PRINCIPLES OF EXTRACTIVE METALLURGY (1403)

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CLASSIFICATION

FREE AND HINDERED SETTLING

- ## INTRODUCTION TO CLASSIFICATION

Classification can be described as separating mixtures of fine particles into two or more products, depending on their variations of size, shape, and specific gravity, by allowing these particles to settle in a fluid medium. In mineral processing, this is usually water, and wet classification is generally applied to mineral particles which are considered too fine to be sorted efficiently by screening. The principles of classification are important in mineral separations utilising gravity concentrators. Classifiers also strongly influence the performance of grinding circuits.

- ## Principles of classification

We know that, when a solid particle falls freely in a vacuum, it is subject to constant acceleration and its velocity increases indefinitely, being independent of size and density. This is the reason why a ball of steel and a feather will reach the ground at same time in vacuum, but in mediums like air and water we have a factor called resistance which increases with increase in velocity. When equilibrium is attained between the gravitational and fluid resistances forces, the body reaches its terminal velocity and thereafter falls at a uniform rate. We use this phenomenon to attain classification between particles in a mixture.

The nature of the resistance depends on the velocity of the descent. At low velocities motion is smooth because the layer of fluid in contact with the body moves with it, while the fluid a short distance away is motionless. Between these two positions is a zone of intense shear in the fluid all around the descending particle. Effectively all resistance to motion is due to the shear forces or viscosity of the fluid and is hence called viscous resistance

The resistance offered at high velocities mainly depends on the fluid displaced by the body , at that point of time the viscous resistance is quite less, the main resistance there is turbulent resistance

Whether viscous or turbulent resistance predominates, the acceleration of particles in a fluid rapidly decreases and the terminal velocity is quickly reached.

- FREE SETTLING

Free settling takes place when individual particles fall freely in a fluid medium without being touched by other particles and with the fluid being still. For well dispersed pulps free settling dominates when the percentage by weight of solid is less than about 15%.

Consider a spherical particle of diameter d and density Ds falling under gravity in a viscous fluid of density Df under free settling conditions i.e. ideally in a fluid of infinite extent. Three forces acting on the particle: Gravitational force acting downward, an upward buoyant force due to the displaced fluid, and a drag force D acting upward.

The equation of motion of the particle is:

F(gravity)- F(buoyancy)-F(drag)=m(dx/dt)

$$mg - m'g - D = m(dx/dt)$$

where m is the mass of the particle, m' is the mass of the displaced fluid, x is the particle velocity, and g is the acceleration due to gravity.

When terminal velocity is reached acceleration i.e. dx/dt is equal to zero and hence, $D=g(m-m')$

Therefore, using the volume and density of sphere

$$D = (\pi/6)gd^3(Ds-Df)$$

Stokes assumed that the drag force on a spherical particle was entirely due to viscous resistance and deduced the expression:

$$D = 3\pi d\eta v$$

where η is the fluid viscosity and v is the terminal velocity.

Hence, $3\pi d\eta v = (\pi/6)gd^3(Ds-Df)$

$$v = gd^2(Ds-Df)/18\eta$$

This expression is known as Stokes' law.

Newton assumed that the drag force was entirely due to turbulent resistance and deduced

$$D=0.055\pi d^2v^2Df$$

Therefore, $V= [3gd(Ds-Df)/Df]^{1/2}$

This is Newton's law for turbulent resistance.

Stokes' law is valid for particles below about 50 µm in diameter and Newton's law holds for particles larger than about 0.5cm in diameter. Therefore an intermediate range of particle size, which corresponds to the range in which the most wet classification is performed in which neither law fits experimental data.

Stokes' law for a particular fluid can be simplified to

$$V=k1d^2(Ds-Df)$$

Newton's law can be simplified to

$$V=k2[d(Ds-Df)]^{1/2}$$

Where k1 and k2 are constants and (Ds-Df) is known as the effective density of a particle Ds in a fluid density Df.

Both laws show that the terminal velocity of a particle in a particular fluid is a function only of the particle size and density. It can be seen that:

1. If two particles have the same density, then

the particle with the larger diameter has the

higher terminal velocity.

2. If two particles have the same diameter, then

the heavier particle has the higher terminal

velocity.

Consider two mineral particles of density Da and Db and diameters da and db respectively, falling in a fluid of density Df at exactly the same settling rate.

Hence, From Stokes' law for fine particles:

$$da^2(Da-Df) =db^2(Db-Df)$$

or $da/db=[(Db-Df)/(Da-Df)]^{1/2}$

This expression is known as the free settling ratio of the two minerals, that is the ratio of particle size required for the two minerals to fall at equal rates.

Similarly, from Newton's law the free settling ratio of large particles is:

$$da/db=(Db-Df)/(Da-Df)$$

The general expression for free settling ratio can be deduced as:

$$da/db=[(Db-Df)/(Da-Df)]^n$$

where n=0.5 for small particles obeying Stokes' law and n=1 large particles obeying Newton's law.

The free-settling ratio is therefore larger for coarse particles obeying Newton's law than for fine particles obeying Stokes' law. This means that the density difference between the particles has a more pronounced effect on classification at coarser size ranges. This is important where gravity concentration is being utilised Over-grinding of the ore must be avoided, such that particles are fed to the separator in as coarse a state as possible, so that a rapid separation can be made, exploiting the enhanced effect of specific gravity difference. The enhanced gravity effect does, however, mean that fine heavy minerals are more likely to be overground in conventional ball mill-classifier circuits,so it is preferable where possible to use rod mills for the primary coarse grind.

- ## Hindered settling

If the settling is carried out with high concentration of solid to liquid so that particles are so close together that collision between particle is practically continuous and the relative fall of particle involves repeated pushing apart of the lighter by the heavier particles it is called hindered settling
As the proportion of solids in the pulp increases, the effect of particle crowding becomes more apparent and the falling rate of the particles begins to decrease. The system begins to behave as a heavy liquid whose density is that of the pulp rather than that of the carrier liquid; *hindered-settling* conditions now prevail. Because of the high density and viscosity of the slurry through which a particle must fall in a separation by hindered settling, the resistance to fall is mainly due to the turbulence created and a modified form of Newton's law can be used to determine the approximate falling rate of the particles

$$V = k[d(Ds-Dp)]^{1/2}$$

where DP is the *pulp density.*
The aforementioned laws show that the terminal velocity of a partical in a particular fluid is a function of particle size and density.it can be concluded that:
1.If two particles have the same density, then the particle with larger diameter has the higher terminal velocity.
2.If two particles have the same diameter,then heavier particles has higher terminal velocity.

The lower the density of the particle, the more marked is the effect of reduction of the effective density, Ds -DP , and the greater is the reduction in falling velocity. Similarly, the larger the particle, the greater is the reduction in falling rate as the pulp density increases.
This is important in classifier design; in effect, hindered-settling reduces the effect of size, while increasing the effect of density on classification.

The hindered-settling ratio is always greater than the free-settling ratio, and the denser the pulp, the greater is the ratio of the diameter of equal settling particles. For quartz and galena, the greatest hindered-settling ratio that we can attain practically is about 7.5. Hindered-settling classifiers are used to increase the effect of density on the separation, whereas free-settling classifiers use relatively dilute suspensions to increase the effect of size on the separation). Relatively dense slurries are fed to certain gravity concentrators, particularly those treating heavy alluvial sands. This allows high tonnages to be treated, and enhances the effect of specific gravity difference on the separation. The efficiency of separation, however, may be reduced since the viscosity of slurry increases with density. For separations involving feeds with a high proportion of particles close to the required density of separation, lower slurry densities may
be necessary, even though the density difference effect is reduced. As the pulp density increases, a point is reached where each mineral particle is covered only with a thin film of water. This condition is known as a quicksand, and because of surface tension, the mixture is a perfect suspension and does not tend to separate. The solids are in a condition of full teeter, which means that each grain is free to move, but is unable to do so without colliding with other grains and as a result stays in place. The mass acts as a viscous liquid and can be penetrated by solids with a higher specific gravity than that of the mass, which will then move at a velocity impeded by the viscosity of the mass.

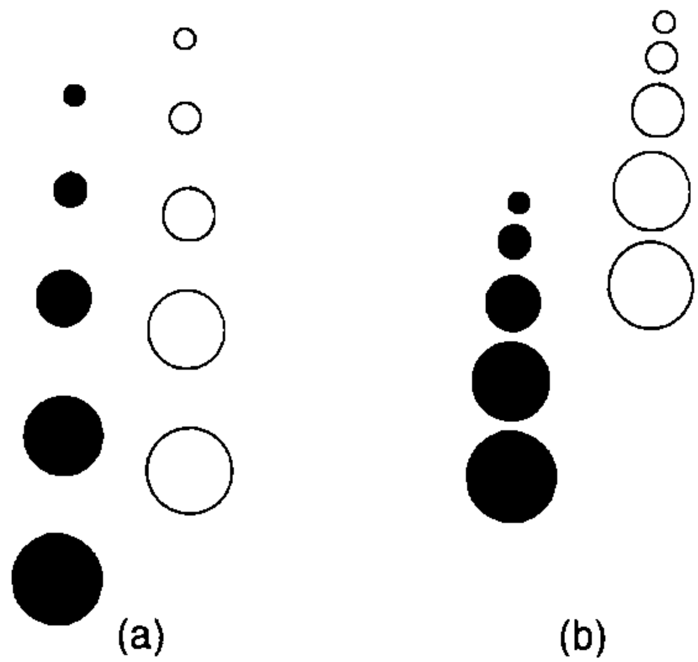


Figure 9.2 Classification by (a) free settling, (b) hindered settling

A condition of teeter can be produced in a classifier sorting column by putting a constriction in the column, either by tapering the column or by inserting a grid into the base.
Such hindered-settling sorting columns are known as *teeter chambers.* Due to the constriction, the velocity of the introduced water current is Greatest at the bottom of the column. A particle falls until it reaches a point where its falling velocity equals that of the rising current. The particle can now fall no further. Many particles reach this condition, and as a result, a mass of particles becomes trapped above the constriction and pressure builds up in the mass. Particles move upward along the path of least resistance, which is usually the centre of the column, until they reach a region of lower pressure at or near the top of the settled mass; here, under conditions in which they previously fell, they fall again. As particles from the bottom rise at the centre, those from the sides fall into the resulting void. A general circulation is built up, the particles being said to teeter. The constant jostling of teetering particles has a scouting effect which removes any entrained or adhering slimes particles, which then leave the teeter chamber and pass out through the classifier overflow. Cleaner separations can therefore be made in such classifiers.

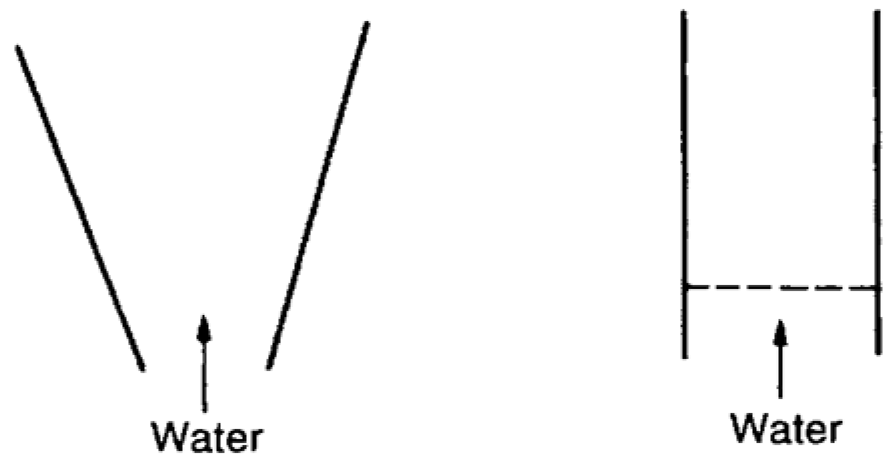
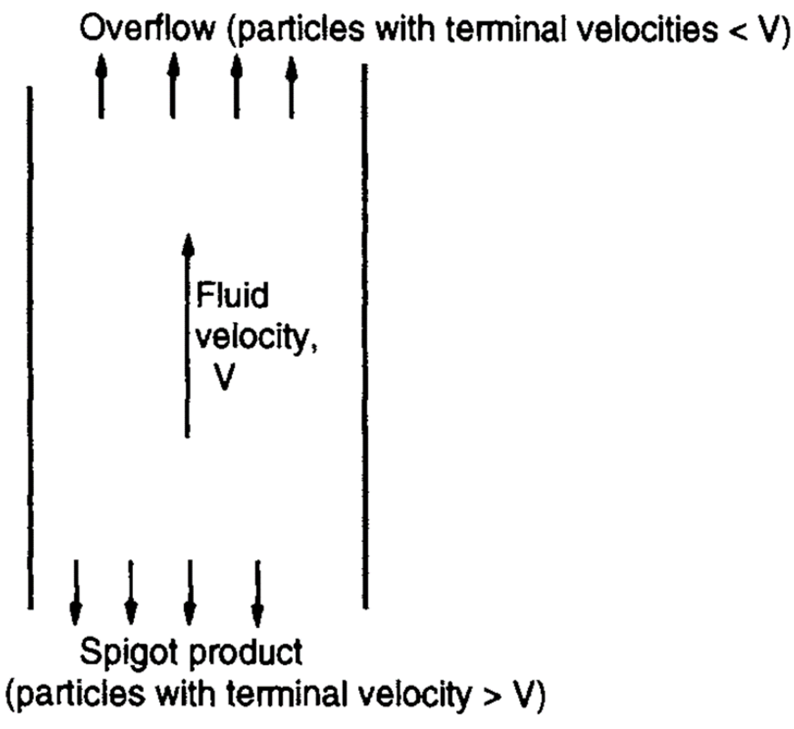


Figure 9.3 Teeter chambers

- ***WHAT ARE CLASSIFIERS***



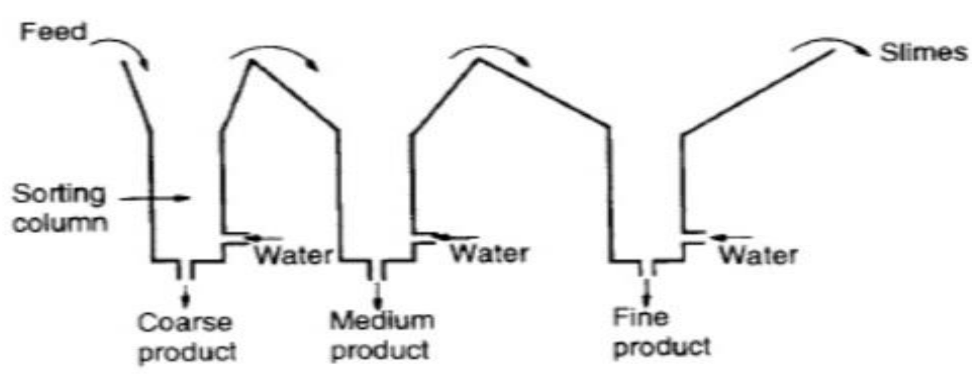
Classifiers consist essentially of a sorting column in which a fluid is rising at a uniform rate. Particles introduced into the sorting column either sink or rise according to whether their terminal velocities are greater or lesser than the upward velocity of the fluid. The sorting column therefore separates the feed into two products -an overflow consisting of particles with terminal velocities lesser than the velocity of the fluid and an underflow or spigot product of particles with terminal velocities greater than the rising velocity

- **TYPES OF CLASSIFIERS**

There are many different types of classifier have been designed and built. They are mainly grouped into two broad classes depending on the direction of flow of the carrying current. Horizontal current classifiers such as mechanical classifiers are essentially of the free-settling type and accentuate the sizing function; vertical current or hydraulic classifiers are usually hindered-settling types and so increase the effect of density on the separation.

Hydraulic Classifiers

Hydraulic classifiers is a classifier in which particles are sorted by specific gravity in a stream of hydraulic water that rises at a controlled rate; heavier particles gravitate down and are discharged at the bottom, while lighter ones are carried up and out. They normally consist of a series of sorting columns through which in each column a vertical current of water is rising and particles are settling out. The rising currents are graded from relatively high velocity in the first sorting column, to a relatively low velocity in the last so that a series of spigot products can be obtained with the coarser, denser particle in the first spigot and progressively finer product in the subsequent spigots. The finest fraction overflows the final sorting column. The size of each successive vessel is increased, partly because the amount of liquid to be handled includes all the water used for classifying in the previous vessels and partly because it is desired to reduce, in stages the surface velocity of the fluid flowing from one vessel to the next.



Principle of hydraulic classifier

Hydraulic classifiers may be free settling or hindered settling types. In free settling particles move down freely without any disturbance of the other particles, when an upward current of fluid flow is carried out.

Free settling classifiers are essentially conical bottomed tanks with a free settling zone. The coarser particles sink first and are removed from the bottom of the settling zone. These units are simple in design but often inefficient in sorting and sizing.

The greatest use for hydraulic classifiers in the mineral industry is for sorting the feed to certain gravity concentration processes so that the size effect can be suppressed and the density effect enhanced. Such classifiers are of the hindered-settling type. These differ from the free settling classifiers in that the sorting column is constricted at the bottom in order to produce a teeter chamber. The hindered-settling classifier uses much less water than the free-settling type, and is more selective in its action, due to the scouring action in the teeter chamber, and the buoyancy effect of the pulp, as a whole, on those particles which are to be rejected. Since the ratio of sizes of equally falling particles is high, the classifier is capable of performing a concentrating effect, and the first spigot product is normally of higher grade than the other products
This is known as the *added increment* of the classifier and the first spigot product may in some cases be rich enough to be classed as a concentrate.

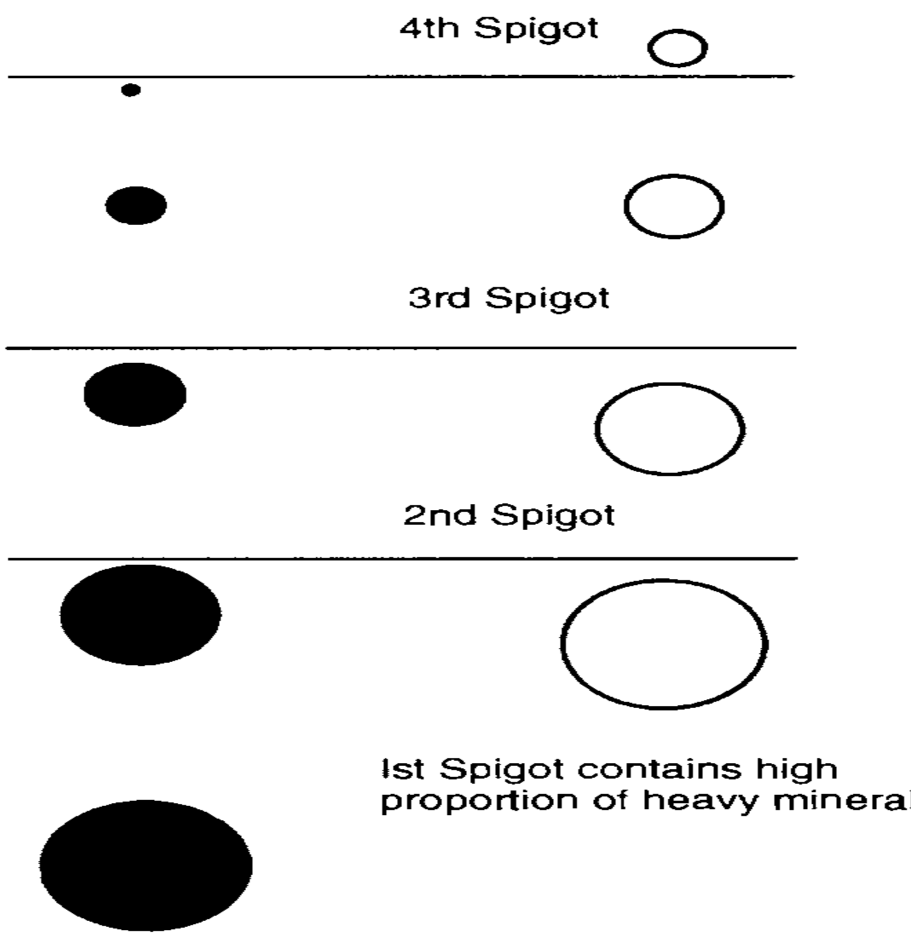
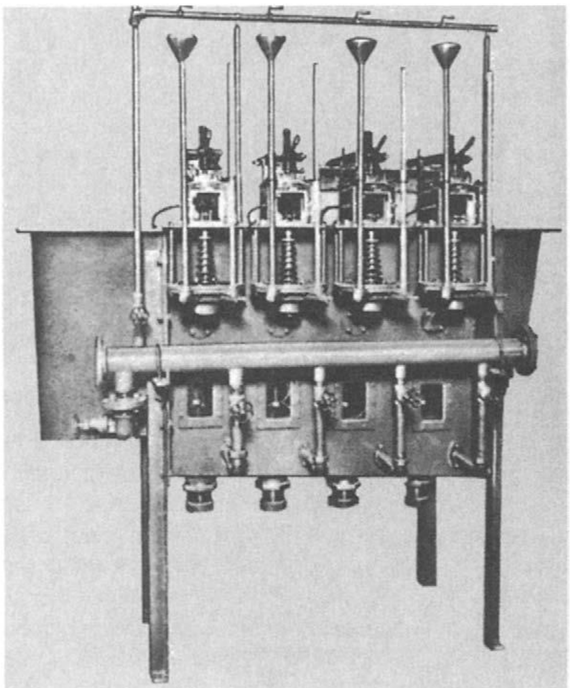
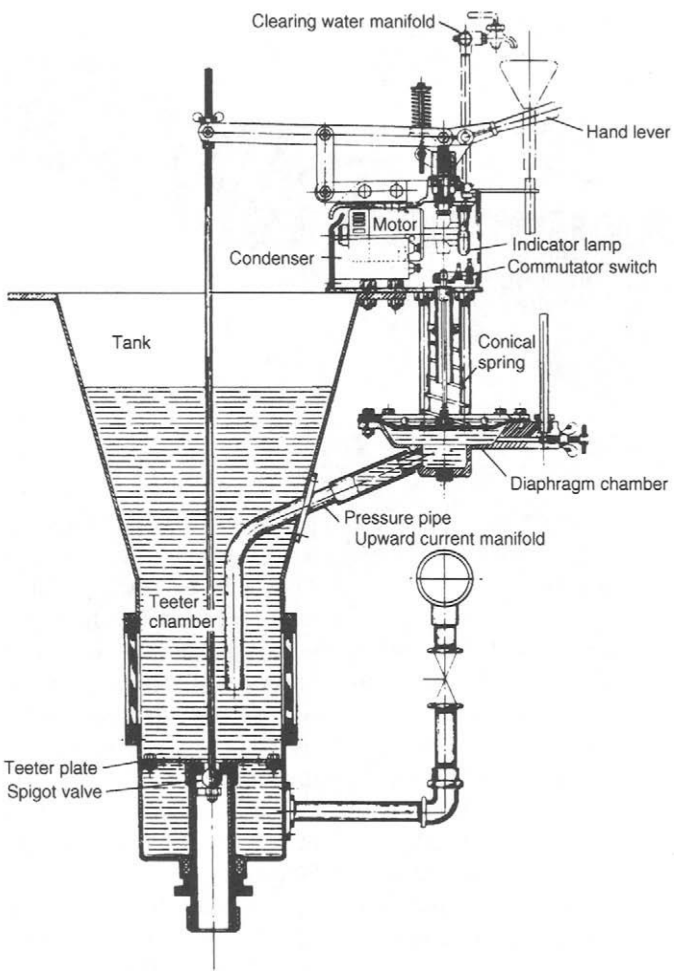


Figure 9.5 Added increment of hindered-settling classifier

During classification the teeter bed tends to grow, as it is easier for particles to become entangled in the bed rather than leave it. This tends to alter the character of the spigot discharge, as the density builds up. In modern multi-spigot *hydrosizers* the teeter bed composition is automatically controlled. The Stokes hydrosizer is commonly used to sort the feed to gravity concentrators Each teeter chamber is provided at its bottom with a supply of water under constant head which is used for maintaining a teetering condition in the solids that find their way down against the interstitial rising flow of water. Each teeter chamber is fitted with a discharge spigot which is, in turn, connected to a pressure-sensitive valve so that the classifying conditions set by the operator can be accurately controlled.



The valve may be hydraulically or electrically operated; in operation it is adjusted to balance the pressure set up by the teetering material. The concentration of solids in a particular compartment can be held extremely steady in spite of the normal variations in feed rate taking place from time to time. The rate of discharge from each spigot will, of course, change in sympathy with these variations, but since these changing tendencies are always being balanced by the valve, the discharge will take place at a nearly constant density. For a quartz sand this is usually about 65% solids by weight, but is higher for heavier minerals.



HORIZONTAL CURRENT CLASSIFIERS

These are the simplest form of classifier in which the main goal is only to separate the solids from the liquids. Consequently, they are sometimes utilized as dewatering devices in small scale processing plants. They are not suitable for fine classification or if a high separation efficiency is required.

They are often used in aggregate industry to de-slime coarse sand products. The principle of the settling cone shown in figure given below. The pulp is fed into the tank as a distributed stream, with the spigot discharge valve intially closed. When the tank is full, overflow of water and slimes commences, and a bed of settled sand builds until it reaches the desire level. The spigot valve is now opened and sand is discharged at a rate equal to that of the input. Classification by horizontal current action takes place ratially across zone D from the feed pipe to the overflow lip. The main difficulty in operation of such a device is the balancing of the sand discharge and deposition rates; it is virtually impossible to maintain a regular discharge of sand through an open pipe under the influence of gravity. Many different designs of cone have been introduced to overcome this problem..

In the "Floatex" separator, which consists essentially of a hindered-settling classifier over a dewatering cone, automatic control of the coarse lower discharge is governed by the specific gravity of the teeter column. The use of the machine as a desliming unit and in upgrading coal and mica, as well as its possible application in closed-circuit classification of metalliferous ores.

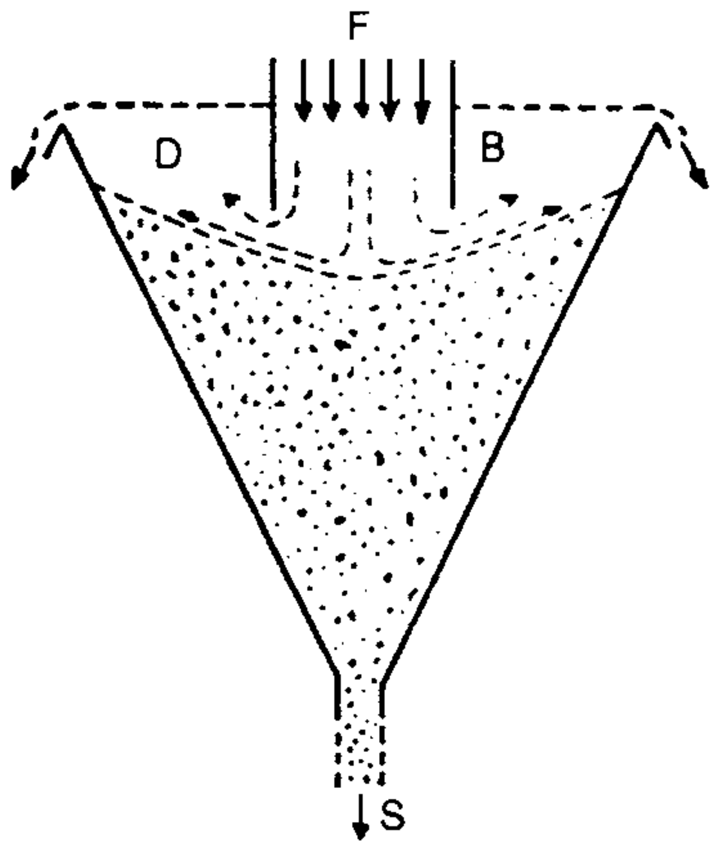
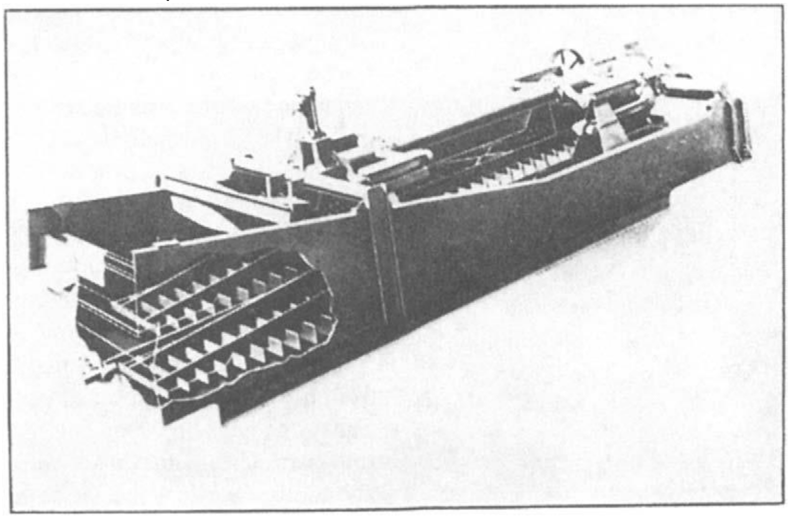


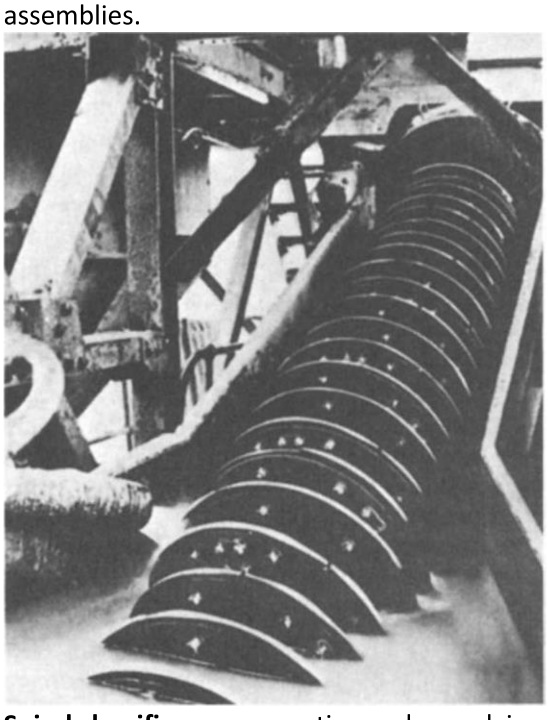
Figure 9.8 Settling cone operation

Mechanical classifiers -Several forms of classifier exist in which the material of lower settling velocity is carried away in a liquid overflow, and the material of higher settling velocity is deposited on the bottom of the equipment and is dragged upwards against the flow of liquid by some mechanical means. Mechanical classifiers have widespread use in closed-circuit grinding operations and in the classification of products from ore-washing plants. In washing plants they act more or less as sizing devices, as the particles are essentially unliberated, so are of similar density. In closed circuit grinding they have a tendency to return small dense particles to the mill, causing over grinding. They have also been used to densify dense media.

The pulp feed is introduced into the inclined trough and forms a settling pool in which particles of high falling velocity quickly fall to the bottom of the trough. Above this coarse sand is a quicksand zone where essentially hindered settling takes place. The depth and shape of this zone depends on the classifier action and on the feed pulp density. Above the quicksand is a zone of essentially free settling material, comprising a stream of pulp flowing horizontally across the top of the quicksand zone from the feed inlet to the overflow weir, where the fines are removed. The settled sands are conveyed up the inclined trough by mechanical rakes or by a helical screw. The conveying mechanism also serves to keep fine particles in suspension in the pool by gentle agitation and when the sands leave the pool they are slowly turned over by the raking action, thus releasing entrained slimes and water, increasing efficiency of the separation. Washing sprays are often directed on the emergent sands to wash the released slimes back into the pool.



The rake classifier utilises rakes actuated by an eccentric motion, which causes them to dip into the settled material and to move it up the incline for a short distance. The rakes are then withdrawn, and return to the starting-point, where the cycle is repeated; the settled material is thus slowly moved up the incline to the discharge. In the *duplex* type shown, one set of rakes is moving up, while the other set returns; Simplex and quadruplex machines are also made in which there are one or four raking assemblies.



Spiral classifiers use a continuously revolving spiral to move the sands up the slope. They can be operated at steeper slopes than the rake classifier, in which the sands tend to slip back when the rakes are removed. Steeper slopes aid the drainage of sands, giving a cleaner, drier product. Agitation in the pool is less than in the rake classifier which is important in separations of very fine material. The size at which the separation is made and the quality of the separation depend on a number of factors.

Increasing the feed rate increases the horizontal carrying velocity and thus increases the size of particle leaving in the overflow. The feed should not be introduced directly into the pool, as this causes agitation and releases coarse material from the hindered-settling zone, which may report to the overflow. The feed stream should be slowed down by spreading it on an apron, partially submerged in the pool, and sloped towards the sand discharge end, so that most of the kinetic energy is absorbed in the part of the pool furthest from the overflow.

The speed of the rakes or spiral determines the degree of agitation of the pulp and the tonnage rate of sand removal. For coarse separations, a high degree of agitation may be necessary to keep the coarse particles in suspension in the pool, whereas for finer separations, less agitation and thus lower raking speeds are required. It is essential, however, that the speed is high enough to transport the sands up the slope.

The height of the overflow weir is an operating variable in some mechanical classifiers. Increasing the weir height increases the pool volume, and hence allows more settling time and decreases the surface agitation, thus reducing the pulp density at overflow level, where the final separation is made. High weirs are thus used for fine separations.

Dilution of the pulp is the most important vari-able in the operation of mechanical classifiers. In closed-circuit grinding operations, ball mills rarely discharge at less than 65% solids by weight, whereas mechanical classifiers never operate at more than about 50% solids. Water to control dilution is added in the feed launder, or onto the sand near the vee of the pool. Water addition determines the rate of settling of the particles; increased dilution reduces the density of the weir overflow, and increases free settling, allowing finer particles to settle out of the influence of the hori-zontal current. Finer separations are thus produced, providing that the overflow pulp density is above a value known as the critical dilution, which is normally about 10% solids. Below this density, the effect of increasing rising velocity with dilu-tion becomes more important than the increase in particle settling rates produced by decrease of pulp density. The overflow therefore becomes coarser with increasing dilution (Figure 9.12). In mineral processing applications, however, very rarely is the overflow density less than the critical dilution.

One of the major disadvantages of the mechan-ical classifier is its inability to produce overflows of very fine particle size at reasonable pulp densities. To produce such separations, the pulp may have to be diluted to such an extent to increase particle settling rates that it becomes too thin for subse-quent operations. It may therefore require thick-ening before concentration can take place. This is undesirable as, apart from the capital cost and floor space of the thickener, oxidation of liberated parti-cles may occur in the thickener, which may affect subsequent processes, especially froth flotation.

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