ADVANCES IN THE APPLICATION OF SPIRAL CONCENTRATORS FOR PRODUCTION OF GLASS SAND

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ABSTRACT

Around the world, spiral concentrators have been successfully applied to glass sand production. Spiral application is both cost effective and environmentally friendly when compared to other techniques for iron bearing and refractory heavy mineral rejection such as flotation and magnetic separation. The coupling of spiral concentrators with hydraulic density separators for damp sand production often results in a process that meets both particle size and mineral/chemistry specifications. Interestingly, glass sand size specifications usually correlate directly to the optimum response particle size for spiral concentrator operation. This paper presents flowsheet alternatives and resulting process performance for glass sand operations representative of commercial operations around the world. The paper also suggests the use of spiral concentrators for rejection of aluminum silicates and mica from quartz sand destined for glass making markets.

INTRODUCTION

The Role of Spiral Concentrators in Glass Sand Production

Glass sand production is dependent on the mineral occurrence characteristics in the deposit, and most importantly, market requirements. Spiral concentrators have long played an important role in the production of saleable glass sand at sites around the world. The traditional purpose of the spiral units is removal of liberated heavy iron-bearing minerals from the sand. Of course, those iron-bearing minerals that are fully liberated will easily be rejected in the spiral, whereas silica sand grains with minor inclusions of the contaminant iron mineral will not reject. Liberation to a degree is imperative for successful application of the spiral technology. With proper feed preparation, i.e., density separator sizing, improved performance capabilities have been realized.

The unwanted minerals in glass sand for the most part are iron-bearing minerals. These minerals have significantly higher specific gravities than quartz. Contaminant minerals such as magnetite and ilmenite, for example, have specific gravities of 4.0 or higher compared to quartz at 2.65. Typically, spirals can separate minerals with a specific gravity differential greater than 0.5units with high efficiency, which makes this separation relatively easy.

In addition to the iron-bearing minerals, aluminum-bearing minerals, such as refractory aluminum silicates and mica, are also likely candidates for rejection in a spiral. The separation of these minerals from quartz is more difficult and requires a slightly different approach than removal of the iron minerals. Testwork has shown promise for removal of mica in a wash water assisted spiral.

Spiral concentrators offer a relatively simple unit operation that translates to low capital and operating cost. This, coupled with reagent free processing, provides the necessary low cost and environmentally desirable process. The actual spiral plant flowsheet most suitable for a particular application will depend on the feed characteristics, especially particle size distribution and

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mineralogical characteristics of the resource. However, certain generalizations apply. For instance, in the production of a marketable quality sand is most always the primary driver, with weight recovery of secondary importance. Therefore, two-stage separation is often advisable to ensure final sand product quality.

Spiral Concentrator Design and Operating Basics

Spiral manufactures now offer a variety of models to the industry, each with specific helix trough profile designs, pitches, and other performance improvement nuances. These lightweight models are made of urethane-lined fiberglass and can be expected to last in excess of 10 years even under heavy service conditions. Compared to other sand beneficiation process such as flotation and magnetic separation, spirals present a relatively low capital cost, have no moving parts and consequently have low maintenance costs. Compared to dry magnetic separation, the spiral process is conducted on wet material and therefore the product does not require drying. In those parts of the world that can sell damp glass sand there is no need to expend the capital and energy cost to dry the sand. Even in places that require dry sand, the removal of contaminates prior to drying saves energy cost. If necessary, additional separation efficiency can be achieved by hydraulic classification of the feed and/or re-treatment of the first pass sand in a second pass through a spiral unit.

Spiral Feed Presentation. Spiral concentrators are flowing film separators that work in a similar principle to shaking tables. The design of the feed box is important to assure proper presentation of the feed slurry to the spiral trough resulting in desirable flow characteristics down the helix trough. With proper feed presentation, the separation process begins immediately at the top of the spiral helix. If the box design is problematic, i.e., presenting the spiral with an uneven or unbalanced feed, the pulp will have to stabilize in the trough before separation initiates and that can require up to one complete turn (revolution) of the helix, thus losing separation potential within the length of the spiral. In addition, if heavy minerals targeted for rejection via product cutters at the inner edge of the spiral trough, somehow through unnecessary turbulence, reach the high water (outer) portion of the trough, their ability to re-enter the flowing pulp and migrate to the center portion of the spiral is improbable and therefore, these particles will report to the glass sand product.

Heavy Mineral Entrapment. Another area of concern is entrapment. As the feed pulp flows down the spiral, heavy minerals can be trapped below the bed of sand in the middle portion of the spiral. Like a temperature inversion, these particles become trapped under the blanket of sand and are unlikely to migrate out and into the region of the heavy minerals at the inner area of the trough. To counteract this problem, spirals are often equipped with surface bumps or repulper designs that help free these trapped minerals and allow them to migrate and report to the proper location within the spiral.

Benefit of Centrifugal Force. As slurry flows down the spiral helix, there is a centrifugal force acting to push the lighter minerals up the trough profile to the outside region. The force is not sufficient to move the heavier minerals to this region therefore they slide down the profile to the inside region of the spiral.

Since this is a flowing film separator, the centrifugal forces are not equal along the depth of the slurry. At the very surface of the spiral, the centrifugal forces are very small. Therefore, the smaller particles have little forces acting on them. At higher depths of the slurry, the forces become greater and therefore, the coarser particles have higher forces acting on to help them report to the outer regions of the spiral.

For glass sands, this variation in forces between the finer and coarser particles generally is a benefit since the majority of the heavy minerals in the deposits tend to be finer than the glass sand. Therefore, the lower forces on the heavy mineral particle help to allow them their reporting to the center of the spiral for rejection. The higher forces on the coarser glass sand particles push them toward the outside and allow them to report to the glass sand product. In many cases with glass sand, the separation between the heavy iron bearing minerals and the sand portion is so extreme that the urethane surface of the spiral can actually be seen between the two particle streams flowing in the trough.

USING SPIRALS TO REMOVE IRON-BEARING HEAVY MINERALS

Throughout the world, there is considerable experience in the use of spirals to remove the iron bearing heavy minerals in glass sand deposits. There are currently more than 25 glass sand spiral installations around the world.

In these installations, spirals having either five or seven turn helixes are employed; the number of turns required depends on the amount of heavy iron-bearing minerals that need to be removed, i.e., with higher amounts of particles needing removal then the longer (7-turn) spirals are desirable. At times, there is also a benefit of passing rougher stage (1st pass) spiral sand product through a second stage of spirals (cleaner pass) to remove the remaining heavy minerals. For example, if the first stage is 70% effective then the second or cleaning stage will be nearly 70% effective on the remaining 70% heavy minerals. Thus, the two-stage spiral process can be said to be 91% effective in heavy mineral rejection.

The cleaner stage also fits well from a plant layout and operational standpoint. In the spiral process, the first stage removes a heavy mineral product at a high pulp density, from the inner area of the spiral trough helix. The lighter glass sand product along with most of the feed pulp water reports to the outer area of the trough helix where it exits the spiral. The pulp density of the first pass sand product is at a reasonable density for directly feeding the second stage. Therefore, the first and second stage spirals can be stacked one above the other with the product from the first stage reporting directly to the second stage. Using this practice eliminates the cost of pumping pulp from the first to the second stage. However, where height restrictions prevent stacking, traditional pumping between spiral stages can be employed.

Spiral separation typically can remove 60 to 80 percent of the heavy minerals in the feed stream. This is dependent on the amount and size distribution of the heavy minerals compared to the silica sand portion. Data from various operations are shown below.

Example 1 Materiales del Istmo, Veracruz, MEXICO.

Successful implementation of a spiral processing, circuit in place of flotation was realized in the mid nineties. A traditional flotation circuit operated on feed having a silica-to-feldspar ratio of 80:20. Their existing flotation plant consistently made a quality product. This required flotation reagents of up to 500g/t (additional reagents were required for waste water treatment) and residual fatty acids and other flotation reagents in the plant effluent water produced difficult environmental problems for management.

Installation of a spiral based plant (Carpco® LC3000 Spirals) after in-plant trials, resulted in an increase in production of more than 40% and an improved final product iron content (as Fe_2O_3) ranging from 0.027 to 0.038% compared to 0.045 to 0.070% from the flotation circuit. The elimination of flotation reagents improved wastewater treatment by eliminating the need for lime addition. Overall, operability of the plant improved with less power required and the simpler circuit required less operator attention. Significant cost savings were achieved.

Example 2 Silice del Istmo, Veracruz, MEXICO

Another spiral plant producing a quality glass sand product in Mexico is the Silice del Istmo operation, also in Veracruz. In this operation the Carpco® LC3000 spirals are operated at nearly 1.8t/ht/h per spiral start in a plant treating a total of 107t/h of new feed. Interestingly, even at this relatively robust feed rate, the resulting quartz product presently contains 0.055% Fe_2O_3 produced from a feed of 0.10% Fe_2O_3. The nature of this circuitry results in a natural sand product size –30+140 mesh which is appropriate for the glass sand market.

Example 3 MEREN, Jordan

Another silica sand plant that is slated for start-up in late 2003 utilizes a double stage LC3000 spiral circuit to improve the iron content. This particular deposit is much higher grade or lower iron than the previously sited examples. The plant has been designed to produce two grades of silica sand. The standard grade sand will contain less than 0.020% Fe_2O_3 and the premium grade sand will contain less than 0.012% Fe_2O_3 from a feed that contains from 0.030 to 0.017% Fe_2O_3. Both products will report to the spiral circuit with the premium sand also being dried and further processed with rare earth roll magnetic separators.

In the process, the feed reports to a Floatex® Density Separator prior to the spiral circuit. The main purpose of the Floatex® Density separator is to remove the $^{+}$0.6µ (30 mesh) size fraction. However, the test showed an addition benefit of also removing a portion of the heavy minerals as shown in the table below. The data is compared to sizing resulting from screen. Screening produces a product based on true size whereas the Density Separator also incorporates the specific gravity of the particles along with particle size.

	Density Separator			Screening	
Size (µ)	% HM	HM % Dist		% HM	HM % Dist
$^{+}$600	0.07	21.7	$^{+}$600	0	0
			$^{-}$600+300	0.04	16
$^{-}$600	0.11	72.9	$^{-}$300	0.56	84

Based on true sizing, there were no heavy minerals in the $^{+}$600µ fraction. However, with the Density Separator sizing, 21.7% of the heavy minerals reported to the coarse fraction. In the plant, the coarse fraction iron content in not important to the end-use. It should also be noted that as previously discussed, the spiral would have difficulty removing the coarse heavy minerals.

The $^{-}$600µ fraction from the above process then reported to the spiral circuit for additional heavy mineral rejection, as shown in the table below.

Product	Wt%	% HM	HM % Dist
1st pass rejects	3.8	1.1	40.0
2nd pass rejects	4.5	0.91	30.0
Middling	8.0	0.06	5.0
Products	83.7	0.03	25.0

The data shows that the spirals were very effective in removing the heavy minerals with 70% of the total heavy minerals reporting to 8.3 weight percent of the feed.

Glass sand however is not sold on the percentage of heavy minerals but rather the iron content of the final product. The table below shows the results of bulk tests conducted on samples from different areas of the proposed mine site.

Location	Feed %Fe_2O_3	Standard Product % Fe_2O_3	Premium Product % Fe_2O_3
Pit 1	0.024	0.015	0.010
Pit 2	0.019	0.012	0.010
Pit 3	0.028	0.020	0.012
Pit 4	0.030	0.019	0.010
Pit 5	0.017	0.015	0.009
Pit 6	0.024	0.013	0.012

The data shows that the spiral circuit was able to meet the objectives of the customer with the average of the six bulk tests at 0.0156% Fe_2O_3 for the standard product.

OPPORTUNITY FOR SPIRAL REJECTION OF MICA

Mica separation is a difficult operation regardless of the process, although flotation and magnetic separation are somewhat effective. Complicating the use of flotation is that a different reagent scheme is often needed to remove mica compared to removal of the heavy iron-bearing minerals. Magnetic separation is effective but the feed rates are often very low since some mica is only weakly magnetic and is a relatively expensive operation, especially after drying.

Spirals have been used for primary mica recovery for many years, while at this time there are no commercial installations for its removal from quartz sand product. Outokumpu has recently introduced a new spiral that has shown good success in removing mica from glass sand. This spiral incorporates a wash water system in a shallow pitch spiral. The wash water aids in pushing the mica outward and into the high water region of the spiral. In conventional spiral operations, the mica becomes trapped at the base of the sand region and flows with the quartz sand to the spiral discharge. Although mica has a specific gravity similar to quartz, its shape factor can make its apparent specific gravity lower.

In this new spiral specifically designed for mica removal, the quartz sand material reports to the central part of the spiral, note that in conventional spiral application heavy minerals would report to this inner trough region. Trough splitters are used in the new spiral to direct the quartz sand product to the inner cutter at each of the spiral turns. Immediately after each splitter position, wash water is added to push (or flush) mica out of the sand fraction to the high water region of the trough for eventual rejection to tailing at the discharge of the spiral. The following photograph illustrates the spiral separation mechanics

Figure 1 Carpco® CS2000W

Data have been developed through both laboratory testing and in-plant trials. Qualitatively, it has been observed that varying the amount of wash water can affect the amount of mica rejected, and similarly, the recovery of quartz. Table 3, below, presents a table showing a set of data from a pilot test of the new mica rejection spiral.

Product	Wt%	% Mica	% Mica Dist
Feed	100	23.2	100.0
Product 1	51.4	11.5	24.7
Product 2	31.6	9.5	12.5
Product 1+2	83.0	10.7	37.5
Reject	17.0	88.4	62.8

The data shows that in excess of 62% of the mica was rejected, while only 2-3% of the quartz was lost in the spiral process. The reject material contained 88.4% mica with a majority of the remaining material being fine quartz particle that would be ultimately rejected in other portions of the process. Therefore, in addition to the spiral being capable of removing the mica, the washing effect also removed some of the undesirable fine particles.

In commercial operation, the quartz sand product is dried and the sent to dry magnetic separation where 20-25 wt% is rejected to the magnetic product which contains the undesirable mica. Assuming a drying rate of 50t/h, there is a 10t/h of rejected material that could be removed by the spiral prior to final product drying. A simple projection of annual savings in natural gas for drying this material equates to approximately $50,000 per annum. Economics may differ outside North America as sand is typically shipped damp elsewhere around the world.

SPIRAL REJECTION OF REFRACTORY HEAVY MINERALS

In addition mica and mica-like aluminum bearing minerals, refractory aluminum silicate minerals also present a problem to glass manufacturers. Fortunately, there are large numbers of high quality glass sand resources around the world that are void of the refractory heavy minerals. However, in some locations such as India, the geology is such that it is a common occurrence to find high quality quartz sand contaminated with these refractory heavy minerals. Their presence in even small amounts such as a few grains per kg of sand can cause glass producers considerable problems since each grain likely results in a glass melt defect.

The refractory heavy minerals pose a unique problem for spiral separation since the specific gravity of these minerals are close to that of quartz than are the iron-based heavy minerals. In addition, the grains that cause the most problems to the glass producers are the coarser grains since these are the most difficult to melt. Refractory mineral grains that are less than 200µ do not pose much of a problem, however, those that are greater than 400µ are very problematic.

As previously discussed, the coarser particles tend to be more difficult to separate in a spiral due to the higher centrifugal forces imposed on these grains in a spiral. These forces tend to push the coarse grains away from the center portion of the spiral and into the region of the finer quartz. The solution to this problem is to present the spiral with a narrower size distribution compared to a typical glass sand size distribution. When the spiral feed is of a narrow size distribution there is a better chance of rejection of the nearer gravity refractory minerals. Note that all gravity concentrators tend to confuse particle size with specific gravity differential and when it is possible to classify the feed into narrow size ranges, the resulting gravity based separation is improved.

Test work and industrial installations have shown that the best method to produce the narrow size distribution is by use of a density separator, sometimes referred to as a hydraulic classifier. These units, such as the Floatex® Density Separator, are more effective in front of gravity separation systems than screens when applied to making size cuts in the 300-500µ range. These same density separators provide an additional processing benefit because of the inherent preferential sizing based on mineral specific gravity. For instance, a 400µ refractory heavy mineral grain will report to the separator underflow (coarse product) whereas a 600µ quartz grain will report to the separator overflow (fine product). The differential in sizing of various minerals compared to quartz is shown in the table below. The same data is then presented in graph form directly following the table. (Figure 2)

Size µ	**Size Mesh**	**Sillmanite (3.2 sg)**	**Olivine (3.5 sg)**	**Ilmenite (4.7 sg)**
850	20	560	470	290
600	30	395	330	200
425	40	280	235	145
300	50	195	165	100
212	70	140	115	75
150	100	100	885	50
100	150	65	55	35
75	200	50	41	25

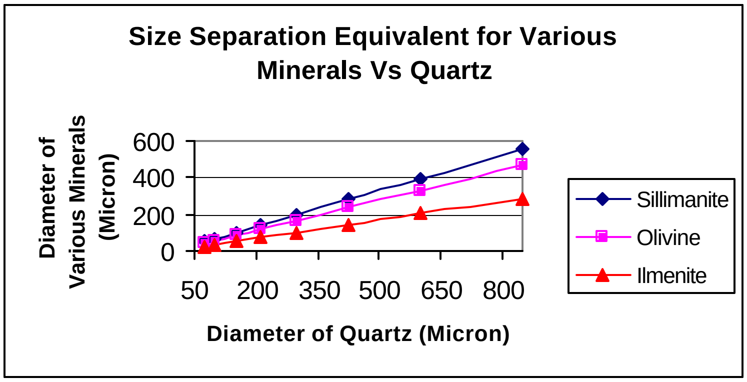

Figure 2

In a properly operated Density Separator, making a 600µ size separation based on quartz, the equivalent size separation for sillmanite would be 395µ, olivine 330 and ilmenite 200µ. That is, quartz particles coarser the 600µ would report to the underflow and finer than 600µ to the overflow. However, for the other minerals such a sillmanite, only the $^{-}$395µ particles would report to the overflow. Therefore the harder to melt and separate $^{-}$600 +395µ particles would report to the underflow as waste or to be used as a product where melting characteristics are not important.

The spiral, now separating feed that is mostly void of refractory heavy minerals in the coarser size range, can more efficiently separate the finer particles. Data from a glass sand plant in India showed that the feed contained 2-4 grains of refractory heavy minerals per kilogram of feed to the plant. The majority of these grains were in the coarser size fractions that would result in stone defects in the glass. At a plant feed rate of 40t/h, this would result in a minimum potential for 80,000 glass defects per hour.

The process has shown to be very effective with little of no sillmanite of the size that could cause glass defects being in the final product after 3 years of operation. A photograph of the glass sand plant is shown below showing the LC-3700 spirals and the Floatex® Density Separator.

Figure 3 St. Gobain Glass Sand Plant

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