TEACHING NEW EMPLOYEES ABOUT PROCESSING EQUIPMENT: WHAT IS THAT AND HOW DOES IT WORK?

Mike Albrecht, Smart Dog Ming, Concord, CA

Introduction

In the mining industry and particularly in the processing plants, we use some large and unusual equipment. Understanding what it is and what it does is important to good operations, but how do you teach a new employee. When I started out in this field, the information on the processing equipment was easy to come by. Equipment manufacturers readily supplied it; their salesmen, often engineers themselves, knew how important the availability of this information was. Old engineers used their notebooks to train the new engineers. Over time this has changed. Equipment manufacturers have changed hands or gone out of business, and often the older engineers are gone. As a start in reversing this, this presentation will be an introduction to sizing, selecting, and operation of some of this equipment, in particular gravity separating equipment. Major portions of this have been excerpted from A Mining Engineers Notebook: Mineral processing (2).

Gravity Concentration

Gravity concentration is the separating of particles by their relative densities (specific gravity). Gravity concentrating has been used to process minerals for a long time, Agricola in De Re Metallic (1556) (1) reported the use of gravity concentrating (jigging) by the Egyptians around 1000BC (3000 years ago). Gravity concentrating is still used in mining for separating the values from the waste; whether gold form rock, or coal from waste, or gems from the host rock.

Particle Settling

The basic principle behind gravity concentrating is related to how a particle will settle in a fluid. By Stokes law, with no other factors being considered (free settling), particles of the same size in a fluid will achieve a settling velocity dependent on two times their relative densities in relation to the fluid density. Also from Stokes law particles of the same relative density will achieve a settling velocity dependent on the square of their size.

While simple settling defines the action of a single particle in a fluid, in actually practice there are many particles of differing density and size. In addition there are boundaries to the fluid which also impact the settling. These add drag to the particles, the drag forces of the fluid, other particles, and the vessel the settling is occurring in, as defined by Reynolds number for various conditions, effect the settling.

Settling is more complicated because of these other particles, and is the interrelation of three factors; hindered settling, differential acceleration, and consolidation trickling. In the simplest processes (such as in riffles or stream beds) the main actions are hindered settling and consolidation trickling. Jigging, tables, and even pans add differential acceleration.

In hindered settling, larger and heavier (denser – high specific gravity) particles will settle sooner than smaller or lighter particles, and move farther. Part of this comes from the ability of the larger heavier particles to push their way through the other particles, and part comes from relative fluid flow rates needed to keep particles in suspension.

In the differential acceleration, larger particles, having a bigger area to work on, move farther and faster than smaller particles with a similar density. Heavier (denser) particles (higher specific gravity) will start moving slower on an acceleration cycle and faster on a settling cycle than particles of the same size, they will also tend to move less on acceleration (inertia) and farther on the settling (again inertia).

In the final stages of settling, the consolidation trickling portion, the larger particles have stopped moving but the smaller particles will continue to move downward through the larger particles. This difference in movement will cause the heavier particles to end up or concentrate to the bottom of a bed, and the bed to have layers, with the smallest particles on the bottom. This is shown in **Figure 1**.

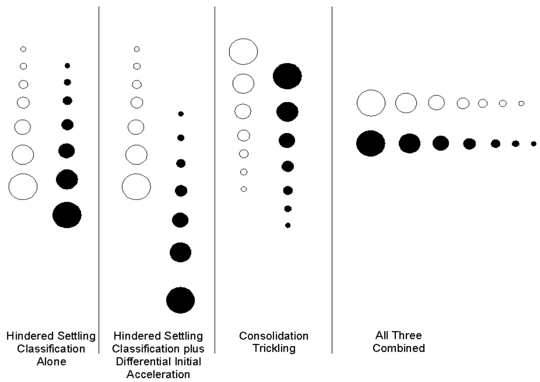

Figure 1: Particle Settling Actions

In the above picture (**figure 1**) the shaded particles are heavier (higher specific gravity) than the open particles. The above describes what happens with particles of the same shape, but particles are not all the same shape. Round and cubical particles will behave as described, but flatter particles distort this simple process.

Two particles of the same size and density will act differently if one is flatter than the other. The flatter particle will act as if it had a lower density, if the flat side is oriented in the direction of the fluid movement, and heavier if it is oriented opposite to the movement. Think of skipping rocks.

Settling Summary

- Hindered settling – how a particle moves downward through a mixture of water and other particles depends on it's size, shape and density.
- Differential acceleration – how quickly a particle moves depends on it's size, shape and density.
- Consolidation trickling – during final stages of settling, the larger particles have stopped moving but the smaller particles will continue to move downward through the larger particles.

In simple processes (jigging, tables, spirals, and sluices) the fluid is water (or in some cases air). In dense media the fluid is a mixture of magnetite, ferrosilicon or similar. Some operations have used dense liquids (salt solutions being the original, and now organic chemicals). Centrifuges and cyclones also increase the force by adding centripetal force greater than just gravity acceleration.

Process Selection

In gravity separation the goal is to separate the particles into groups, those having value and those that do not. The most efficient processing does this by using a natural difference between one particle and another. The relative density of the particles is the easiest to use. For example, coal has a density of 1.5 compared to the non-coal material with a density of 2.3, and gold has a density of 17.6 compared to the average waste of 3.0. For particles whose size is large, this difference is sufficient to allow an easy low cost separating means. When particles become small in size, other factors, such as shape, make this separation more difficult. Processing costs are inversely related to the feed particle size. Coarse particles are easier to process than fine particles. Because of this, most coal is cleaned at the largest size practical. **Figure 2** shows the normal range of application of mineral processing equipment. Fine sizes may require multi-stage or sophisticated circuitry.

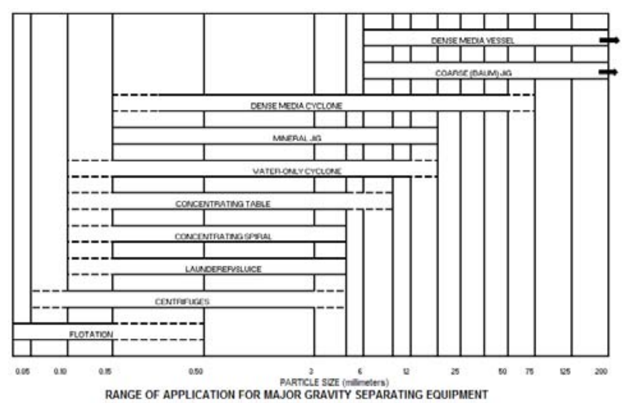

Figure 2: Range of Applications

Each type of gravity separating device has a range of application over which it is most efficient. The above figure (**Figure 2**) presents the ranges for some of the common equipment types. Even over the ranges shown, it is often best to use different size equipment for the top and the bottom sizes, an example of this would be dense or heavy media cyclones, where separate cyclones should probably be used for <6mm feed versus >6mm feed. The selection of the appropriate processing circuit used for any particular minerall is made by:

- considering the desired concentrate specification,
- how the material separates into a concentrate (values/clean coal), middlings and a reject/refuse to give the optimum yield at a quality that can be marketed,
- the capital and operating cost that can be borne in a market.

Table 1: Water Based or Dense Medium?

Type of Process

Water Based Processes	Heavy Medium Processes
Lower Cost	Higher Cost
Less Efficient	More Efficient
Less Flexible	Greater Flexibility

Most process decisions depend on the choice between an all water process and dense medium processes with flotation for the fines. Dense medium involves the use of a fluid that is heavier than the sink material and lighter than the float to assist in the separation. The most common fluid being a mixture of magnetite and water. The Factors shown in Figure 4 normally decided which system to be used. Water Process plants (jigs, tables, spirals, and water-only cyclones) are generally cheaper to install and operate than dense media circuits (dense media vessels and cyclones). They have the added advantage that, quite commonly, they do not require separation of the feed into various size fractions. On the negative side, however, they all have the following disadvantages compared to the dense medium circuits.

- They produce lower yield for a product grade even in the case of materials which are 'easy' to clean.
- They generally do not operate well, if at all, at separation gravities below 1.50.
- In case of 'difficult' to clean materials, they do not operate effectively.

Gravity Separation Equipment

This is an overview of the primary gravity separating devices and how to choose between them. For more details on each device see the referenced article on them.

Jigs

Mineral jigs have been around for a long time, there use was in De Re Metallic by Agricola published in 1556. Jigging has been a widely used means of cleaning coarse coal for more than a century. The first jigs were a basket loaded with mixed particles that was moved up and down in a tank of water. Thus agitated, the particles became rearranged in layers of increasing density from bottom to top. The same principle is used in modern jigs to stratify and separate the products. Jigging can be applied to a wide size-range of particles with top sizes up to eight inches.

Dense Medium Vessels

Heavy medium separation provides more accurate separation and potential higher recovery \than jigging. The feed is slurried in a medium with a specific gravity close to that of the desired separation. The lighter fraction floats and the heavier fraction sinks. The two fractions are then mechanically separated. While other media have been used, most heavy medium process is separated in suspensions of magnetite or ferrosilicon in water. This suspension is achieved using very finely ground magnetite or ferrosilicon. By varying the amount of media in the suspension, the specific gravity of the medium is changed, which changes the gravity of separation. The process is versatile, offering easy changes of specific gravity to meet varying market requirements, and the ability to handle fluctuations in feed in terms of both quantity and quality. In practice, feed sizes may range from about k-inch to about six inches. The feed to any particular vessel will cover a portion of this range. For more information see An Introduction to Dense Medium Vessels.

Dense Medium Cyclones

For coal and minerals in a size range of 1-3/4 inch to 28 mesh, the heavy medium cyclone is becoming widely utilized. In its operation, a slurry of ore/coal and medium (magnetite or ferrosilicon dispersed in water) is admitted at a tangent near the top of a cylindrical section that is affixed to a cone-shaped lower section. The slurry forms a strong vertical flow and under gravimetric forces, the higher specific gravity moves along the wall of the cone and is discharged at the apex. The lighter particles of lower specific gravity move toward the longitudinal axis of the cyclone and finally through the centrally positioned vortex finder to the discharge outlet. The heavy medium cyclone functions efficiently even with large amounts of near gravity material in the feed. .

Water-only Cyclone

Research on cyclones led to the development of the water-only or compound water cyclones, which performs a specific gravity separation employing only water and inertia. Its design feature which permits the use of "water-only" is the wide angle or angles in its conical bottom. This promotes the formation of a hindered settling bed, as the dense particles move down the side wall. Less dense particles cannot penetrate this heavy bed and move back into the main hydraulic current to be discharged out the top of the unit through the vortex finder. Applied in easier cleaning situations than heavy medium devices, water-only cyclones have been used to process material with a top size range of 1-3/4 inch to 28 mesh, generally as a scalping device to reduce the load on other equipment. Water-only cyclones washing 28 mesh x 0 are generally used in coal because of the presence of oxidized coal which has proved difficult to process by flotation.

Centrifugal Concentrators

Most small particle processing is done in a moving stream of water. This water is used to transport the material being processed and help carry the separated particles away from each other. When processing particles 0.5 mm in size and larger and when there is a large difference in density between the particles, a water based gravity separation process is very efficient. From 0.5 mm to 0.1 mm efficiency drops off, but the devices can still be effective. But, when the particles become smaller than 0.1 mm in size or the density difference between the particles is small, the speed with which the particles will move apart maybe less than the speed at which the water is flowing. This prevents the particles from separating.

One solution is to increase the force on the particles by speeding up their movement. Current available technology has increased this force by 5 to 10 times in cyclones. This is a significant improvement, but, still only works for a small range of sizes and densities. Into this area the use of centrifugal concentrators has stepped which can increase the force to 50 to 150 times which is much greater than any other available technology. They can separate particles which were heretofore impossible to separate by other than flotation or chemical processes..

Other Fine Particle Processing

In addition to centrifuges, several other technologies have been introduced such as fine heavy media cyclones, and air sparged cyclones to process very fine particles.

Fine heavy media cyclones (using ultra-fine ground magnetite) have been used at a plant in Pennsylvania, USA. Fine heavy media cyclones are efficient and work well, but are expensive to install and operate due to the complex nature of the media (finely ground magnetite) recovery circuit. Conventional heavy media uses a magnetite ground to be less than .6 mm, this circuit uses magnetite ground to be less than .1 mm. To reduce losses of the magnetite (reduce operating costs) a special multi-stage media recovery circuit is required. This requires more capital and operating costs than a standard circuit. The circuit is also highly susceptible to fluctuations in the feed.
Air-sparged cyclones use a fragile, high cost, special gas permeable metal cylinder.

Air-sparged cyclones are variations on conventional froth flotation. As such they suffer some of the same limitations, i.e., lower efficiency than gravity separation and not all coal is foldable. They both use chemicals and have to have very clean water. The chemical use also restricts the amount of water that can be reused without adding other chemicals.

Flowing Film Concentration

Launderers, spirals and tables fall into the general class of flowing film concentrators were the primary means of separation is a flowing film combined with stratification. They utilize the principal of flowing film separation, and combine this with bed stratification to enhance recovery and increase capacity. The actual separation mechanism varies by device, but the general principal is having a feed stream a rate where the coarse heavy particles settle to form a bed which then aids the concentration of finer heavy particles. The lighter particles are then carried away by the flow of water. In the case of spirals, centripetal forces aid in the separation.

Flowing Film Separations

A flowing film in a gravity separation device introduces additional forces, besides what is discussed in An Introduction to Gravity Concentration. The principal effect encountered comes from the flow usually is not uniform from one place to another. As a result, the shearing forces between adjacent layers of fluid produce rotation and other effects on various particles.

To make this clear, consider a fluid, such as water, flowing over a surface. If the velocities at different levels above the surface are indicated by arrows of proportionate length, the picture will be similar to that shown in Figure 3.

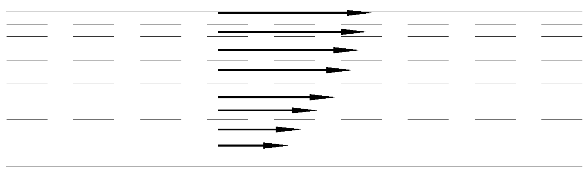

Figure 3: – Velocity Distribution in Flowing Current

Taking the stream from Figure 1, and introducing particles into it , such as in Figure 2. One of the effects of the flowing stream will be to induce rotation in the body as shown, since the top portion is acted on by currents of greater velocity than the lower. If the particle rests on the bottom, it will progress by rolling along the surface, and if it is higher in the stream it will combine a rotary motion with its forward one.

The force encountered by a particle as a result of its contact with the underlying surface or bottom of a stream, or with other particles resting on the bottom, plays an important part in flowing stream separations. If you consider a coefficient of friction existing between such a particle and the surface, the force on the rolling particle would be the coefficient times the component of the vertical force between the surface and the particle. This would in turn depend on the force of gravity, the buoyancy force and the force due to vertical currents that may be present. These are the forces considered in the discussion of classification and it is evident that if these are the factors to be considered light material will be carried faster by a flowing stream than heavy.

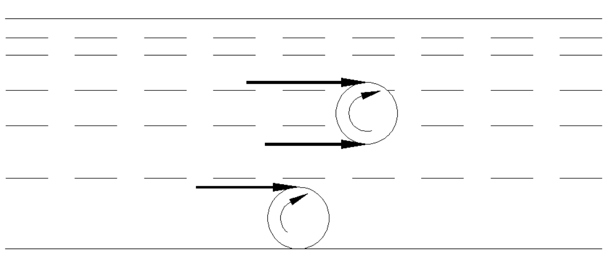

Figure 4: Rotational Impact on Particles from Velocity Distribution

This is a very oversimplified analysis, however, and it is easier to accept the findings of experiment, which show that:

- Material of low density is carried faster than material of high density.
- In mixtures of particles of a range of sizes coarse particles in general are carried along the bottom of a stream faster than fine ones.

These generalizations are based on observation of material carried by a flowing stream. They appear to depend not only on the factors previously considered but also on an additional effect; namely, the ability of some particles to hide behind others and thus avoid the effect of the flowing current. This is primarily the reason that coarse particles move faster than small ones. This generalization is subject to the reservation that extremely large particles-out of the range of sizes otherwise present-may not move at all.

Launders

Launders, in principle at least, represent an ideal method of gravity concentration. In theory the bed density in a launder stream increases from the top to the bottom, a desirable condition from the standpoint of selectivity in the separation. The mobility decreases with depth. If heavy material is withdrawn from the bottom of a flowing stream, it is evident that it will at some time have passed through a zone where the bed density is as high and the mobility as low as practicable - condition already recognized as most desirable in gravity concentration processes. Launders have the additional advantage of requiring a minimum number of moving parts in their construction.

In the launder, a stream of fluid carries the material to be separated down a channel provided with draws for separating a heavy-gravity product and means for overflowing a lighter one. If properly constructed and operated, a comparatively solid bed of material will form on the bottom of the launder. Above this bed there will be found a layer of particles moved along by the stream at a comparatively slow speed. Above this successive layers will move with greater and greater velocity.

It is evident that in the flowing mass of material hindered-settling conditions will prevail and will govern the fall of particles to the bottom, where the selective effect of the flowing stream will be effective in transporting lighter material faster and consequently further down the launder. This will be made clear by noting in sequence the effects of hindered settling and of stream selection.

In hindered settling, particles settle in the following order:

- Large heavy particles.
- Large light particles and small heavy ones.
- Small light particles.

If the launder is operated so that only the first two reach the bottom where stream selection is apparent, these will be subjected to removal in the following order:

- Large light particles.
- Large heavy particles.
- Small heavy particles.

If this process can be stopped with the removal of large light particles, the separation will be a perfect one.

Practically it has not been possible to accomplish this completely. Turbulence in the flowing stream, the lessening of the density of the bed by the act of withdrawing products and entrapment of light particles by the bed arise to defeat the perfect operation of the process. It would seem that research could do much to overcome these difficulties and a closer realization of the theoretical advantages of launder processes might be achieved.

Spirals

Spirals behave in general like a launderer, but with the addition of centrifugal force (actually centrifugal force is an apparent force, and the actual action is a "fictious force" caused by the inertia of the particles and is a reaction to being confined by the outer wall). This causes the water to pile up on the outer edge with the lighter and finer particles and the larger heavier particles to report to the inside. Beyond this the actions are very similar to a launder.

Tables

Concentrating tables (or shaking tables) introduce no principles of separation that have not been considered. The sequence of hindered settling followed by flowing stream selection is frequently utilized by submitting material to be concentrated to a preliminary classification. This is so common a practice that classification and tabling has almost come to be recognized as a unitary process.

Particles in a bed of material on a shaking table are subjected to the action of hindered settling in the way already discussed. A differential motion of the table suffices to cause heavy-gravity material to move along the table between riffles, if these are present, while a cross stream carries low-gravity material transversely.

A theoretical objection to shaking tables is found in the fact that mobility is imparted to the bed of material from beneath, with the result that a zone of low bed density will be found immediately adjacent to the surface. The separation is thus not as sharp as could be desired at any one place. In effect, however, the separation occurring between any two riffles is supplemented by the re-treatment between the adjacent pair and the large number of successive separations produces an acceptable end result.

Air Tables

In discussing the mechanics of hindered settling (in An Introduction to Gravity Concentration), nothing was said about the nature of the fluid beyond the fact that it possessed viscosity and was capable of exerting a force against particles moving relative to it. In air tables the fluid in question has the property of being compressible. This property in itself introduces no new forces into the behavior of a bed of particles being separated. The principles are the same. Hindered settling occurs in the same way as though the fluid were incompressible. When operating with deep beds of material, however, the air in the lower portion is under the pressure of the bed and undergoes considerable change in volume in rising to the top. Frequently this causes geysering in an improperly operating device and is overcome by maintaining the bed in a state of partial mobility through shaking, flowing, or other movements.

Another feature that differentiates air tables and air classification from processes using water is the density of the fluid. Air being substantially weightless compared with most solids, the density of the bed must be built up from the material itself. This apparent disadvantage of air processes is outweighed by the avoidance of the necessity for drying the products. Thickening difficulties are also avoided, though dust may become a problem.

Conclusion

The preceding discussion has been an attempt to present an overview of gravity separation equipment and its application. Other information and literature is available dealing with the theory of gravity separation and how the equipment is used. In conclusion, it may be admitted that theories of gravity concentration are in a somewhat unsatisfactory state and how the equipment works is still not fully understood. This has been an attempt to at least interest others in continuing the study and use of this equipment and process. For more information on specific devices see the Mineral processing section of *"A Mining Engineers Notebook"* (2).

References

1. Agricola, Georgius. (1556). "De re metallica." Translated 1950 translated by: H. C. Hoover, L.H. Hoover. Dover, NY.
2. Albrecht, M. C. (2013), "*A Mining Engineers Notebook"*, http://www.smatdogmining.com, 2013