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Electrostatic beneficiation of phosphate ores: Review of past work and discussion of an improved separation system

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Abstract

Beneficiation of phosphate ores by dry electrostatic processes has been attempted by various researchers since the 1940's. The underlying reasons for developing dry processes for phosphate recovery are the limited amount of water in some arid regions, the flotation chemical costs, and the waste water treatment costs. While electrostatic processes may not provide a complete alternative to flotation, it may be suitable as a supplement for some streams such as reducing fines/slimes content of ore prior to flotation, processing of flotation tailings for recovery of lost product, and minimizing environment impacts. While much work was performed using both high-tension roller and free-fall separators at laboratory scales, the only evidence of commercial installation is the circa 1940 "Johnson" process at Pierce Mine FL; There is no evidence in the literature of current commercial use of electrostatics, though strong interest in dry processes continues for use in arid regions. The various research projects reported emphasize that feed preparation (temperature, size classification, conditioning agents) have a major impact on performance. While some good separations have been achieved by removing silica from phosphates, and with fewer examples of calcite and dolomite from phosphate, the results are less positive when multiple impurities are present. Research work continues to further refine these methods, but fundamental limitations on the conventional electrostatic systems include low capacity, the need for multiple stages for adequate upgrading of ore, and operational problems caused by fines. Some of these limitations may be overcome by newer electrostatic processes including a triboelectric belt separator.

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1. Reported work on electrostatic beneficiation of phosphate ores

Phosphate concentration from natural ores has long been performed by a variety of methods using sometimes substantial amounts of water. However, due to the shortage of water at various phosphate deposits around the world, as well as increasing costs of permitting and waste water treatment, the development of an effective, economic dry process is highly desirable.

Methods for dry electrostatic processing of phosphate ores have been proposed and demonstrated at small scales for over 70 years. However, commercial applications of these methods have been very limited. The “Johnson process” [1] was used commercially starting in 1938 for a period of time at the American Agricultural Chemical Company plant near Pierce Florida USA. This process used a very complex series of roller electrodes (Figure 1) for multi-stage concentration of phosphate recovery from deslimed washery tailings, flotation pre-concentrates, or flotation tailings. Starting with 15.4% P₂O₅ and 57.3% insolubles material in the fine tailings, though a combination of size classification, desliming, and pre-conditioning of the dried tailings, material with 33.7% P₂O₅ and only 6.2% insolubles was recovered. In another example, upgrading of flotation tailings with 2.91% P₂O₅ resulted in a product of 26.7% P₂O₅ with an 80% recovery. Johnson observed that it was necessary to treat the washery tailings with chemical reagents typically used in phosphate flotation to obtain high phosphate grade and recovery. He specifically mentions the effectiveness of fuel oil and fatty acids as reagents.

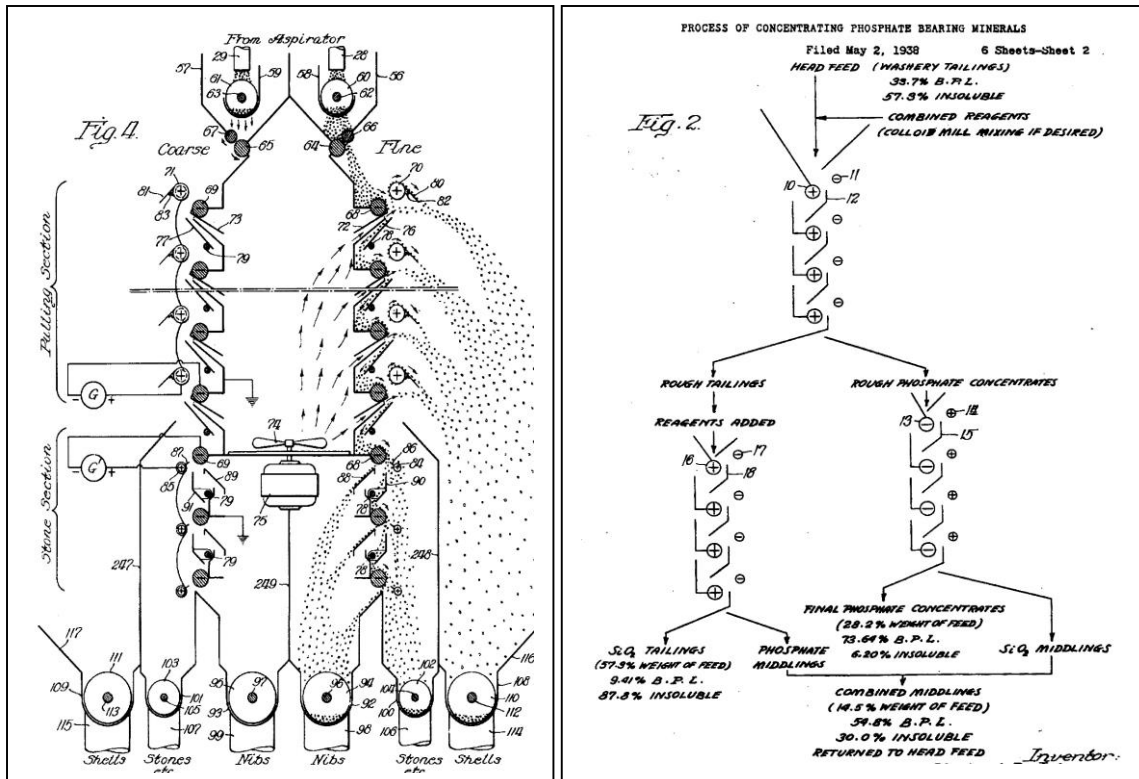


Figure 1, Johnson process apparatus and flow sheet US Patent 2,135,716 and 2,197,865, 1940 [1][2]

While this commercial installation is cited in the literature as starting about 1938, it is not clear how extensively or for how long this process was used. In his summary of the status of electrostatic separations up to 1961, O. C. Ralston [3] writes that five large Johnson separators were installed each processing about 10 tons/hr of -20 mesh feed. Each separator was 10 rolls high with applied voltage of 20 kV. No other commercial-scale phosphate concentrators using electrostatics were installed in Florida according to Ralston. Based on the process equipment description, the authors

have concluded that the overall capacity of the process was rather low in relation to the capacity of other processes, such as wet flotation. Low capacity and the costs of drying the feed ore from wet mining in Florida are likely the reason for limiting the further application of the process in the 1940s and 1950s.

In the 1950's and 1960's workers for International Minerals & Chemicals Corporation (IMC) examined the application of dry electrostatic separation processes for mineral beneficiation. Floridian phosphate ore processing was of particular interest to IMC. The IMC work utilized a free fall separator design sometimes with particle charging enhanced by passing through an agitator or impactor such as a hammer or rod mill. [4] A subsequent patent [5] included some enhancement of the separation using chargers of different materials, though the final patent in the series [6] concluded that particle-particle contact charging at an elevated temperature (>70°F) was more effective than using a charger system. Representative examples of results reported in these patents are shown in Table 1.

Table 1. Reported results from International Minerals & Chemicals Patents 1955-1965

Feed % P₂O₅	Product % P₂O₅	% Recovery	Reference
14.4	33.6	Not Given	Lawver 1955 [4]
29.7	35	56	Cook 1955 [7]
29.1	33	96	Lawver 1957 [8]
28.4	34.4	92.6	Lawver 1956 [5]

The various IMC patents examined the influence of particle size, including processing of various screen cuts independently, though little work involved very fine (<45 μm) particles. Sample conditioning varied widely, including temperature adjustment, pre-washing and drying, and different drying methods (indirect drying, flash drying, heat lamps with specific IR wavelength ranges). Different impurities (i.e. silicates versus carbonates) required different handling and pre-treatment methods to optimize the separation. While it is clear from the patent descriptions that IMC was attempting to develop a commercial scale process, examination of the literature does not indicate that such an installation was ever constructed and operated at any IMC site.

In the 1960's work specifically on carbonate containing phosphate ores from North Carolina was performed at the North Carolina State University Minerals Research Laboratory, [9] Using a laboratory scale free-fall separator and a synthetic mixture of ground shell carbonate and phosphate pebble flotation concentrate in a very narrow size range (-20 to +48 mesh), the research showed that pre-conditioning the material with an acid scrub or fatty acids influenced the relative charge of the phosphate as either positive or negative. Relatively sharp separations were obtained. However, when using a natural ore containing a considerable amount of fines, only poor separations were possible. The best reported separation from a residue from flotation upgrading with an initial P₂O₅ concentration of 8.2% recovered a product of 22.1% P₂O₅. No recovery level was reported. Notably, one of the reported difficulties was a build-up of fines on the separator electrodes.

Additional work on electrostatic separation of North Carolina phosphate using a high tension roller type separator [10] concluded that while separation of phosphate and quartz was possible, drying cost were prohibitive. However, given that calcined phosphate ores are dry, the researchers suggested that electrostatic separation of such ores may be possible. Separation of calcined phosphates were poor in the reported work. Separation appeared to be related to particle size rather than composition. Suggested improvements included use of other electrostatic separation systems, reagents to enhance particle charging characteristics and very close screen sizing of materials. There is no evidence that any follow-up work was performed on this project.

Somewhat earlier work using high-tension roller separators [11] successfully removed aluminium and iron compounds from run-of-mine ore from Florida. The ore was dried, crushed, and carefully sized prior to separation. The P₂O₅ concentration was increased marginally from 30.1% to 30.6% but the removal of the Al and Fe compounds enabled a much better subsequent recovery by flotation methods. This work illustrated the use of an electrostatic separator to address a problem with a specific ore that limited conventional wet processing.

Along with investigations into separation of many other materials, Ciccu and co-workers tested the separation of a variety of phosphate ores including sources from India, Algeria, Tunisia, and Angola. [12] Electrostatic separation was of interest as an alternative to flotation from an economic standpoint due to the fact that large deposits of phosphates are found in arid regions. [13] Using laboratory-scale free fall separators with a “turbocharger”, these researchers were able to obtain separation results similar to flotation processes from ores with relatively simple gangue compositions. Specifically, they found that phosphate charged positive in the presence of silica, but negative in the presence of calcite. However, if the ore contained significant amounts of both silica and carbonate, electrostatic separation was poor and flotation processes proved more flexible for obtaining practical separations. From studies of the effects of the turbocharger on charging of individual particles, these researchers concluded that the gangue material charged primarily by particle-particle contact rather than contact with the turbocharger surfaces. [13] [14] Charging was also highly sensitive to material temperature, with good separation only obtainable above 100°C. Additionally, the presence of fine material caused problems in the separator and good results depended on careful sizing of particles in up to three size ranges prior to separation. A summary of results from this group is presented in Table 2. No full-scale applications appear to have been implemented based on this work.

Table 2. Reported results from Ciccu, et. al. from laboratory-scale free fall separators

Ore Source and Type	Feed % P ₂ O ₅	Product % P ₂ O ₅	% Recovery	Reference
Algeria, phosphate/carbonate	24.1	32.9	80	Ciccu, 1972 [12]
India, phosphate/carbonate with complex gangue including quartz	18.2	29	52.6	Ciccu, 1993 [13]
Angola, phosphate/quartz	23.1	32.3	84.4	Ciccu, 1993 [13]
Algeria, phosphate/carbonate	25.1	29.5	86.1	Ciccu, 1993 [14]

Electrostatic separation of an Egyptian ore was studied by Hammoud, et al. using a laboratory-scale free fall separator. [15] The ore used contained primarily silica and other insolubles with an initial P₂O₅ concentration of 27.5%. The recovered product had a P₂O₅ concentration of 33% with a 71.5% recovery.

An additional study of an Egyptian ore with primarily siliceous gangue was conducted by Abouzeid, et al. using a laboratory roller separator. [16] The researchers specifically sought to identify dry techniques to concentrate and / or dedust phosphate ores in districts with water shortages. This study obtained a product with 30% P₂O₅ from a feed material with 18.2 % P₂O₅ with a recovery of 76.3 % after careful sizing of material to a narrow range between 0.20 mm and 0.09 mm.

In a subsequent review article covering the full range of beneficiation processes for phosphate recovery, Abouzeid reported that while electrostatic separation techniques were successful in upgrading phosphate ores by removing silica and carbonates, the low capacity of the separators available limited their use for commercial production. [17]

Electrostatic separation of Florida ores was studied recently by Stencil and Jian using a laboratory flow-thru free-fall separator. [18] The objective was to identify an alternative or supplemental processing scheme to the long-used flotation systems since flotation could not be used on material of less than 105 µm. This fine material was simply landfilled, resulting in a loss of nearly 30% of the phosphate originally mined. They tested deslimed raw ore, fine flotation feed, rougher flotation concentrate, and final flotation concentrates obtained from two processing plants in Florida at feed rates up to 14 kg/hour in a lab-scale separator. Good separation results were reported with the fine flotation feed (+0.1 mm; ~12% P₂O₅) from one source which was upgraded to 21-23% P₂O₅ in two passes with 81-87% P₂O₅ recovery by rejecting primarily insoluble silica. Similar results were achieved when tribo-charging the feed using either a pneumatic conveying tube or a rotating tribo-charger.

The most recently reported research into electrostatic separation of phosphate ores involved systems designed to better optimize charging of the materials prior to introduction into a free fall separator, Tao and Al-Hwaiti [19] identified that there were no commercial use of electrostatics for phosphate beneficiation due to the systems low

throughput, low efficiency and the need to work with narrow particle size distributions. These researchers specifically sought to overcome the low particle charge density associated with systems dependent on particle to particle contact or impact on a simple charging system. Working with a Jordanian ore with primarily silica gangue, the material was crushed to -1.53 mm and carefully deslimed to remove material below 0.045 mm. A small laboratory scale free-fall separator was fitted with a newly designed rotating charger designed with a stationary cylinder and a rotating drum, or charger, and an annular space in between. An external power supply was used to apply an electric potential between the fast rotating drum and the stationary cylinder. After charging by contact with the rotating drum, the particles pass into a conventional free-fall separator. Working with 100 gram batch size and starting with a deslimed feed P_2O_5 content of 23.8%, after two passes a concentrate with up to 32.11% P_2O_5 was recovered, though only with an overall recovery of 29%.

In an effort to beneficiate phosphate fines (< 0.1 mm), Bada et al. employed a free fall separator with a rotating charging system very similar to that of Tao's.[20]. The starting material was from a flotation concentrate containing fines with a P_2O_5 of 28.5%. A product of 34.2% P_2O_5 was recovered but again with a low recovery rate of 33.4%.

This "rotary triboelectrostatic free-fall separator" was again applied to the dry beneficiation of phosphates by Sobhy and Tao. [21] Working with a crushed dolomitic phosphate pebble from Florida with a very broad particle size range (1.25 mm - <0.010 mm), a phosphate concentrate with 1.8% MgO and 47% P_2O_5 recovery was produced from a feed starting with approximately 23% P_2O_5 and 2.3% MgO. The optimum results on the lab-scale device was achieved when feeding 9 kg/hr and - 3kV applied to the rotary charger. The separation efficiency was reported to be limited by both poor liberation of material in the large particles and interference of different particle sizes in the separation chamber.

Better results were achieved when processing a flotation feed sample with narrower particle size distribution of 1 to 0.1 mm. With an initial P_2O_5 content of approximately 10%, product samples were obtained with approximately 25% P_2O_5 content, P_2O_5 recovery of 90%, and rejection of 85% of the quartz. This demonstrated efficiency was noted as much better than that obtained with a free-fall separator with a more conventional charging system as used by Stencil [18] demonstrating the advantage of the newly designed rotary charger. Processing a flotation concentrate containing 31.7% P_2O_5 resulted in a product of greater than 35% P_2O_5 with a recovery of 82%. This upgrading was noted to be better than possible by flotation.

This laboratory scale separator with a separation system width of 7.5 cm was described as having a capacity of 25 kg/hr, equivalent to 1/3 tonne/hr/meter of width. However, the reported effects of feed rate on separation efficiency showed that optimal separations were obtained at only 9 kg/hr or slightly over one-third the nominal capacity of the system.

Overall, previous work on electrostatic upgrading of phosphate ores have been limited by the relative charging of complex gangue and the detrimental influence of particle size effects, in particular the effect of fines. The large majority of work involved only laboratory scale equipment with no validation that commercial scale, continuously operated equipment could be used. Additionally, the low capacities of available electrostatic process equipment has made commercial applications uneconomical.

2. Limitations of conventional electrostatic separation processes

High tension roller electrostatic separation systems as used by Groppo [10] and Kouloheris et al. [11] are commonly used for upgrading a variety of materials when one component is more conductive than others. In these processes, the material must contact a grounded drum or plate typically after the material particles are negatively charged by an ionizing corona discharge. Conductive materials will lose their charge quickly and be thrown from the drum. The non-conductive material continues to be attracted to the drum since the charge will dissipate more slowly and will fall or be brushed from the drum after separation from the conducting material.

The following diagram (Figure 2) illustrates the fundamental features of this type of separator. These processes are

limited in capacity due to the required contact of every particle to the drum or plate. The effectiveness of these drum roll separators are also limited to particles of about 0.1mm or greater in size due to both the need to contact the grounded plate and the required particle flow dynamics. Particles of different sizes will also have different flow dynamics due to inertial effects and will result in degraded separation.

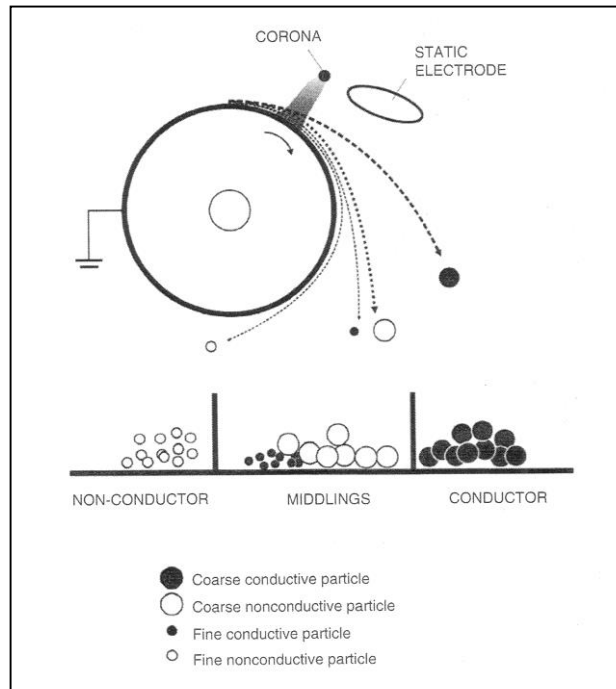


Figure 2: Drum electrostatic separator (Elder and Yan, 2003 [22])

The limited attempted application to phosphate beneficiation is due to the non-conductive nature of both phosphates and typical gangue material. Kouloheris observed primarily some removal of iron and aluminium containing particles that, due to their conductive nature, are “thrown” from the roller. Presence of this sort of material in phosphate ores is not common. Groppo noted that the only material that was “pinned” to the roller as a “non-conductor” were fines, indicating a separation by particle size rather than material composition. [9] With possible rare exceptions, phosphate ores are not amenable to beneficiation by high tension roller separators.

Drum roller separators have also been utilized in configurations that rely on triboelectric charging of particles rather than charging induced by ionization induced by a high-tension field. One or more electrodes positioned above the drum, such as the “static” electrode illustrated in Figure 2, are utilized to “lift” particles of opposite charge from the drum surface. Such a system was used by Abouzeid, et al. [16] who found that separation efficiency was altered depending on the polarity and applied voltage of the static electrodes. The Johnson Process [1] used another variation of a drum roller separator. However, the limited capacity and efficiency of a single roller system leads to the very complex systems such as illustrated in Figure 1. As stated above, it appears that this complexity and overall inefficiency of the process severely limited its application.

Triboelectrostatic separations are not limited to separation of conductive / non-conductive materials but depend on the phenomenon of charge transfer by frictional contact of materials with dissimilar surface chemistry. This phenomenon has been used in “free fall” separation processes for decades. Such a process is illustrated in Figure 3. Components of a mixture of particles first develop different charges by contact either with a metal surface, as in a tribo-charger, or by particle to particle contact, as in a fluidized bed feeding device. As the particles fall through the

electric field in the electrode zone, each particle’s trajectory is deflected toward the electrode of opposite charge. After a certain distance, collection bins are employed to separate the streams. Typical installations require multiple separator stages with recycle of a middling fraction. Some devices use a steady stream of gas to assist the conveying of the particles through the electrode zone.

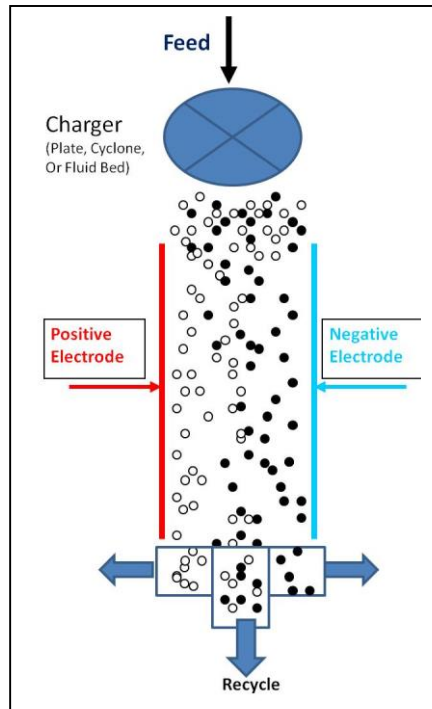


Figure 5: “Free fall” triboelectrostatic separator

Rather than depending solely on particle to particle contact to induce charge transfer, many systems of this type use a “charger” section composed of a selected material with or without applied voltage to enhance particle charging. In the 1950’s, Lawver investigated using various devices including a hammer mill and rod mill to recharge material between separation stages [4] as well as simple plate chargers of various materials. [5] [6] However, Lawver concluded that material temperature was of overriding importance and particle-particle charge transfer above ambient temperature provided better results than the use of a charger. Ciccu et al. [12] investigated the relative degree of charge transfer and concluded that minor gangue material acquired charge primarily through particle-particle contact due to the low probability of impact frequency with a charger plate. This illustrates a limitation to the use of charger systems: all particles must contact the charger surface so the feed rate must be relatively low. Contact can be improved by using turbulent conditions for conveying the material or by using a large surface area moving charger. The recent work of Tao [19] and Bada [20] and Sobhy [21] use a specially designed rotating charger with applied voltage but only on a very small scale laboratory separator. While this improved charger design has been shown to be superior to older systems, demonstrated processing capacities of these systems are still quite low. [21]

This type of free fall separator also has limitations in the particle size of the material that can be processed. The flow within the electrode zone must be controlled to minimize turbulence to avoid “smearing” of the separation. The trajectory of fine particles are more effected by turbulence since the aerodynamic drag forces on fine particles are much larger than the gravitational and electrostatic forces. This problem can be overcome to a degree if material with relatively narrow particle size range is processed. Much of the research discussed above included pre-screening material into different size ranges in order to optimize separation. [5] [6] [7] [9] [12] [14] [16] [19] [20] [21] The

need to treat different particle size ranges from the same ore requires a complex process for sizing and segregating these size fractions.

Particles of less than 100 μm cannot be effectively separated in “free fall” systems. Specially designed separators have been used to process fine materials using a flowing air channelled through a system to create a laminar flow in the separation zone. This type of separator is used in some of the latest work discussed. [19] [20] [21] Also, very fine particles tend to collect on the electrode surfaces and some method of cleaning the electrodes must be included for use as a continuous commercial process.[23] This problem may not be evident during small laboratory scale trials but must be considered in commercial scale systems .

Another limitation of the free fall separator is that the particle loading within the electrode zone must be low to prevent space charge effects, which limit the processing rate. Passing material through the electrode zone inherently results in a single-stage separation, since there is no possibility for recharging of particles. Therefore, multistage systems are required for improving the degree of separation including re-charging of the material by subsequent contact with a charging device. The resulting equipment volume and complexity increases accordingly.

3.0 STET Belt Separator

Although it has not been used commercially in the phosphate industry, ST Equipment and Technology LLC’s (STET) triboelectrostatic belt separator (Fig. 6) has the demonstrated capability to process fine particles from <0.001 mm to about 0.5 mm. [24] These separators have been in operation since 1995 separating unburned carbon from fly ash minerals in coal fired-power plants. Through pilot plant testing, in-plant demonstration projects and/or commercial operations, STET’s separator has demonstrated separation of many minerals including potash, barite, calcite and talc. Since the primary interest in this technology has been in its ability to process particles less than 0.1mm, the limit of conventional free-fall and drum roll separators, the upper particle size limit of STET’s current design is not accurately known. Currently, this limit is being determined and efforts are under way to increase it by design changes.

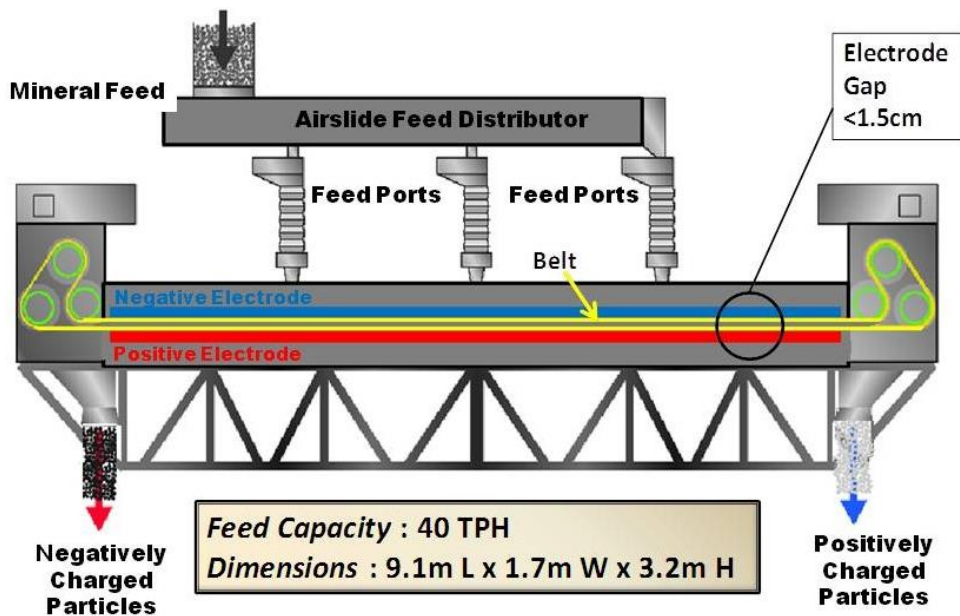


Figure 6: Separation Technologies’ Triboelectric Belt Separator

The fundamentals of operation of the STET separator are illustrated in Fig. 7. The particles are charged by the triboelectric effect through particle-to-particle collisions in the air slide feed distributor and within the gap between the electrodes. The applied voltage on the electrodes is between ± 4 and $\pm 10\text{kV}$ relative to ground, giving a total voltage

difference of 8 to 20 kV. The belt, which is made of a non-conducting plastic, is a large mesh with about 60% open area. The particles can easily pass through the holes in the belt. Upon entry into the gap between the electrodes the negatively charged particles are attracted by the electric field forces to the bottom positive electrodes. The positively charged particles are attracted to the negatively charged top electrode. The speed of the continuous loop belt is variable from 4 to 20m/s. The geometry of the cross-direction strands serves to sweep the particles off the electrodes moving them towards the proper end of the separator and back into the high shear zone between the oppositely moving sections of the belt. Because the particle number density is so high within the gap between the electrodes (approximately one-third the volume is occupied by particles) and the flow is vigorously agitated, there are many collisions between particles and optimal charging occurs continuously throughout the separation zone. The counter-current flow induced by the oppositely moving belt sections and the continual re-charging and re-separation creates a counter current multistage separation within a single apparatus. This continuous charging and recharging of particles within the separator eliminates any required “charger” system prior to introducing material to the separator, thus removing a serious limitation on the capacity of other electrostatic separators. The output of this separator is two streams, a concentrate and a residue, without a middlings stream. The efficiency of this separator has been shown to be equivalent to approximately three stages of free-fall separation with middlings recycle.

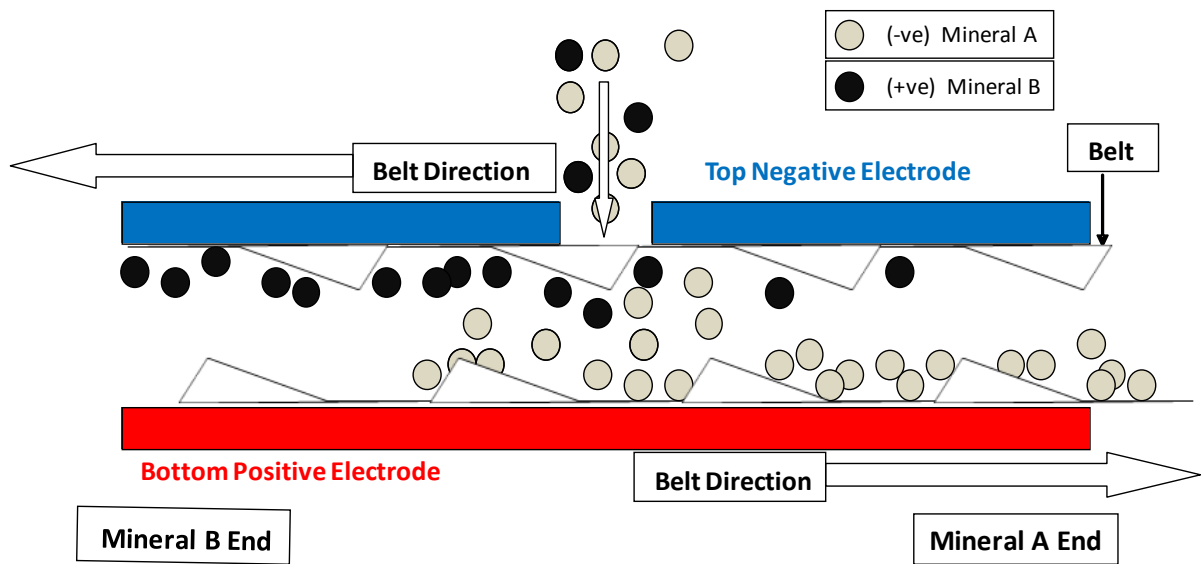


Figure 7: Fundamentals of STET Belt Separator

The highly efficient separation of particles less than 0.5 mm makes this an ideal and proven option for separation of fines (dust) from a potash dry grinding operation. The STET separator can process a wide range of particle sizes efficiently without the need for classification into narrow size ranges. Because of the vigorous agitation, the high shear rate between the moving belts, and the ability to handle very fine particles (<0.001 mm) the ST separator might be effective in separating phosphate ore slimes where other electrostatic separators have failed.

3.1 Capital and Operating Costs

A comparative cost study was commissioned by STET and conducted by Soutex Inc. [25] Soutex is a Quebec Canada based engineering company with extensive experience in both wet flotation and electrostatic separation process evaluation and design. The study compared the capital and operating costs of tribo-electrostatic belt separation process to conventional froth flotation for the beneficiation of a low-grade barite ore. The operating costs were estimated to include operating labor, maintenance, energy (electrical and fuel), and consumables (e.g. chemical reagent costs for flotation). The input costs were based on typical values for a hypothetical plant located near Battle Mountain, Nevada USA. The total cost of ownership over ten years was calculated from the capital and operating cost by assuming an

8% discount rate. The results of cost comparison are present as relative percentages in Table 3.

Table 3. Cost Comparison for Barite Processing

Technology	Wet Beneficiation	Dry Beneficiation
	Froth flotation	Tribo-electrostatic belt separation
Purchased Major Equipment	100%	94.5%
Total CAPEX	100%	63.2%
Annual OPEX	100%	75.8%
Unitary OPEX (\$/ton conc.)	100%	75.8%
Total Cost of Ownership	100%	70.0%

The total purchase cost of capital equipment for the tribo-electrostatic belt separation process is slightly less than for flotation. However when the total capital expenditure is calculated to include equipment installation, piping and electrical costs, and process building costs, the difference is large. The total capital cost for the tribo-electrostatic belt separation process is 63.2% of the cost of the flotation process. The significantly lower cost for the dry process results from the simpler flow sheet. The operating costs for the tribo-electrostatic belt separation process is 75.5% of the flotation process due to mainly lower operating staff requirements and lower energy consumption.

The total cost of ownership of the tribo-electrostatic belt separation process is significantly less than for flotation. The study author, Soutex Inc., concluded that the tribo-electrostatic belt separation process offers obvious advantages in CAPEX, OPEX, and operational simplicity.

4. Summary

While beneficiation of phosphate ores by dry electrostatic processes has been attempted by various researchers since the 1940’s there has been very limit use of such processes on a commercial scale. The limited success has been due to a variety of factors attributable to the separator systems designs and the complexity of the ores.

Feed preparation (temperature, size classification, conditioning agents) has a major impact on performance of the separation systems. Opportunities for further work in this area, in particular the exploration of chemical conditioning agents to enhance the differential charging of particles to enable greater efficiency in subsequent separation. The use of such charge-modifying agents may result in processes that can successfully beneficiate ores with complex gangue material, including both silicates and carbonates.

While work continues to further refine these methods, fundamental limitations on the conventional electrostatic systems include capacity, the needed for multiple stages for adequate upgrading of ore, and operational problems caused by fines. In order for viable commercial-scale applications of the demonstrated laboratory techniques, significant improvements must be made to assure reliable, continuous operation without degradation of efficiency.

The STET triboelectric separator provides the mineral processing industry a means to beneficiate fine materials with an entirely dry technology. The environmentally friendly process can eliminate wet processing and required drying of the final material. The STET process operates at high capacity – up to 40 tonnes per hour by a compact machine. The STET separator can process a wide range of particle sizes efficiently without the need for classification into narrow size ranges. Because of the vigorous agitation, the high shear rate between the moving belts, and the ability to handle very fine particles (<0.001 mm) the STET separator might be effective in separating slimes from phosphate ores where other electrostatic separators have failed. Energy consumption is low, approximately 1-2 kWh/tonnes of material processed. Since the only potential emission of the process is dust, permitting is typically relatively easy.

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