

GRAVITY CLASSIFICATION & HYDROCYCLONE

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Classification is a method of separating mixtures of minerals into two or more products on the basis of the velocity with which the grains fall through 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.

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. Thus a lump of lead and a feather fall at exactly the same rate.

In a viscous medium, such as air or water, there is resistance to this movement and the value increases with velocity. When equilibrium is attained between the gravitational and fluid resistance forces, the body reaches its terminal velocity and thereafter falls at a uniform rate.

The nature of the resistance depends on the velocity of 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. At high velocities the main resistance is due to the displacement of fluid by the body, and viscous resistance is relatively small, this is known as turbulent resistance.

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

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 less 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 less than the velocity of the fluid and an underflow or spigot product of particles with terminal velocities greater than the rising velocity.

Free settling :

Free settling refers to the sinking of particles in a volume of fluid which is large with respect to the total volume of particles, hence particle crowding is negligible. For well-dispersed ore pulps, free settling predominates when the percentage of solids by weight is less than about 15.

Consider a spherical particle of diameter and density D_s falling under gravity in a viscous fluid of density D_f under free-settling conditions i.e., ideally in a fluid of indefinite extent. The particle is acted upon by three forces : a gravitational force acting downwards, an upward buoyant force due to the displaced fluid and a drag force D acting upwards. The equation of motion of the particle is

$$mg - m'g - D = m \frac{dx}{dt} \quad \dots \quad (1)$$

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

When the terminal velocity is reached, $dx/dt = 0$, and hence $D = (m - m') g$.

$$\text{Therefore} \quad D = \frac{\pi}{6} g d^3 (D_s - D_f) \quad \dots \quad (2)$$

Stokes assumed the drag force on a spherical particle to be entirely due to viscous resistance and deduced the expression.

$$D = 3\pi d\eta v \quad \dots \quad (3)$$

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

Hence, substituting in equation (2)

$$3\pi d\eta v = \frac{\pi}{6} g d^3 (D_s - D_f)$$

and

$$v = \frac{g d^2 (D_s - D_f)}{18\eta} \quad \dots \quad (4)$$

This expression is known as Stokes' law.

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

$$D = 0.055\pi d^2 v^2 D_f \quad \dots \quad (5)$$

Substituting in equation (2)

$$v = \left(\frac{3g d (D_s - D_f)}{D_f} \right)^{1/2} \quad \dots \quad (6)$$

This is Newton's law for turbulent resistance.

Stokes' law is valid for particles below about 50 micron in diameter. The upper size limit is determined by the dimensionless Reynolds number. Newton's law holds for particles

larger than about 0.5 cm in diameter. There is, therefore, an intermediate range of particle size, which corresponds to the range in which most wet classification is performed, in which neither law fits experimental data.

Stokes' law (4) for a particular fluid can be simplified to

$$v = k_1 d^2 (D_s - D_f) \quad \dots \quad (7)$$

and Newtons' law (6) can be simplified to

$$v = k_2 d(D_s - D_f)^{1/2} \quad \dots \quad (8)$$

where k_1 and k_2 are constants and $(D_s - D_f)$ is known as the effective density of a particle of density D_s in a fluid of density D_f .

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 densities D_a and D_b and diameters d_a and d_b respectively, falling in a fluid of density D_f at exactly the same settling rate. Their terminal velocities must be the same and hence from Stokes' law

$$d_a^2 (D_a - D_f) = d_b^2 (D_b - D_f)$$

or

$$\frac{d_a}{d_b} = \left(\frac{D_b - D_f}{D_a - D_f} \right)^{1/2} \quad \dots \quad (9)$$

This expression is known as the free-settling ratio of the two minerals, i.e., 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

$$\frac{d_a}{d_b} = \left(\frac{D_b - D_f}{D_a - D_f} \right) \dots \quad (10)$$

Consider a mixture of galena (density 7.5) and quartz (density 2.65) particles classifying in water. For small particles, obeying Stokes' law, the free settling ration (equation 9) is

$$\left(\frac{7.5 - 1}{2.65 - 1} \right)^{1/2} = 1.99$$

i.e., a small particle of galena will settle at the same rate as a small particle of quartz which has a diameter 1.99 times as large.

For large particles obeying Newton's law, the free settling ratio (equation 10) is

$$\left(\frac{7.5 - 1}{2.65 - 1} \right) = 3.94$$

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 mineral particles has a more pronounced effect on classification at coarser size ranges.

The general expression for free-settling ratio can be deduced from equations (9) and (10) as

$$\frac{da}{db} = \left(\frac{Db - Df}{Da - Df} \right)^n \quad \dots \quad (11)$$

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

The value of n lies in the range $0.5 - 1$ for particles in the intermediate size range of 50 micron - 0.5 cm.

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 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 particles.

$$v = k \ d(D_s - D_p)^{1/2} \quad \dots \quad (12)$$

where D_p is the pulp density.

The lower the density of the particle the more marked is the effect of reduction of the effective density, $D_s - D_p$, and the greater is the reduction in falling velocity. Similarly, the larger the particle the greater in 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.

This is illustrated by considering a mixture of quartz and galena particles settling in a pulp of density 1.5. The hindered settling ratio can be derived from equation () as

$$\frac{d_a}{d_b} = \frac{D_b - D_p}{D_a - D_p} \dots (13)$$

therefore in this system,

$$\frac{d_a}{d_b} = \frac{7.5 - 1.5}{2.65 - 1.5} = 5.22$$

A particle of galena will thus fall in the pulp at the same rate as a particle of quartz which has diameter 5.22 times as large. This compares with the free-settling ratio, calculated as 3.94 for turbulent resistance.

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.

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 fullteether 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.

A condition of teeter can be produced in a classifier sorting column by putting a constriction in 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 scouring 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.

Spiral Classifier

A spiral classifier consists of an inclined tank enclosing one or more revolving helixes, commonly called 'spirals'. The tank is equipped with an overflow weir and an overflow box for collecting the overflow product which generally consists of fine solids and water, although under certain conditions very nearly clear water may constitute the overflow. The settled product, commonly termed 'rake', is discharged at the upper end of the tank by the revolving spiral.

The raking mechanism is made up of double or single spirals mounted on a shaft, spirals being continuous from the overflow weir to a point above the feed entrance. The double and single spiral construction are termed double pitch and single pitch respectively.

The feed enters through a feed opening at one, or, in some cases, both sides of the tank and the overflow is discharged at the lower end over an adjustable weir. In some cases the feed and overflow points are reversed. The heavier, or coarser, solids settle to the bottom, and in simplex machines are advanced by the action of the spiral along the bottom and one side of the tank out of the settling pool to the point of discharge. In the case of duplex machines, the spirals are operated toward each other so that the sands are conveyed up the center of the tank between the spirals.

The lower end of the spiral is equipped with a lifting mechanism to remove the spiral from settled solids for ease of starting and inspection. A spiral drive is so arranged that the spiral may rotate and be lifted or lowered simultaneously.

Spiral classifiers are furnished in two general types : The high weir type in which the spiral is not completely submerged at the lower end, and the submerged-spiral type in which the spiral is completely submerged to provide a larger settling pool.

Spiral classifiers are generally set at a tank inclination of from 3 to 4 in/ft., although for special conditions these limits may be exceeded. The operating speed of the spiral varies generally between 10 RPM for small units to 2 RPM for large units, but these limits are exceeded for special conditions. The power required will depend upon the size of the classifier and the rake load. It varies from 1 HP on the small simplex sizes to 25 HP on the larger, duplex sizes.

Classification at a particular particle size, called the 'separation size' is accomplished by gently introducing a slurry of feed solids and liquid (usually water) into the classifier 'pool'. Minimal turbulence at the entry point promotes predictable settling rate, therefore, the use of a feeder box is best. For the same reason the feed should enter at or a little below the pool level and on the side opposite from the coarse conveying side on simplex machines. The depth a particle settles after entering the classifier depends on its hindered settling rate, its velocity and distance it must travel toward the overflow weir. By correlating time and velocity against settling rate, a specific separation can be performed.

The feed entry must be located so that the velocity of the liquid toward the weir, together with the distance to the weir allows proper time so that the specified fine particles will be carried over the weir while the specified coarse particles will settle below the weir height. These coarse particles settle to the bottom of the pool where the spiral (or helix) will convey these particles up the inclined tank and where they will be discharged out the upper end of the tank. While being conveyed the coarse fraction (rake) is agitated and washed in a counterflow manner so as to further reduce the amount of under-size fines carried out with the coarse rake fraction.

Operating Parameters

Spiral classification are mechanical gravity separators and hence depend on the difference in settling rate between coarse and fine/and/or heavy and light gravity particles in the pool. The variables easiest for an operator to control in an existing classifier installation are feed rate and turbulence. Concentration of solids in the feed and spiral

rotation speed affects both capacity and turbulence.

Some fundamentals laws of classification that apply are :

1. Coarse particles have a relatively faster settling velocity than fine particles of the same specific gravity
2. Heavy gravity particles have a relatively faster rate settling rate than light gravity particles of the same size.
3. Porous and/or irregularly shaped particles will generally settle slower than would be predicted for spherical impermeable particles of the same size classification and specific gravity.
4. Settling rates of solid particles become progressively slower as the viscosity or density of the fluid medium increases.
5. There is a point (called critical dilution) where lowering the density or viscosity by adding more liquid creates velocity effect toward the weir which overcomes the increase in settling rates, thereby coarsening the separation.
6. Conversely at the critical dilution point less liquid will cause a viscosity and buoyancy effect(hindered settling) which will also coarsen the separation.

The control of liquid into classifiers is important to the spiral classifier operator, although not nearly as critical as with hydrocyclones, since separation into overflow and

rake products is made largely by the buoyancy, viscosity and degree of agitation in the pool.

Lower water concentration creates lower velocity of the overflow toward the weir. This results in high overflow solids capacity per unit width of the weir. However, the resultant high percent solids results in a narrow spread of hindered settling rate of the particles. This makes for a 'dirty' separation with a fairly high percentage of misplaced particles.

High concentration of water past the critical dilution has the same effect. However, if the weir width is increased and the feed entry geometry is proper the critical dilution liquid concentration may be increased. Under those circumstances much sharper separation (lower percentage of misplaced particles) can be obtained.

Water in the overflow varies considerably. Often it is dictated by the next processing step. This would be flotation requiring say 30% solids 70% H_2O in the feed to the flotation cells. Often the total water to the classifier is specified and the overflow water is the amount left after deducting the water in the rake product. Sometimes there are no restrictions and the application engineer is free to specify the desirable amount of water necessary for the separation.

Total water to the classifier is usually introduced with the feed solids. However, if there is reason to spray wash the rake product on the drainage deck, this water is added to the feed water. Also, for various reasons, auxiliary water is sometimes added to the classifier, which reports to the overflow.

Water in the rake product varies to some degree. Depending on the coarseness of the solids and the specific gravity of the particles, it can vary from say 15% for fairly coarse solids of

high specific gravity (such as iron ore concentrate) to say 25% for fairly fine solids of low specific gravity (such as coal). In most cases this provides a rake product dry enough for transporting on a conveyor belt.

Conditions affecting the amount of water in the rake product :

1. Specific gravity of the particles.
2. Size of the particles.
3. Amount and position of spray washing on the drainage deck above the emergence of the solids from the pool, if any.
4. Slope of the drainage deck.
5. Length of the drainage deck.
6. Spiral RPM (transporting speed).
7. Special design features, such as separated outer shoes, a 'dam angle' at the bottom of the tank at the discharge lip or shortening the spiral at the discharge end.

Overflow

As the feed slurry enters the classifier pool, it immediately moves toward the overflow weir at a velocity dependent on the overflow volume and the width of the weir. These conditions determine the overflow weir crest.

During this travel, the solids, particles all settle downward at a settling rate dependent on their shape, their size, specific gravity and percent solids of the fluid.

Experience has proven that if a particle settles to a depth of two times the weir crest by the time it reaches the weir,

it will probably not overflow and will report in the rake product. If it has not settled this amount, it will probably report in the overflow.

As the overflow percent solids increase, settling rates for the particles decrease. Also, for the various size particles the settling rates variation is less. Therefore, sharpest separations can be obtained in dilute overflows (if less than critical dilution) and as the overflow becomes thicker the separations become less sharp, which is called a dirty separation.

All the above is based on comparatively free travel of the material toward the weir in a quiescent pool. Pool turbulence excessive enough to disrupt free settling will result in a dirty separation. Therefore, the feed material must flow into the pool somewhat below the surface as gently as possible, and the spiral RPM must be slow enough to create no disruptive turbulence.

Quality of separation under all the above variations of conditions is difficult to predict, and can only be determined by past experience.

R a k e

If the classifier is being used to close circuit a ball mill the length of the slope of the tank as well as the distance between the feed opening and the sand discharge must be compatible with the closed circuit diagram. The dryness of the rake product is not important as it is usually introduced into the mill scoop feeder box by gravity from a chute and utilising flush water. However, the tank slope is also a function of the spiral raking capacity and pool length must be acceptable from an overflow capacity consideration.

If a classifier is not close circuiting a mill, the rake material is usually transported on a conveyor belt, and must be sufficiently dry for this purpose. The proper dryness of the rake material is a function of the size and nature (drainability) of the material, the speed of the spiral, the slope of the tank and the length of the drainage deck above the pool. Of course, if spray washing on the drainage deck is required, the length of the drainage deck must be increased. Normal logic and experience are extremely valuable in those determinations.

Over the years it has been determined that the minimum practical classifier slope is 3'' per-foot, and is used for the finest size separations (such as 200 mesh). This balances the necessary long pool length for maximum overflow capacity and necessary flat slope for the efficient raking of the fine rake material with a tank and spiral length that are not excessive.

Also, it has been determined that the maximum practical slope is 4'' per foot, and is used for the coarsest size separations (such as 20 mesh). This results in a comparatively short tank and spiral while still allowing sufficient pool length for obtaining adequate overflow capacity and gives good raking capacity for the coarse material.

The first Akins Classifier (and to my knowledge the first spiral classifier) was a deep rectangular trough containing a steel conveying spiral extending throughout its length. It was set along side a grinding mill at a slope. The lower end was at a height to accept the mill discharge and additional water to form a pool. A weir was provided to overflow the small size finished particles. The upper end was at a height to allow the larger size particles that needed more grinding to be raked out of the pool, up the tank bottom where

they were drained and then flushed into the mill feed box. Although no longer used, this machine is termed a 'Low Weir'.

The features of a spiral classifier for a particular application are selected to perform the following functions -

1. Allow particles larger than a desired size of classification to settle and to produce an overflow with minimum oversize.
2. Produce an overflow of sufficiently high solids content to meet the requirements of subsequent processing.
3. Agitate the settled underflow solids
4. Drain and remove the underflow solids(rake) from the settling pool.

A great many factors determine efficiency of classification, and experience with actual operating data is extremely important.

The following parameters govern the size and type of classifier required for a specific application.

Feed solids tonnage, specific gravity and dry bulk density.

Feed solids particle size distribution.

Feed solids concentration in the feed slurry.

Feed slurry liquid and specific gravity.

Required classification and settling rate of feed particle of required separation size in feed slurry liquid.

Solids concentration required in the overflow.

Solids concentration required in the rake.

Feed temperature.

Feed pH and corrosion with respect to mild carbon steel.

The dryness of the rake product is a function of the particle sizes and drainability, spiral speed, draingage deck length, classifier tank slope, and settled product rate. The rake capacity for a classifier is related to the specific gravity of the particles, spiral diameter, spiral speed, pitch of the helix, slope of the machine and drive horsepower.

Overflow capacity of a classifier is dependent on overflow velocity, particle settling rates, turbulence and distance the particle must travel from the feed point to the overflow weir.

By proper design of the feed entry, pool area, volume and geometry, the spiral classifier has the ability to handle feed volume fluctuations for short periods of time without upsetting the system. This material process system dampening effect means that sophisticated and costly control equipment are not usually required. Since the overflow and rake product are easily observed the need for control instrumentation is often eliminated.