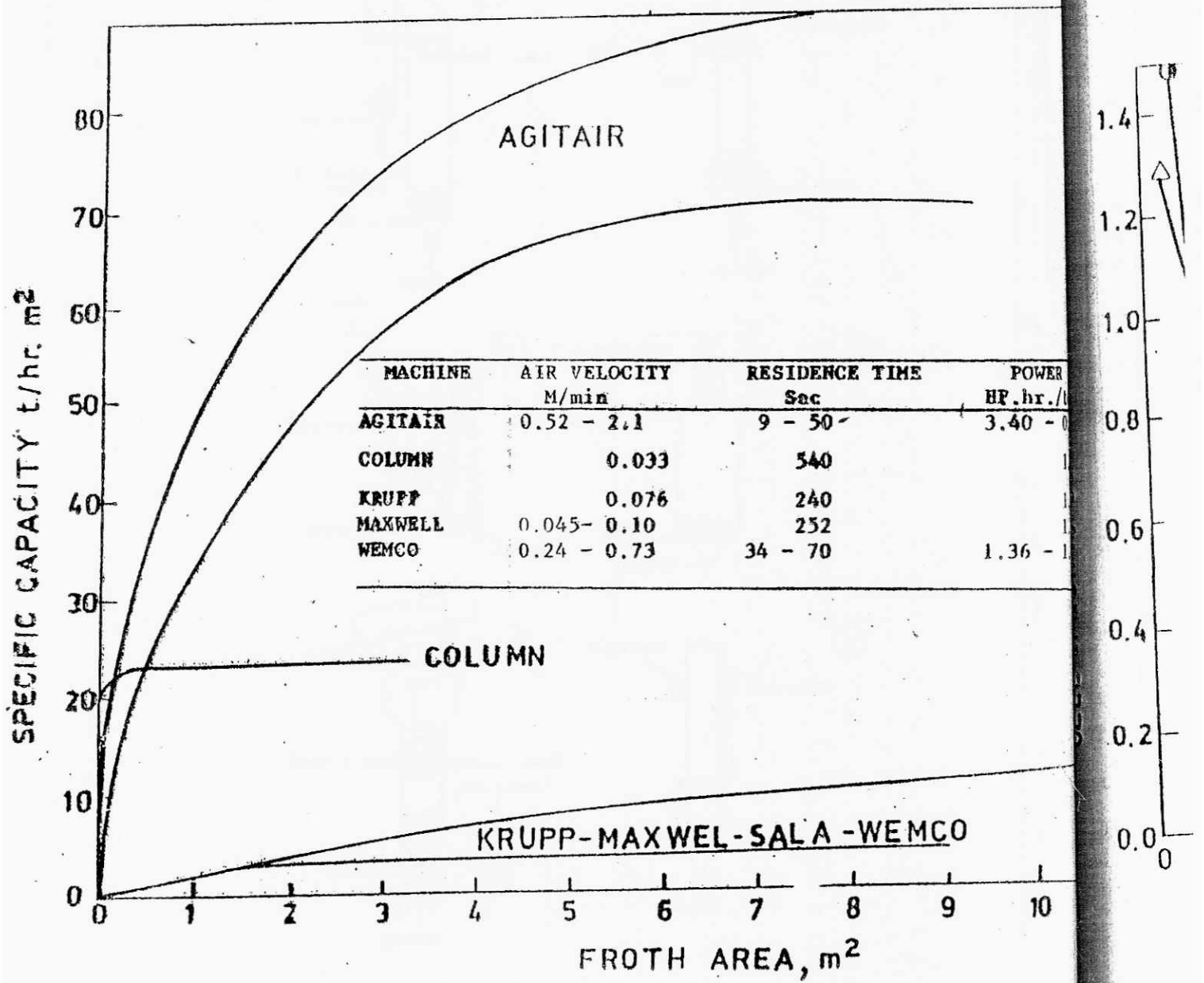


Fig. 10 : Specific capacity of flotation equipments
(Narasimhan 1983).

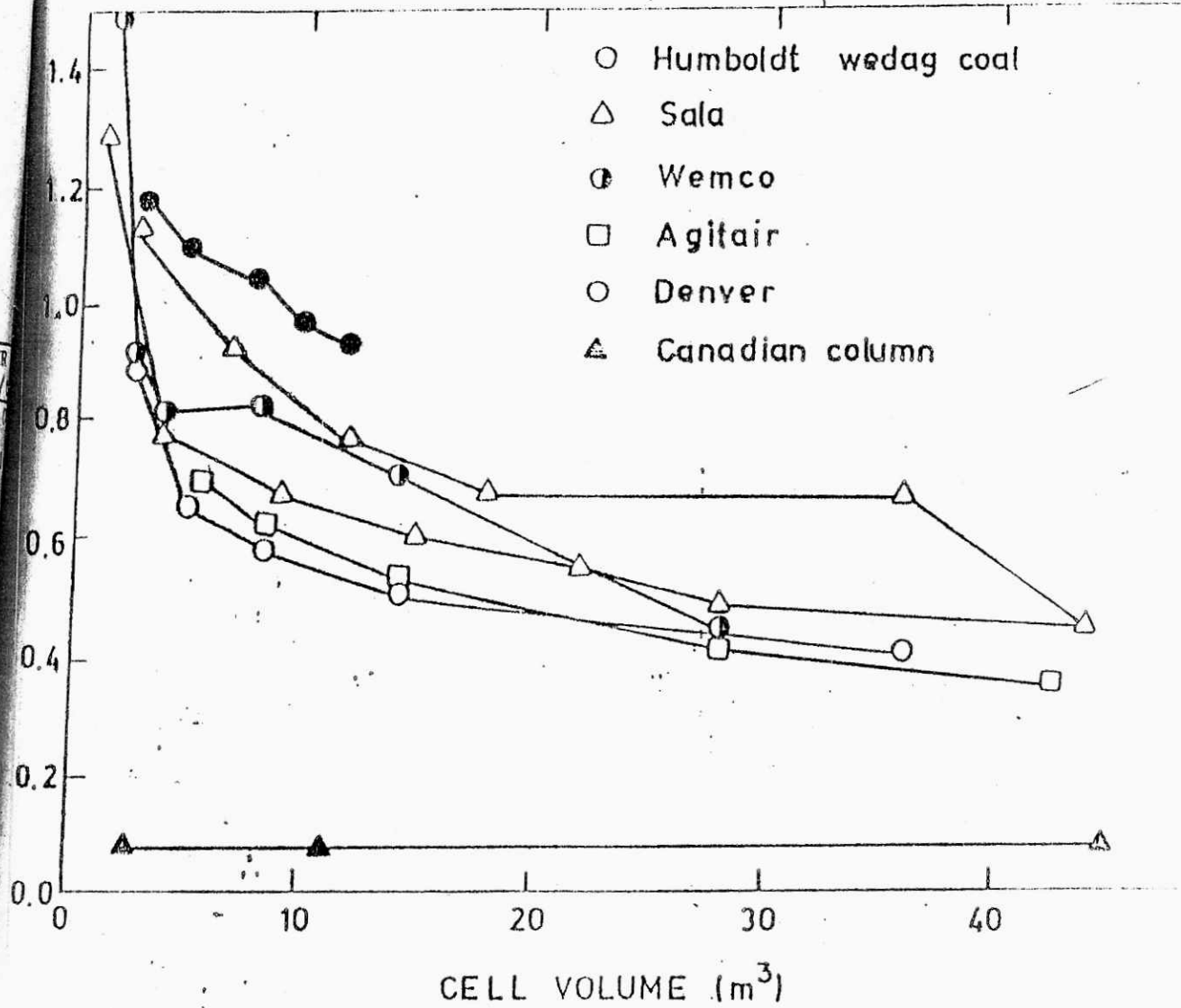


Fig. 11 : Relation of specific surface area to cell volume of flotation machines (moon 1982).

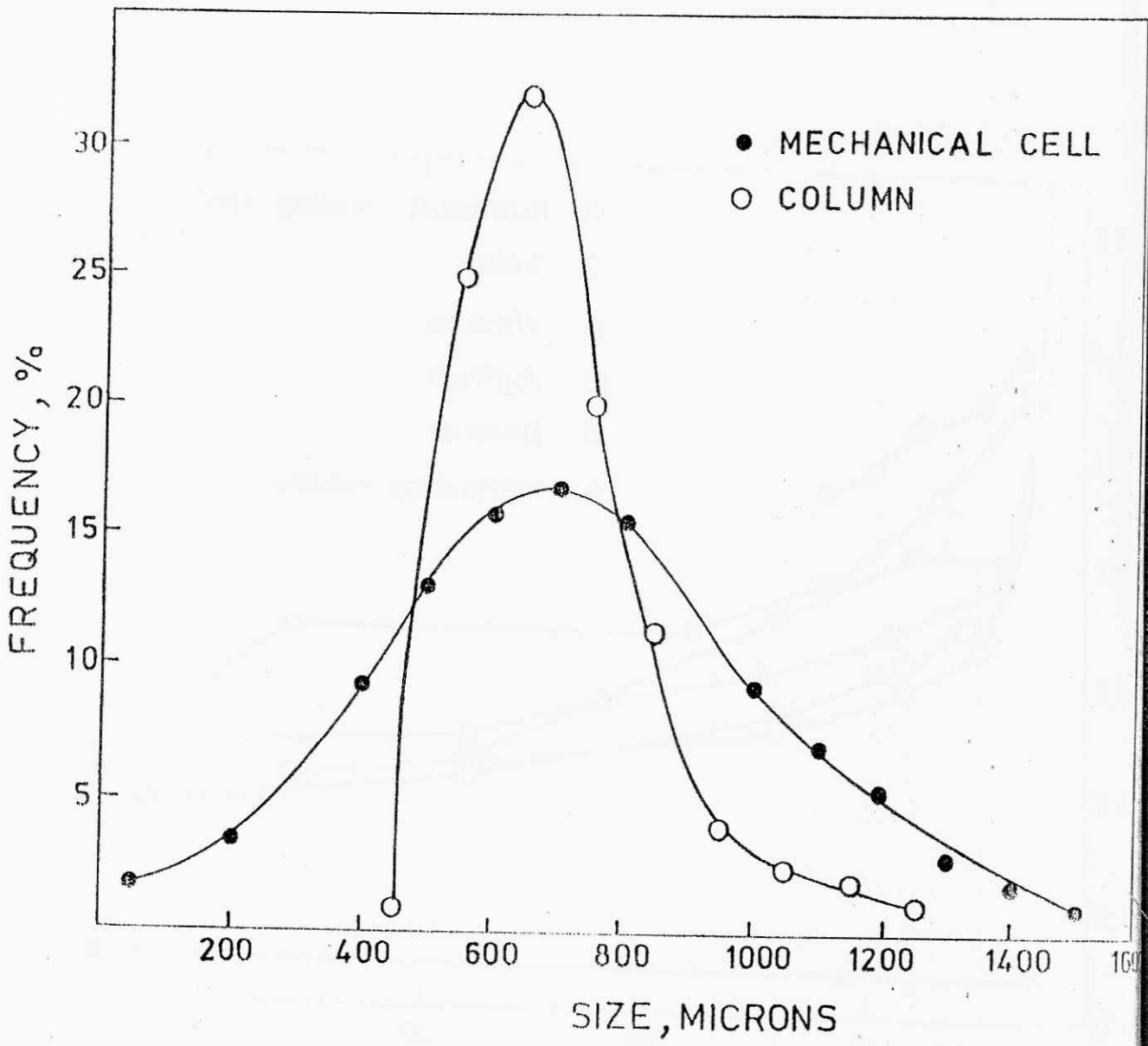


Fig. 12 : Bubble size distribution

Small
on 1

0.1
0.02
0.06
0.04
0.02
0.01
0.30
0.00
0.00
0.00
0.00

0.691

CELL

Smaller particles
on bigger bubbles

larger particles
bridged by smaller
bubbles

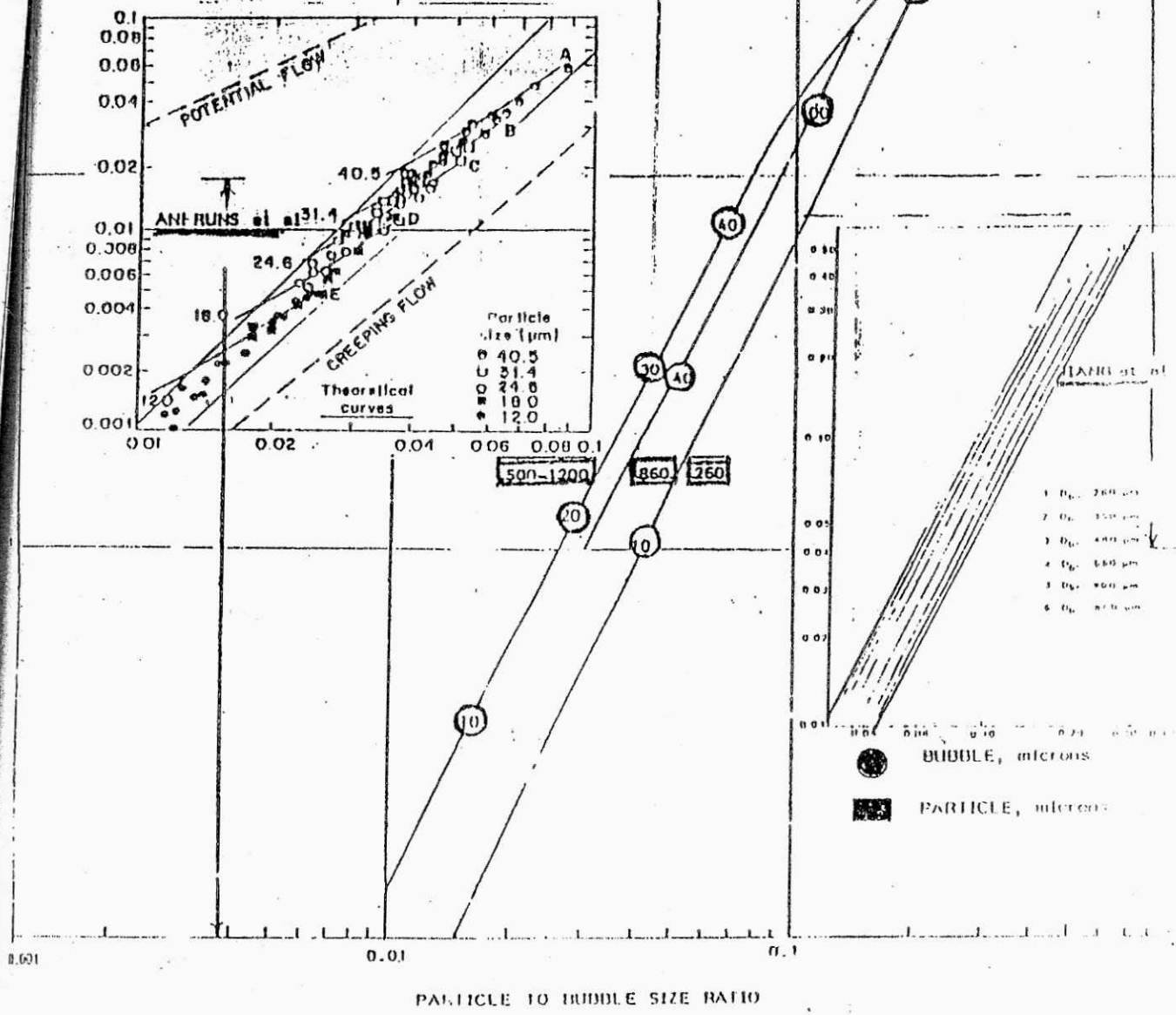


Fig. 13 : Dependence of flotation efficiency on the ratio of particle to air bubble size.

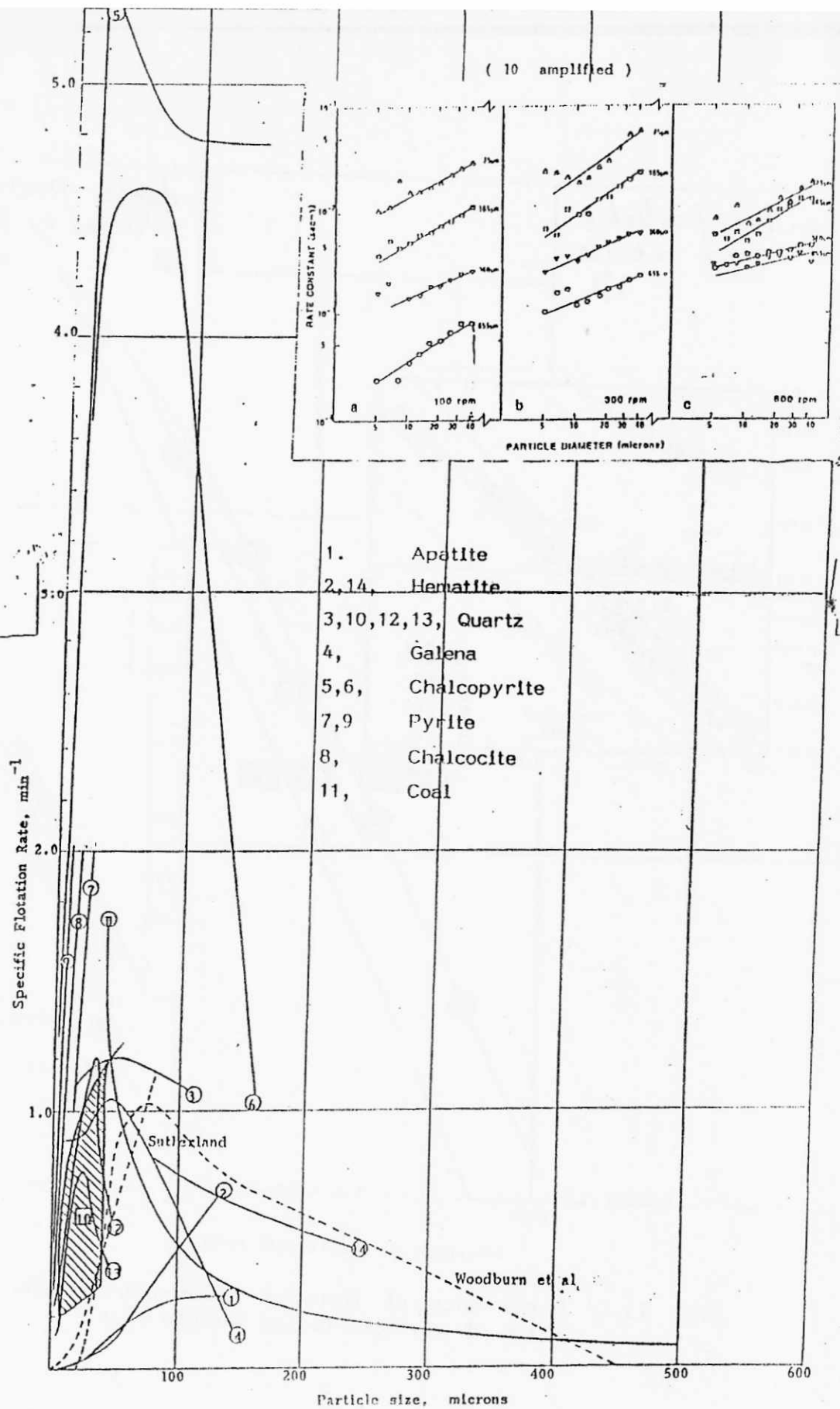


Fig. 14 : Variation in flotation rate constant for different minerals.

(a)

(b)

(c)

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