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Fine particle processing – A difficult problem for mineral engineers

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ABSTRACT

In general, most of the ores contain valuable mineral in finely disseminated form resulting in the recovery of these fine mineral particles exceedingly difficult. Mineral industries in common generate a lot of rejects in the form of fines and slimes, which ultimately create environmental and social problems besides causing losses of mineral values. In view of the recent stringent policy imposed by the Govt. of India on environment, there is an urgent need to attempt a possible solution to such problems. In this paper, why slimes are a problem, the limitation of present processes and equipment and the advances in mineral processing for recovery of mineral values from fines have been focussed.

INTRODUCTION

In general most of the ores contain valuable minerals in finely disseminated form resulting in the recovery of these fine mineral particles exceedingly difficult. As the good grade ores are diminishing fast, it is highly essential to recover the mineral values from the fines mostly being lost today. In most of the unit operations, the efficiency of recovering such fine particles is very low. A quantitative universal description of slimes is not possible, however, a definition that may be generally acceptable is the portion of an ore which is too fine to be commercially exploited by the processes developed for the coarser size fractions.

Slimes losses are common to all mineral processing operations but usually only attain economically significant levels in the processing of oxides and for few other soluble salt minerals, fluorspar and certain carbonates. In general slimes accumulation in most of the ore bodies are due to weathering and decomposition of certain rock components. Subsequently further secondary slimes are produced during comminution of an ore to its liberation size. As the quantity of the secondary slime is dependent on the liberation size and the natural breakage characteristics of the ore and to some extent on the comminution process used, attempts are possible to minimise the excess production of fines. However, there is nothing that can be done about the presence of primary slimes.

Because of the losses of mineral and metal values in the fine size range, considerable interest is growing in developing new processes and in improving old processes for the recovery of fine particles. Standard physical separations are made in mineral processing plants utilising differences in physical properties of desired and gangue minerals. Therefore, it is imperative to first of all discuss about the size limits of standard separation methods.

The fine particles below 100 microns includes ultrafines down to super colloids and treatment of such material is a critical problem. Everthough attempts have been made and techniques to some extent have been developed for concentration of such fines, but the problems of different magnitude, still remain to be solved before their commercial successes. It is important to note that these problems depend on a large extent on the fundamental behaviour of fine particle system and their characterisation.

Considerable interest is evinced in developing suitable process technology for recovering metal values from fine size ranges which are classified as below suggested by Sivamohan and Forssberg which is well accepted [1,2].

Fines – particles below 100 micron size
Very fines – particles below 20 micron size
Ultrafines – particles less than 5 microns size
Colloids – particles less than 1 micron size
Super colloids – particles less than 0.2 micron size

As the good grade ores are exhaustable, the dependence on low grade ores to meet the growing global demand in the mineral industry is linked up with the more serious problem of the decrease of liberation size and the direct consequence of this is more generation of fines. The most recent techniques which are being applied for processing of different fines and ultrafines are : (a) carrier flotation, (b) spherical agglomeration and emulsion flotation, (c) vacuum flotation, (d) electro flotation, (f) pressure release flotation, (g) flocculation, (h) high gradient magnetic separation, (i) super conducting magnetic separator, (j) Bartles mozley separator, (k) high intensity wet magnetic separator, (l) Reichert cones, (m) Bartles cross belt separator, (n) shear flocculation and (o) centifugal jig etc.

Limits of present concentration processes and equipment

In Fig. 1 the practical size range of various unit processes is given [3]. The upper size limit is essentially governed by the dominance of gravitational forces which

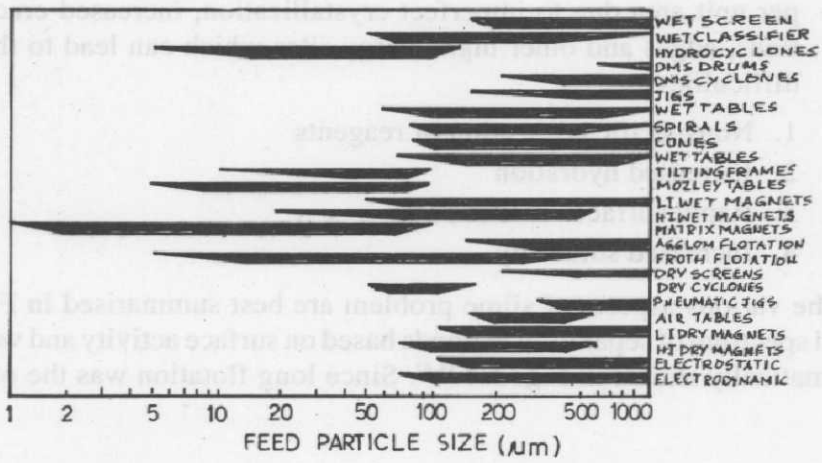

Fig. 1 : Effective range of application of conventional mineral processing techniques [3].

begin to interfere with the separation process at coarse size. The low size limit, however, is determined by the principles of separation on which the process under consideration operates. Any material having sizes below this lower size limit would be considered as a fine material for that operation. It is evident from this diagram that at present only leaching can be used for the commercial extraction of metals from ores in the complete sub-sieve size range. Unfortunately with respect to run of mine ore, this process is only applicable in the limited fields of gold, copper and uranium extraction although the use of bacterial leaching may eventually widen the scope of the process.

Why slimes are a problem?

The handling of very fine particles is a problem mainly because they have a small mass, high surface area and also high surface energy.

A) Small mass leads to (1) low particle momentum, (2) heterocoagulation, (3) particle entrainment in concentrates (e.g., froth), (4) low probability of collision with a bubble and (5) difficulty in overcoming the energy barrier between particle and particle and particle and bubble.

B) High surface area leads to (1) a high dissolution rate in water, (2) adsorption of large quantity of chemicals, (3) rigidity of froth, (4) high pulp viscosity and (5) undesirable coating of the valuable particles by ultrafine gangue particles.

C) It is also often said that the very fine particles can have a high surface energy per unit area due to imperfect crystallization, increased cracks, dislocations, edges and other high energy sites which can lead to the following difficulties :

1. Nonspecific adsorption of reagents
2. Increased hydration
3. Rapid surface reaction, and
4. Increased solubility

The various aspects of slime problem are best summarised in Fig. 2 [4]. The broad spectrum of separation methods based on surface activity and wettability are schematically shown in Fig. 3-4 [5-6]. Since long flotation was the only physico-

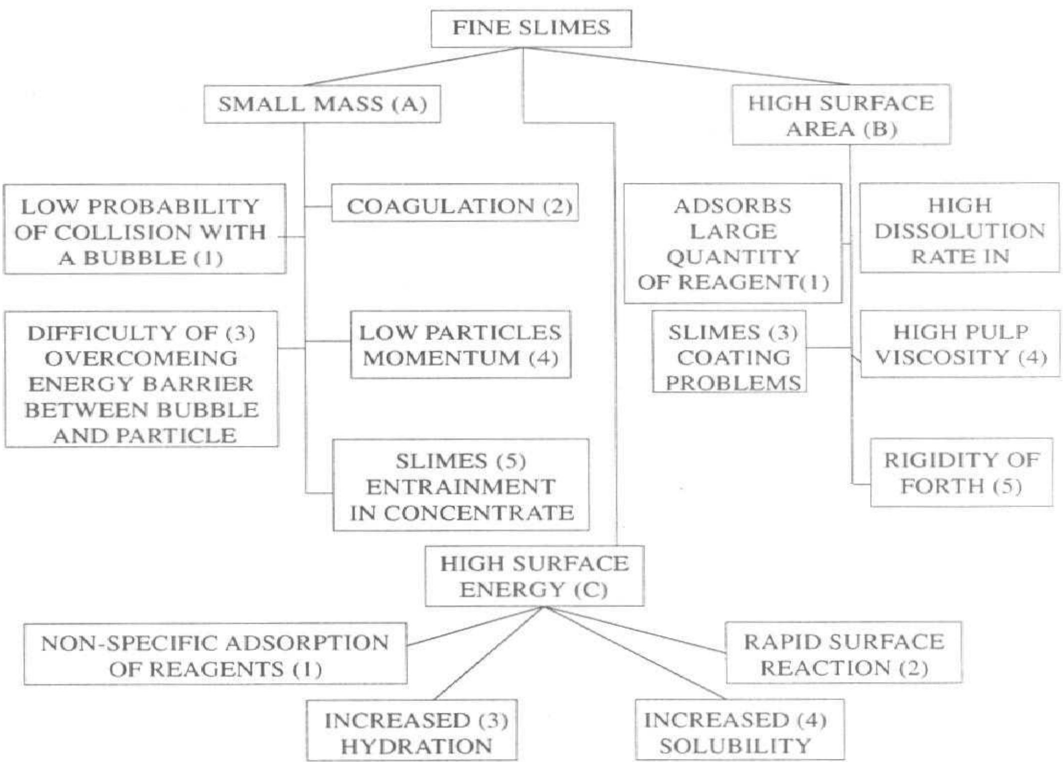

Fig. 2 : The various aspects of the slimes problem with particular reference to flotation [4].

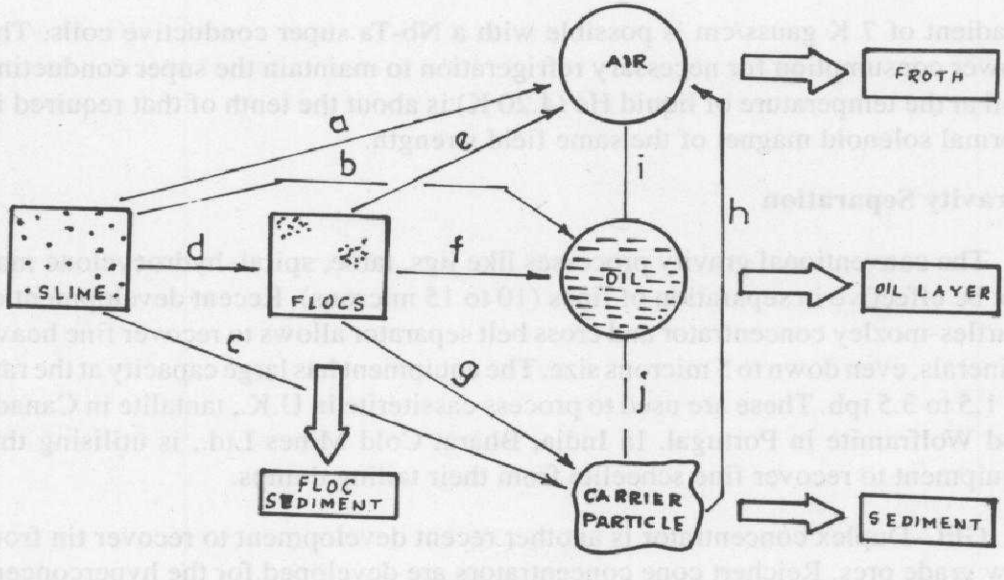

Fig. 3 : Beneficiation of mineral fines [6].

chemical methods over pure chemical treatment when the reagent requirement is much less only 0.01% of that required for dissolution. Nearly all of the operations dealing with very fine particles are carried out in aqueous media. As is well known, the surface and interfacial properties of these colloidal particles, and particularly electrical phenomena dominate their behaviour. It is because of this that the separation methods for fine particles are usually based on differences in surface and interfacial properties of the materials to be separated.

FINE PARTICLE PROBLEMS AND APPLICATION OF SOME UNIT PROCESSES

Magnetic Separation

Both low and high intensity wet magnetic separations operate over a fairly wide size range and are almost as effective as flotation for selectively recovering very fine particles. The former process is, however, limited to the separation of ferro magnetics, and the latter, although having a wider application, is considerably more expensive to operate. The main problem with wet magnetic separation system is not the magnetic flocculation of very fine particles but the recovery of these flocs against the inertial forces developed within the separators.

High intensity and high gradient magnetic separators are now increasingly in use to separate feebly magnetic minerals from fines and slimes. Use of ceramic magnet, super conducting magnet in place of Alnico magnet have increased the potential application of this technique. A field strength of 150 K gauss with high gradient of 7 K gauss/cm is possible with a Nb-Ta super conductive coils. The power consumption for necessary refrigeration to maintain the super conducting coil at the temperature of liquid He (4.20 K) is about the tenth of that required in normal solenoid magnet of the same field strength.

Gravity Separation

The conventional gravity processes like jigs, table, spiral, hydrocyclone may not be effective in separation of fines (10 to 15 microns). Recent development of Bartles-mozley concentrator and cross belt separator allows to recover fine heavy minerals, even down to 5 microns size. The equipment has large capacity at the rate of 1.5 to 3.5 tph. These are used to process cassiterite in U.K., tantalite in Canada and Wolframite in Portugal. In India, Bharat Cold Mines Ltd., is utilising this equipment to recover fine scheelite from their tailing dumps.

GEC-Duplex concentrator is another recent development to recover tin from low grade ores. Reichert cone concentrators are developed for the hyperconcentration of cassiterite and gold, beneficiation of iron ore, concentration of titanomagnetite, recovery of tungsten, scavenging uranium and zircon from flotation tailings and upgrading of oxidised Cu-Pb ores. Reichert concentrators are currently being tested at Kudremukh Iron Ore Co. in India for the separation of iron values from the tailings.

A wide range of Reichert plastic spirals with fibre glass reinforcement is made by Mineral Deposits Ltd., Australia. The various models have different through profiles to give a choice to feed characteristics. These spirals are currently used for the concentration of chromite, dense minerals (rutile, limenite and zircon), silica sand, gold and also for coal cleaning in the fine size range.

A portable tromel jig was specially developed for the concentration of placer deposits by Denver Equipment Company, U.K. This jig uses half as much water as other jigs and allows separation of small amounts of high grade concentrate. It is suitable for minerals with high specific gravities. New types of jigs (Batac Jig) have also been developed to treat particles in the size range of flotation to reduce the cost of operation and gaining momentum for its use at various places for appropriate feeds.

Out of the various gravity systems the flowing film techniques offers the best chance for the recovery of fine particles because all separations are dependent on a large extent on the depths of settlement required and the fluid flow through the machine. Thus the larger surface area provided by shaking tables and tilting frames together with the small settlement zone are both conducive to the recovery of fine particles. However, the mass of small particle is low and for efficient operation the separation of minerals of even relatively high density differential is normally limited to particles above 20 micron in size.

Magneto Hydrostatic Separation (MHS)

A combination of magnetic and gravitational forces has opened a newer avenue in dense media separation. The forces act on a magnetic fluid in a static magnetic field gradient. Paramagnetic liquids may be salt solution of Mn (ores), Fe (ores), Co (ores) chlorides and nitrates. Sometimes an ultrafine ferromagnetic suspension of iron, ferrite or magnetite in aqueous or organic liquid ferrofluid is used. The magnetic field gradient exerts forces on the magnetic fluid in the direction of increasing field strength. Particles present in the fluid experience an apparent density of 15 g/cm^3. The density may be simply regulated by varying magnetic field strength. This is interesting to note that in a single operation several compo-

Table 1 : New slimes processes, present state of the technology (symbols refer to Fig. 2)

Process	Aspects of the slimes problem which the process Eliminates	reduces	has no effect	Not relevant	Present scale of operation
Piggy-back	A3-4	A1-A2 A5	B,C		Limited commerical operation
Column flotation	A5	A1-B5	A2-4, B1-4, C		Limited Plant trials
Mozley table		A4, B4, A2		B1-3, B5 C, A1-A3	Limited Commerical plant
Electrostatic separation (with pulsed corona)		A4, A5		B, C A1-3	Laboratory trials
Liquid-liquid extraction(spherical agglomeration etc.)		A1,A3 A4,A5	A2 B1-4, C	B5	Pilot plant trials
Selective flocculation	A4	A2,A5 B1,B3	B3-B4 C	B5,A1 A3	Pilot plant trials
Electrophoresis (non aqueous)	A4,B2 C4	A2,A5	B1,B3 B4,C1-3,	A1,A3 B5	Laboratory trials

nents may be separated including fines and ultrafines.

NEW METHODS OF SLIME TREATMENT

Some of the emerging technique for the treatment of very fine particles are summarised in Table 1 and all of these symbols refer to Fig. 2. The development of column flotation was largely in order to increase the capacity of flotation equipment particularly with respect to fine feeds and to permit a more efficient cleaning system of the concentrate produced. With respect to the slime problem, this system therefore provides more effective forth cleaning (reduction in slime entrainment). With respect to gravity concentration processes recently developed, the Bartles-mozley concentrator, has been considered a significant advancement. It definitely extends the range of operation for the recovery of heavy minerals down to particle sizes 100 to 5 and is also effective in the presence of colloidal slimes.

The size range of application of magnetic and electrostatic separators has been on the high tension roll unit. The effect of pulse corona discharge, high rotor speeds etc., have produced satisfactory separation down to particle sizes of 5 µm.

The use of oil/water emulsions with their extremely large interfacial areas, is an obviously attractive method for the treatment of slimes. The separation of the oil and water phases after emulsification can be done by screening. If particle is stabilized, spherical agglomerates form, by liquid-liquid extraction or with relative low oil concentrations by flotation. Different oil based processes with characteristics of separation is shown in Table 2.

Table 2 : Characteristics of separation process using oil

Techniques	Ionic Collector	Oily Collector	Oil Consumption	Conditioning	Method of separation
Extender flotation	Yes	Yes	0.05–0.5	Regular	Flotation
Agglomeration flotation	Yes	Yes	a few kg/t	Intense	Flotation
Emulsion	No	Yes	up to a few kg/t	Regular	Flotation
Oil agglomeration	No*	Yes	5–10%	Slow/intense shearing	Sizing
Liquid-liquid extraction	Yes	Yes**	N/A	Intense	Phase separation

One of the most promising of the emerging slime processes is that of selective flocculation. Success of the process will depend upon obtaining at least one component well dispersed and also having significant differences in the surface properties of the minerals in the system.

Selective flocculation technique is increasingly becoming popular to treat fine particles especially below 20 microns. This technique is an industrially established process for the concentration of nonmagnetic taconites. For the selective flocculation of copper minerals, PAMC chelating polymers (Polyacylamide-glyoxalbis-hydroxymal) have been synthesised and have been tested successfully. Polymer flocculants those are physically surface active by virtue of hydrophobic nature, adsorb selectively on hydrophobic minerals. This may be used for selective flocculation of hydrophobic minerals in the presence of hydrophyllic slimes. In a three stage selective flocculation process, applied to copper ore from Zaire on which flotation was almost completely ineffective, about 20.0% copper grade could be obtained with 65.0% recovery.

There is a new development in selective flocculation in which fine material slimes are treated with a conventional flotation collector, whose selective adsorption on certain mineral species provides the differentiation in surface characteristics before the flocculant is applied. The flocculant then added will only adsorb on the hydrophobic surfaces resulting from the collector adsorption. This method provides simpler, cheaper and probably more widely applicable method for obtaining selectiveity than that provided by specially prepared selective polymers.

Challenges

The role of mineral technologists has become very difficult and challenging due to

(a) Treatment of very lean, complex and disseminated ores

(b) Increase in global requirement, with rigid specifications

To overcome the challenges, mineral technologist is working simultaneously in two directions. Firstly, he is processing forward the engineering developments of the equipments and processes. Secondly at the same time, he is exploring the fundamental and applied aspects of research in the area of mineral processing to evolve systematic and scientific approaches for solving the existing and any new problem.

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