REVISITING SPIRAL CONCENTRATION AS APPLIED TO IRON ORE BENEFICIATION[1]

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Abstract

The application of concentrate spirals during the iron ore processing started in the sixties decade in a specular hematite concentration in Canada. Since then, its acceptance has been ample among the most iron ore producers companies. The spirals, although having a very simple functioning, have one of the most complexes separation mechanisms even if one considers all the gravimetric beneficiation methods. The main separation mechanisms described in literature are presented in this paper. Besides that, the project variables are of fundamental importance with respect to the achievement of a better efficiency for the processing of different types of ores or different stages in the process. The main operational problems occurring in spiral circuits are presented and some suggestions of improvements are made.

Key words: Spiral concentrator; Iron ore

REVISITANDO CONCENTRADORES ESPIRAIS APLICADOS AO BENEFICIAMENTO DE MINÉRIOS DE FERRO

Resumo

A aplicação de espirais concentradoras no processamento de minérios de ferro data da década de 60 na concentração de hematita especular no Canadá. Desde então, sua aceitação tem sido ampla entre as empresas produtoras de minério de ferro. A espiral, apesar de ter um funcionamento muito simples, possui um dos mais complexos mecanismos de separação entre os métodos gravíticos. Os principais mecanismos de separação descritos na literatura são apresentados neste artigo. Além disso, as variáveis de projeto também são importantes no que diz respeito a uma melhor eficiência para o processamento de diferentes tipos de minérios, ou diferentes etapas de processo. Por fim, os principais problemas operacionais em circuitos de espiral são apresentados, com algumas sugestões de melhorias.

Palavras-chave: Espiral concentradora; Minério de ferro.

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INTRODUCTION

The spiral separator was developed by I. B. Humphreys in the 40's, with the purpose of separating gold associated with pyrite. The first industrial application occurred in 1943 in a chromite beneficiation plant located in Oregon. The first use for heavy sand separation started in 1944 on Florida ores. The first application in iron ore concentration took place in Quebec, Canada, where a specular hematite ore is beneficiated employing over 2000 spirals (initially 100% iron cast, single-starters) unities in the plant. Improvement of the equipment design and technology happened subsequently when the Humphreys patent expired. Reichert developed fiberglass spirals in Australia and since the molds are much easier to make and the precision of design the internal surfaces is much higher in this case, all iron cast spirals basically ceased to be produced (Chaves, 2008).

Probably, spirals are the lowest capital cost mineral concentrator available today. Combined with their low operational cost, and the absence of movable parts, they have a widespread use in dense mineral separation. Application in iron ore beneficiation is very common. However, processing of very fine fractions of ore (<0.038mm) are not possible, making froth flotation and magnetic separation methods more competitive for concentrating fine size ranges. This work presents the main operational principles of spiral separation, with a special overview during iron ore application. The mechanism of separation, operational and design variables and plant operation are discussed.

VARIABLES AND SEPARATION PRINCIPLES OF SPIRAL CONCENTRATORS

The spiral concentrator consists of a trough disposed helicoidally around a central column, as show in Figure 1. The main geometric variables are the step, the high, inclination and radial inclination of the trough.

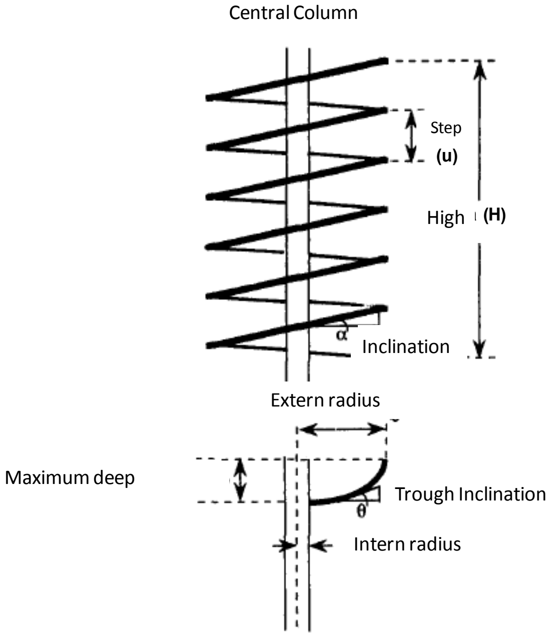


Figure 1: Geometric parameters of a spiral concentrator. (Modified from Kapur and Meloy, 1998)

According to Holland-Batt (1995), a flow moving in the spiral trough is composed of two flows: A primary flow in the vertical direction, due to gravitational force; and a radial flow, due to the centrifugal force. These two vectors produces a distribution of the particles as presented in Figure 2. Two main zones, separated by an intermediary zone are observed.

While pulp moves downwards, high-density particles are carried to the inner region of the trough, concentrate zone, where the particles are submitted to a laminar flow. The separation action takes place in the transition zone where the secondary flow lifts the lower density particles to the recovery zone (light particles zone) while high density particles settle, reporting to the concentrate zone. The flow behavior changes from laminar flow in the inner region to turbulent flow in the outer zone. Once the separation mechanism depends of the interaction of particles with the water flow, it can occur by density and by size. Finer particles tend to be drag out by the secondary flow to the light zone, while the coarser ones tends to settle and report themselves to the concentrate zone. However, very coarser particles are commonly reported to light zone, due to an applied torque that makes then roll through the trough.

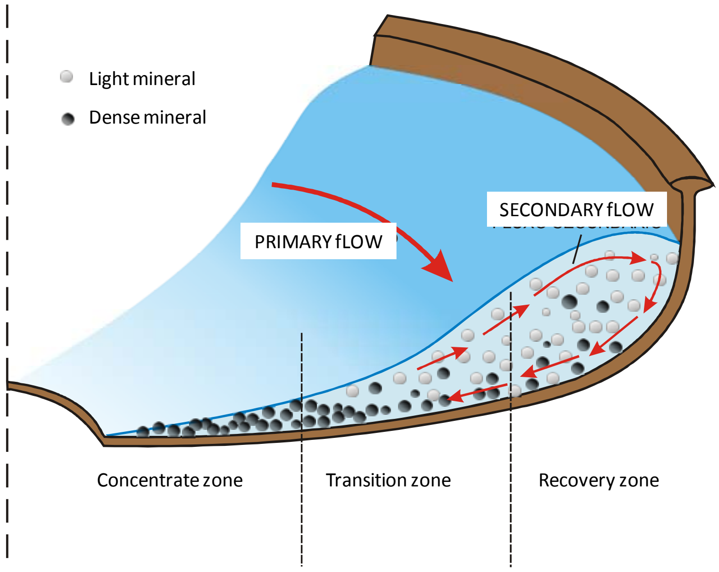


Figure 2: Main zones in a spiral trough (Arenare, 2008)

Particle transportation will occur in two different ways: the suspension way where interaction between particles is not significant and in the bed way where this interaction is strongly marked. Particles near the inner zone move in the bed while the particles in the outer zone move in suspension. Larger beds can occupy the intermediary zone, creating disturbances on the separation mechanism. This is usual in ores with a high grade of dense minerals (Atasoy e Spottiswood, 1995)

HYDRODYNAMIC SEPARATION

Once particles are submitted to different flow ways (laminar, intermediary and turbulent), different forces will take place in determining when a particle will report to the dense zone or the light zone. Consider in detail and subject to an analysis these forces is difficult because the fact that many of these forces are immensurable. However, five forces could be cited as the main ones (Kapur and Meloy, 1998):

- Gravity force (F_g): make particles settle and go to the concentrate zone;
- Centrifugal force (Fc): it acts moving the particles radially to the light zone;

- Drag force (F_D): this force is made by the fluid on the particle in the direction of its movement. The particles located in the free pulp surface are dislocated to the outer zone direction while for the particles located in trough surface are directed to the inner zone direction.
- Bagnold forces (F_B): acts lifting particles when they are near the trough surface. This force creates a movement of expansion and contraction of the bed, which allows for particles segregation by size and density.
- Friction force (F_a): caused by trough surface opposing the particle movement

The vector sum of these five forces will determine the direction take by a particle in the spiral trough (Figure 3).

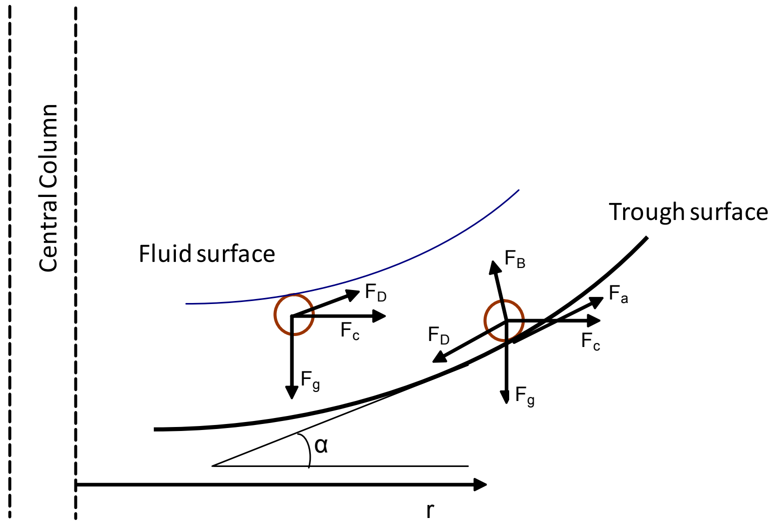


Figure 3: Main forces acting in a particle moving in a spiral trough.

OPERATIONAL VARIABLES

Three main operational variables control a spiral operation: feed rate, pulp density and size distribution.

The spiral feed rate can be listed as the most important operational variable, once it will determine the primary flow velocity and consequently the secondary flow velocity. Lower feed rates lead to a rapid settling of particles that prevents the transition zone separation effect that depends on the friction forces between particles causing most of the particles going to the dense concentrate. Higher velocities in the primary flow are obtained with higher feed rates. Centrifugal forces turn more intense lifting the light, locked and denser fines particles go to the light zone. A high-grade concentrate and a low recovery are obtained in these conditions. Figure 4 (Burt, 1984), presents the results of iron ore separation in different flow rates values.

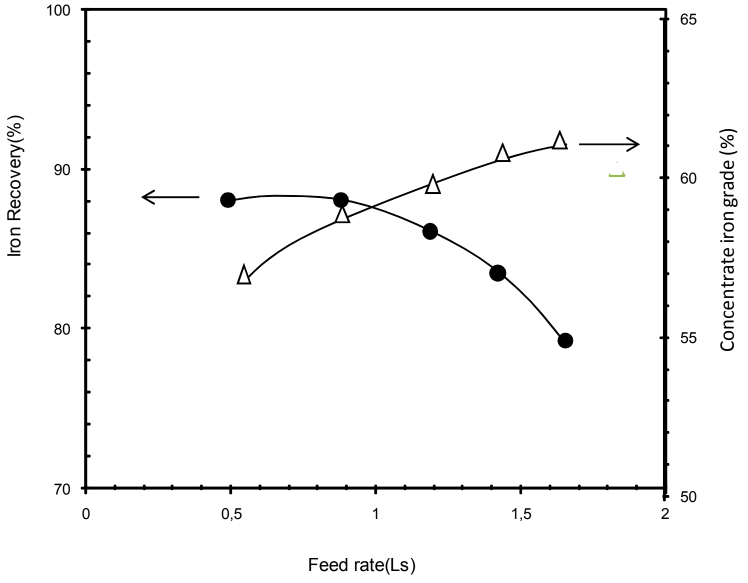


Figure 4: Recovery versus iron grade in a spiral for different flow rates.

Pulp density exercises a secondary role in spiral separation efficient and is associated with feed rate. Figure 5 presents results produced by Dallire et al. (1978), where pulp density and feed rate were compared. As one can see, iron recovery showed a great variation for higher density pulps (the denser is the pulp the lower is the iron recovery) while recovery is always decreasing with higher feed rate values. The opposite effect is observed in the concentrate iron grade. Comparing with low-density pulps, higher density pulp tends always to produce a high-grade concentrate.

As mentioned before, particles size is very important in the spiral separation mechanism. The existing new equipments are able to process ores with sizes ranging from 2 mm to 0,074 mm. However, feed can not has a broad size distribution, because denser fines particles may be lifted to the light particles zone. Coarser particles also go to the light particles zone by a rolling movement, once a torque force around its mass center will take place and friction force is not high enough to avoid this kind of movement. Concentrate grade has not a considerable change with a wide size distribution feed, but recovery can be drastically affected, with a loss of dense material in the light particles zone. (Richards et al., 2000)

The effect of feed iron content in the spiral efficient was studied by Dallire et al. (1978). As showed in Figure 6 (a), even for 20 % and 32% of solids, the higher is the feed iron content the higher is the concentrate iron grade. In the recovery curves depicted in the Figure 6 (b), the curve with 20% solids pulp shows an increase in the recovery when the feed iron content arises, while the 32% solids pulp has a peak for feed iron contents around 40% iron and decreasing recoveries for higher iron content values. This fact could probably be connected to a overload in the dense bed.

The splitter position is the simplest way of choosing one specific pair of grade and recovery. When the cutters are positioned closer to central column, they will produce a high grade concentrate with a low recovery, and vice versa.

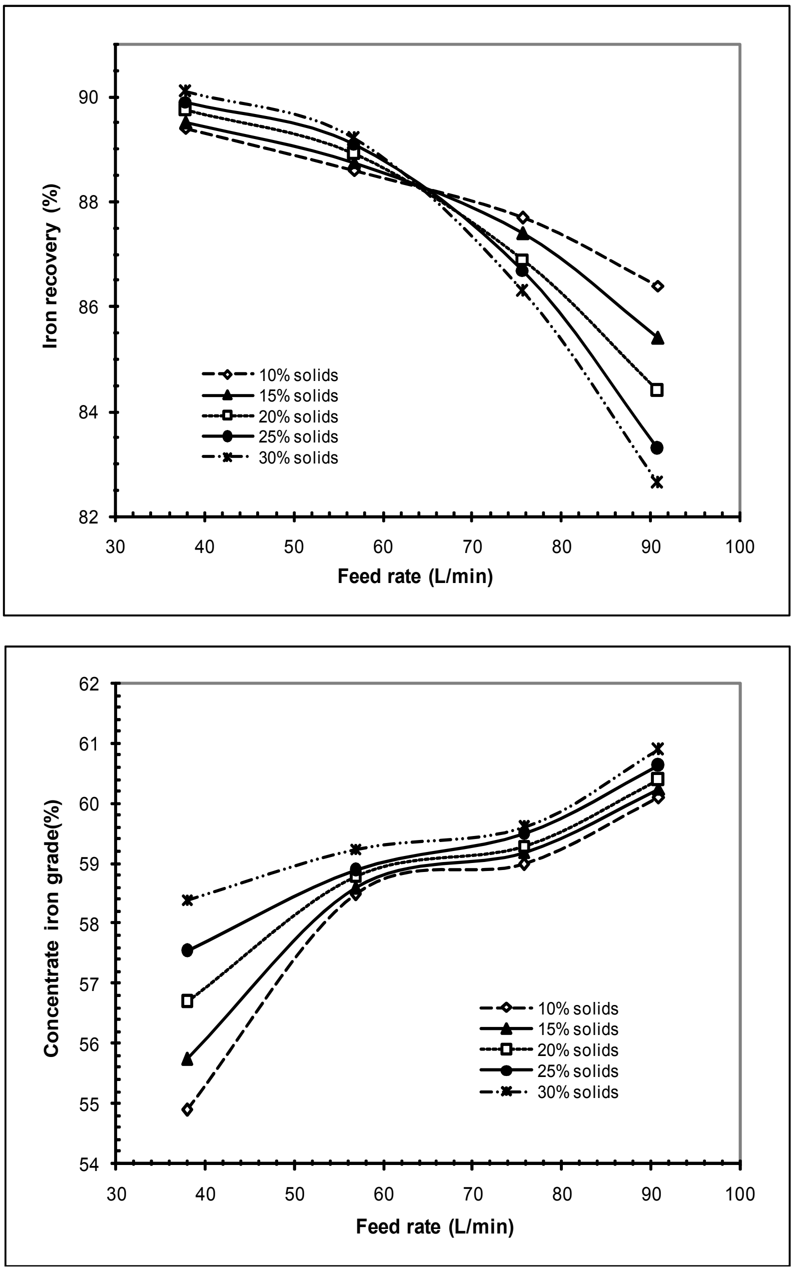


Figure 5: a) Pulp density effect on iron recovery and (b) on iron grade in concentrate (modified from Dallire et al., 1978)

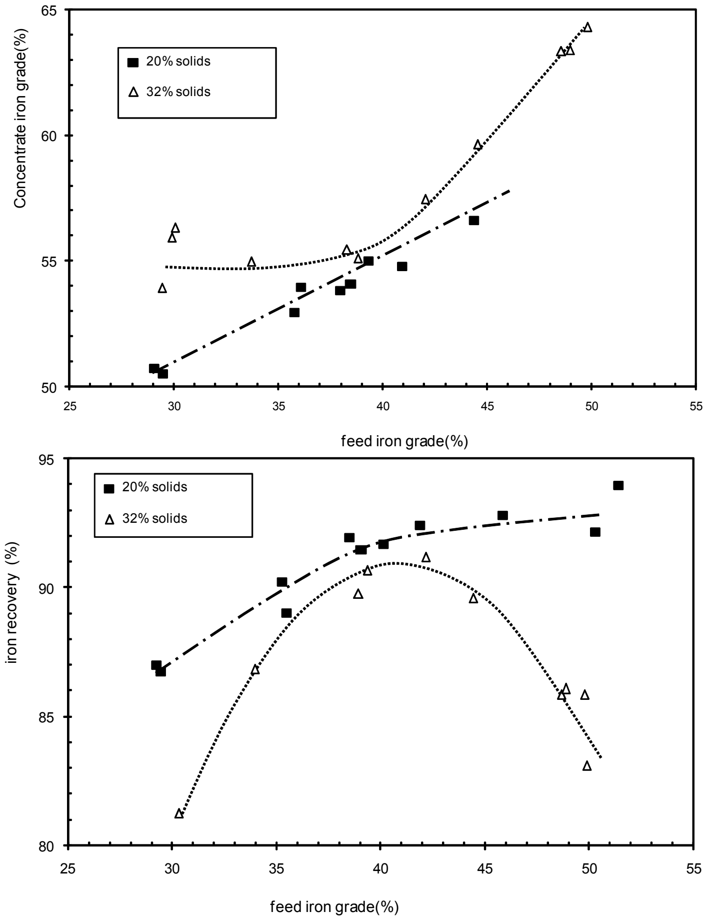


Figure 6: Effect of feed grade in concentrate grade (a) and iron recovery (b) for different pulps densities. (Modified from Dallire et al., 1978)

DESIGN VARIABLES

The correct choice of some design variables of spirals is important in the optimal performance for the beneficiation of any ore. Six main variables can be listed: helix diameter, step, number of turns, washing water, splitter position in trough and feed system.

The feed capacity of the spiral is direct associated with helix diameter. The feed size range that spirals can separate also depends on diameter. The largest helix will allow for a better separation of materials with wide size distribution avoiding segregation by size. In a general way, iron ore beneficiation is done in intermediate diameter spirals models. (Holland-Batt, 1995)

Primary flow velocity is determined by the step and as well as it determines feed capacity. Larger steps mean higher capacity because of high flow velocity. Regarding the separation process the main effect is on the density of separation but not in recovery and grade (Wills, 1992). Low-density separation needs small step spirals while the separation of dense minerals needs greater steps spirals as in the hematite and quartz system.

The usual objective of the operation is determined mainly by the number of turns. When the number of turns is greater, there will be more chance for the particles go to their equilibrium position: dense concentrate zone or light zone. The influence of centrifugal force is greater in the initial turns, lifting most of particles to light zone (light or dense ones). In this way, a bed of only very dense particles is found in the inner zone, which is adequate for a cleaner stage. After some turns, particles find their position and most of dense ones will position in the inner zone. However, light particles can report to dense zone, which makes possible a good recovery with middling grade, aimed by rougher process. (Wills, 1992)

When considering the use of spirals in iron ore beneficiation washing the water system is usually required, with the target of replacing the water that reports to the concentrate zone. Due to the high grade of dense minerals, the amount of water lost is considerable and if replacing water is not added a loss in the efficiency of separation in the transition zone could occur (Domenico, 2005). The main problem associated to washing water is the orifices blocking by process water.

When spirals are used in the iron ore plants the splitters are usually located along the trough. This practice normally occurs because of the high quantity of dense minerals present in these ores in order to avoid the overloading of the inner dense bed. This would consequently generate some inefficiency on the separation mechanism.

Recent work from Richards et al. (2000) presented new spiral models able to process finer ores. The FM1 spiral model, of MD Mineral Technologies (currently Roche Mining), was designed to achieve a less turbulent regime in the external section, avoiding finer particles of being trapped by turbulence, and giving them conditions of settling and go to dense bed. Ores with particle size down 30μm were tested and upgrade ratios in the range of 2 to 4 were obtained in rougher application. Figure 7 presents results of tests with two different spiral types processing a Canadian iron ore with d95 = 150μm. At feed rates of 1 to 1.5t/h, the FM1 achieved concentrate grades of 62.1% Fe, and 35.5% Fe at Fe unit recoveries of 43.0% and 61.4%, respectively.

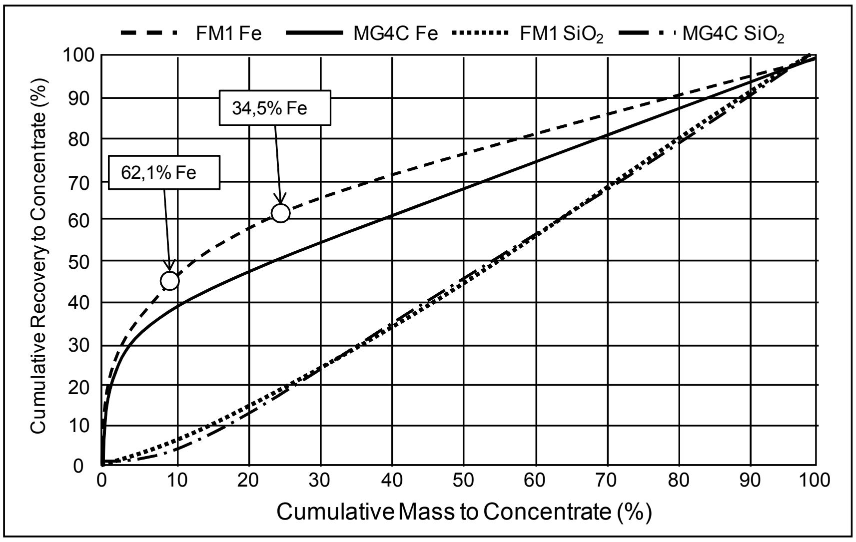


Figure 7: Spiral performance comparison (FM1 and MG4C) on fine iron ore – Recovery versus yield. (Richards at al., 2000)

COMMON OPERATIONAL AND DESIGN PROBLEMS IN A SPIRAL CIRCUIT

Although spiral separator is not an equipment that can be considered complicated, once it has no mobile parts, after the selection of the equipment operational variables must be carefully controlled to obtain the expected results.

When using spirals during iron ore beneficiation a common operational problem is related to wash water. The wash water is usually the process water coming from the thickeners overflow. Recovery of fine particles in the thickeners underflow is not always adequate which makes some of these particles to report to the overflow and the consequent is (severe) clogging of the water addition orifices at the spiral.

Control of feed characteristics is of great importance for ensuring a constant operation, grade and recovery indexes at the concentrate. The main feed variables to be constantly controlled are rate, size distribution, iron grade and pulp density. Fluctuations in a spiral circuit normally occur in two positions: in the plant feed or in the individual spiral banks.

Considering the plant feed, one of the most important variables is the quality of the received ore. Ore bodies that cannot offer a homogeneous composition, because of geologic complexity, will probably generate an inconstant feed with respect to grade. Feed production rate must be constant, avoiding possible overloading of the spirals. The feed size distribution, as cited before should be as narrow as possible. A correct operating of grinding, screening and classifying equipments must be guaranteed. In some plants where grinding is not applied and all material is fed in the spirals the lost of coarser particles in light particles tailings may be considerable. Particles coarser than 1,2 mm should be screened or classified by hydrocyclones after comminution or after the treatment by other gravimetric equipments.

When plants are designed with multiple spiral banks, primary distributors are required. The Figure 8 presents a scheme of a spiral circuit where it can be seen a pump sump, a primary pulp distributor, a secondary pulp distributor, the spiral itself and the launders for collecting the products. Abela (2003) described the correct operation of a distributor that considers the equal distribution throughout the number of outlets without bias in terms of slurry rate, solids percentage, tonnage, grade and size distribution.

Some care must be taken in the designing of primary distributor. Sufficient pipe length must be allowed for the flow to establish a symmetrical profile that supports a homogeneous density profile across the section, avoiding segregation on the pulp. The delivery lines to each bank should have the same length when possible and the tubes angles. If they cannot be equal, a siphon should be used for preventing different pressures in the pulp.

The Figure 9 shows a scheme of a bank of spiral fed by primary and secondary distributors. Secondary distributors are mainly of two types: The slot type, figure 10 (a), and the orifice type, Figure 10(b). The pulp in the slot type distributor is discharged into compartments via a slot. The level of pulp in the vessel determines the volume of the discharged pulp. The blocking of slots will make flow rate to others slots gets higher, causing variations in the spiral feed rate. This is the main disadvantage of using this type of distributor. The orifice type works with a constant feed and the orifices controls the discharge volume at the outlets. Variations in the flow rate are prevented by using an anti-syphon device (syphon breaking device, shown in Figure 8) distributor to atmosphere. According to Abela (2003), the orifice type distributor offers a more constant feed rate than the slot type.

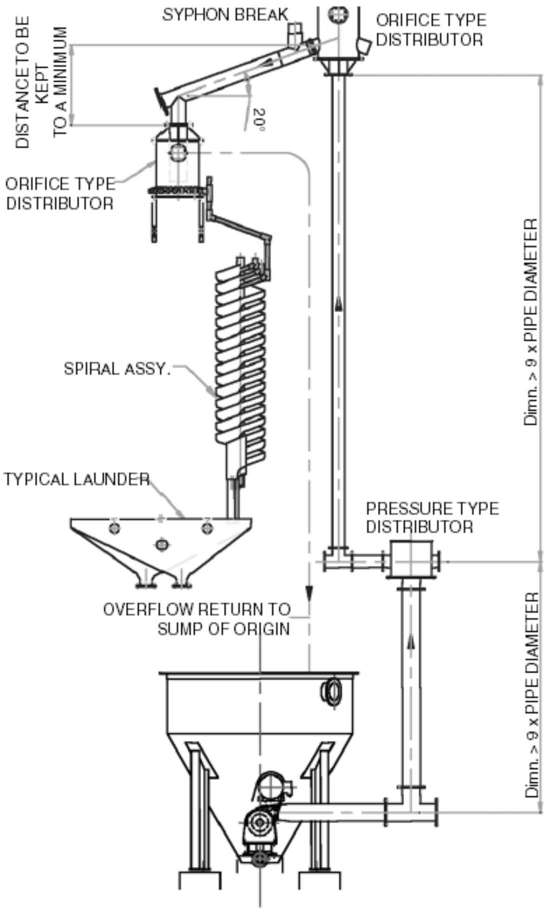


Figure 8: Scheme of a typical spiral circuit (Abela, 2003)

Operational control must be efficient for identifying any changes in pulp characteristics. Sampling dispositive installed in equipments could help in finding changes. However, visual control by operators could give good operational results. Variation in iron grade from ROM can be visualized if wideness of denser bed changes. Silica grade also will change color in dense bed, if separation is not efficient. Variation in feed or pulp density can affect wideness of dense bed. A greater pulp density, associated with high iron content, can cause a overloading in dense bed, creating a new cutting zone (in different position than original splitter). Lower feed values will carry less material by centrifugal force, what also can be visualized.

The slimes content can also have a negative effect in the separation mechanism once they change the pulp viscosity. The main practical effect of the slimes is the finer particles, which can contain hematite particles, reporting to the light particles zone and the subsequent decreasing of concentrate iron recovery (Abela, 2003). This problem can be partially controlled by a more efficient scrubbing and desliming operation and a more efficient control of the water process quality.

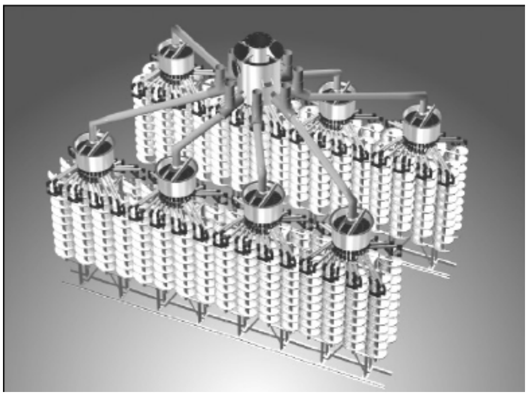
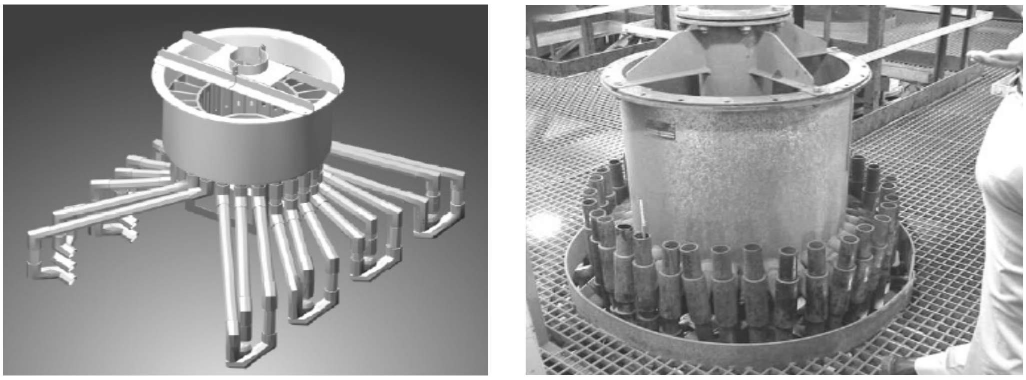


Figure 9: Primary and secondary distributors in the spiral banks (Abela, 2003)



(a

(b

Figure 10: Slot type feed distributor (a) and a complete orifice type feed distributor with syphon breaks (b) (Abela, 2003)

CONCLUDING REMARKS

Applications to iron ore are wide spread in Brazil and around the world. Spirals have special success for treating the -1+0,15mm sinter feed fraction for the sinter feed production or just to remove the iron in this fraction in the pellet feed production with the aim of saving energy during grinding. Special care must be taken during operation to avoid the feeding of coarse material, which normally results in plugging the feeders or the rejection of the coarse material to the tailings. The “say” that spirals do not require much attention and need little maintenance does not express the whole truth about these wonderful pieces of equipment. They do require a little attention. They also deserve well-programmed maintenance interventions. There exists some examples of spiral plants that did not achieve the projected production and in the most of these cases, the problem was just not following the project premises and not exercising appropriate operational and maintenance procedures.

Single start spirals are no longer in use. However, going above double starters is something that must be considered with lot of care. Two helices are fine but three (triple start spirals) in iron ore beneficiation should be avoided. Most of the times feed rates are exceeding design capabilities and, in a triple-start spiral, there is almost no room for visual inspection of the spirals during operation.

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