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# Silicate Mineral and Potash Flotation

by

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**Abstract.** The silicates represent the largest and most common group of minerals on earth. Yet in spite of the chemical similarities, numerous mineral processing plants worldwide are operating successfully to yield varied commercial products for numerous uses. The silicates which are commercially produced in the United States by flotation include quartz, feldspar, mica, spodumene, talc, kaolin, and wollastonite. The operation of several plants and the conditions affecting mineral separation by flotation are described. Since the process is usually dictated by the desired market, specifications for the most common products are provided.

Potash is a basic fertilizer component, along with phosphate and nitrogen. Potash is typically produced from underground evaporite beds or recovered from natural brine solutions. Flotation of potash is unique in that it is processed in a saturated salt solution. The potash flotation process is outlined and several commercial operations are described.

## Flotation of Silicates

**R. Bruce Tippin**

Mineral Processing of the silicates by flotation includes a large variety of minerals, including those listed in Table 1. All of the minerals listed in the table have been commercially processed by flotation but several* are no longer being mined or processed. These plus others are usually termed "Industrial Minerals." This suite of minerals is large and often their chemical compositions are very similar. In spite of the chemical similarity, separating the minerals by flotation has been successful and numerous processing plants are in operation worldwide. Quartz (silica), the major component in many of the industrial mineral deposits may be a valuable product or a waste material.

For a more complete summary of industrial minerals, their application, use and technical aspects, the readers are referred to the book "Industrial Minerals" by Lefond, published by the SME or "Industrial Minerals", a monthly magazine published in London. Information is also available through the US Geological Survey in their publication "Mineral Industry Surveys."

**Table 1**
**Commercially Produced (flotation) Silicate Minerals**

| | |
|---|---|
| Quartz | Wollastonite |
| Feldspar | Spodumene* |
| Mica | Talc |
| Nepheline syenite* | Kaolin |
| Vermiculite | Pyropholite |
| Potash | Phosphate |
| Kyanite* | Olivine* |

Industrial minerals are produced to a specific market with individual physical and chemical characteristics. Depending upon the application, the physical characteristics may be more important than chemical characteristics. These physical properties may include such things as max or min particle size, particle size distribution, surface area, color, shape, bulk density and a host of others.

The production and marketing of industrial minerals is much different than the metals, which are internationally traded commodities with published prices. Market value of the industrial minerals can range from as little as a few dollars per ton to several thousand dollars per ton. The value of the mineral product is dependent upon the quality and end usage as well as the demand. Uses for various industrial minerals are given in the above referenced publications. Some prices of industrial mineral products are provided in the Industrial Minerals magazine but these are usually quite general as most companies sell their products by individual contracts and the price is confidential. The sale of industrial minerals is highly competitive and this situation sometimes leads to proprietary technologies.

The majority of industrial mineral plants are small tonnage facilities, less than 1000 tpd, but others handle quite large volumes of ore. The small tonnage plants are a result of the market and the location. Typically these industrial minerals are considered low cost material which means that transportation can directly influence the value of the ore deposit. Yet as these plants move their product mix toward hi-value materials, location will become less an influence.

The number of plants producing a specific industrial mineral may be few. For example, there were only two mines in the country producing spodumene (a lithium mineral). Unfortunately, both of the spodumene mines have recently been closed. As is too often the case, the majority of our supply of lithium now comes from a foreign country. Lithium is a strategic mineral with a great number of usages. Vermiculite is another mineral where there are only two producers in the country.

Other industrial minerals are very large tonnage facilities supplying worldwide markets and operated by international companies. These would include the fertilizers potash and phosphate. Other large volume industrial minerals are kaolin and clay.

The largest industrial mineral is sometimes not thought of as being a mineral commodity at all. This is quartz. The stone, sand and gravel operators serving the construction business handles by far the greatest mineral tonnage in the country. However, the quartz used in the construction industry seldom required flotation or any other type of mineral separation.

Specifications are a critical component in the sale of industrial minerals. Many plants operate on long term, single source contracts where the tonnages are guaranteed and the product specifications rigidly adhered to. Quality control and consistency in a product is often a key issue. A good example of this is the paint industry where mineral fillers are used and color matching is mandatory. It is possible for railcars or bulk shipment to be rejected at the customer's site because the material does not meet specifications. Usually the rejected material is returned to the producers at their cost or sold at a reduced price.

Many of the industrial minerals occur in deposits that contain several valuable components. It is not uncommon for there to be a primary product at a plant and several other by-products which are produced from the same deposit. In one operation, over 90% of the mined ore is marketed, including the clay slimes, which are used to make a high-quality brick. This is in contrast to the metal mining industry where the valuable component is sometimes less than 1% of the feed. (Note: Iron ore is the major exception.)

It is interesting to note that over the past decade, technical improvements and increased economics in the mining industry have centered on improving the efficiency by size. Larger trucks, larger shovels, larger float cells, and larger grinding mills. This is not true with most industrial minerals. The majority of industrial mineral plants are small tonnage operations where these improvements are not applicable. The small industrial mineral plants have had to adjust to higher costs and foreign competition by means other than volume throughput. The industrial minerals industry has adjusted the higher cost of production by turning plant waste material into by-products, developing new markets for its products or shifting part of its production into high-value materials.

Flotation is the primary means of separation for industrial minerals; however, it is often used in combination with gravity separation and magnetic separation. Less often, the process involves chemical leaching. The generalized flotation process is usually the same in the plants processing the same mineral but each plant will contain subtle differences in the process flowsheet or operating procedures to meet their customers' specific needs. The overall process used at a facility is naturally dependent upon the mineralogy of the ore deposit but also it is strongly dependent upon a particular market specification, its location and end use. An ore deposit may be very good but the market location may make its development uneconomic. Marketing industrial minerals is customer driven and sometimes this is a difficult concept to understand by investors or potential mine owners.

It is not possible in this paper to cover the flotation aspects of all the silicate minerals because of the number of minerals, the diversity of applications and the propitiatory nature of certain industrial minerals. This paper will concentrate on the flotation of three items, (1) Feldspar/Quartz/Mica as produced jointly, (2) Quartz, and (2) Mica.

## Flotation of the Pegmatite Minerals: Quartz-Feldspar-Mica

Flotation is used extensively in the separation of quartz, mica and feldspar from the North Carolina pegmatite's in the western part of the state. The basic flotation process was developed over 50 years ago and has not changed much. The equipment has become better, efficiencies have increased, operating costs have been reduced and new reagents have been introduced to improve the separation. The market conditions have changed but not the technology.

The companies have been able to effectively adjust to the changing market needs, new products in new industries and tightening of material specifications on almost every product. Some of the markets for these three minerals are shown in Table 2.

**Table 2**
**Typical Markets for Pegmatite Minerals**

- Mica
    - Surface Coating
    - Ceramics
    - Absorbents
    - Fillers and Extenders
    - Lubricants
- Feldspar
    - Glass
    - Ceramics
    - Insulators
    - Fillers and Extenders
    - Abrasives
    - Fiber glass
- Quartz
    - Glass
    - Refractories
    - Fillers and Extenders
    - Ceramics
    - Pesticides and abrasives
    - Electronics (High Purity Quartz)

These operations tend to be small, usually in the range of 350 to 750 tons per day. Mining is by open pit, using trucks and shovels. The mine seldom operates more than one shift on a five or six day week basis. The Run-of-Mine ore from the pit runs 6 to 8 inches maximum.

The ore feeding the plant is crushed to about 1-1/4 to 1-1/2 inches. Usually crushing is done in two stages using a primary jaw crusher and a standard cone in closed circuit with a screen. One plant crushes in the pit but the others have crushers set up at the processing plant nearby. Stockpiles separate the mine and the plant so each operates independently.

The ore is considered medium hard to hard but liberation of the quartz, feldspar and mica is not a concern because it occurs coarser than the product specifications. Grinding size is selected for market applications rather than for either liberation or flotation. The ores are usually ground to somewhere between minus 20 mesh and minus 30 mesh. The major markets for mica, quartz, and feldspar require a minus 20 mesh product but restrict the amount of minus 100 mesh. To minimize the generation of fines and maximize production, rod mills in closed circuit are used as the means of grinding. Even though iron contamination is critical in the final products, the grinding is done in mills with metal liners and rods. The iron generated by grinding is removed later in the process and does not cause undue problems.

In the past screens, spiral classifiers, and cyclones have been used to close circuit the rod mills. Today most operators have installed hydrosizers in the grinding circuit. These units have been found to be very effective in reducing overgrinding and produce a closely sized material suitable for the markets.

Prior to flotation, the ore is subjected to scrubbing and desliming. Hi-density attrition scrubbers not only remove surface fines from the ore particles; it also enhances the flotation efficiency. Very little secondary fines are produced from blasting at the mine or from crushing. Soil overburden in the mine does yield some clay type material but this is normally minimal. After scrubbing, the ore is deslimed in cyclones at 150 to 200 mesh. The clay would consume excess reagents and the fines must ultimately be removed to meet size specifications of the final product.

Separation of the three minerals is accomplished in three stages of flotation. The first stage recovers the mica, the second stage removes contaminating minerals and the third stage separates the feldspar from the quartz. All the producers use small mechanical flotation cells although column cells have been investigated.

Mica can be floated in either an acid or alkaline circuit. Only one company is known to float mica in an alkaline circuit using a fatty acid as the collector. The flotation of mica in an acid circuit is considered by some operators to be more positive than in the alkaline pulp and to have better selectivity.

An acid mica float is used by most of the companies producing the quartz-feldspar-mica products. The natural characteristics of mica make it very easy to float using primary amines as the cationic collector. The pH of the flotation pulp is reduced to less than 3.0 using sulfuric acid. For better control and better separation of the coarse mica, fuel oil and a frother are added along with the amine. Since mica flotation is so positive, the conditioning time needed for mica is short, usually less than one minute, and the conditioning pulp density is not critical.

Normally only one stage of flotation is needed to produce an acceptable mica concentrate. However, some operators subject the primary mica concentrate to a single stage of cleaning. The mids are either recycled back to the flotation feed or rejected directly to waste.

The underflow pulp from the mica circuit is thickened in cyclones ahead of the next flotation circuit. Some fines are rejected in the cyclone overflow during the thickening process.

The second stage of flotation is used to remove impurities ahead of the quartz/feldspar separation. The major mineral contaminants found in the pegmatites are garnet and biotite, minerals that contain iron. Thus, this flotation is commonly termed the 'iron float'. The pH of the pulp remains acidic, possibly with minor adjustment during conditioning. Petroleum sulfonate is used as the collector and a frother is added for control purposes. The froth on top of the cells is very light and sparse. Sometimes it appears that nothing is being removed in the froth. Less than 5% of the total ore is rejected in this step, however, this is a very important step of the process. The contaminates must be removed to achieve product specification. Typically, these cells are "pulled" hard to ensure the garnet and biotite do not carry over into the next flotation stage where both the froth and the cell underflow are final products.

**Note:** Even this step of the process does not remove enough of the iron minerals to meet some market specifications. In this case, after drying and sizing the quartz, feldspar or feldspathic sand is subjected to hi-intensity magnetic separation before shipment to the customer.

The material remaining after the mica and iron float is essentially a quartz and feldspar mixture, termed feldspathic sand. At this point a marketing decision is made as to what product is needed. The flotation plants have designed in the flexibility to alter the circuit (1) to make a feldspathic sand, or (2) to make a quartz product and a feldspar product separately.

In producing feldspathic sand, the quartz and feldspar mixture coming directly from the iron float circuit would be filtered, dried, ground and sold as a product. Both quartz and feldspar are used in the manufacture of glass. If the proportions of quartz/feldspar concentrate meet the requirements in the customer's glass mix, it is less costly to purchase the feldspathic sand product than to buy the quartz and feldspar separately.

If both quartz and feldspar are to be made as individual products, the third flotation stage is used to make the separation. Both minerals are saleable products and can be marketed into several industries. Prior to the quartz feldspar separation, the underflow from the iron float is dewatered in cyclones, which removed the reagents from the previous float stages and discards any remaining fines. After dilution with fresh water, hydrofluoric acid (HF) is added to the pulp and the pH is lowered to about 2.5. The use of HF is critical to the separation of quartz and feldspar.

Hydrofluoric acid makes the separation highly selective, almost perfect. However, its use does not come without a penalty. Besides its safety hazzards, HF is highly regulated in discharge water and very closely monitored. All the pegmatite mines in the Spruce Pine mining district of North Carolina are located in the same watershed along the South Toe River. This river serves as the domestic water source for several towns and there are rigid fluoride restrictions on water discharge. This is one of the factors limiting expansion and development of new mines in the area.

Several research investigations have been successful in developing a non-HF flotation process for the separation of quartz and feldspar. However, none of these have been implemented commercially.

Amine is used as the collector for the feldspar, which is floated away from the quartz. Like the mica float, this mineral separation by flotation is very selective and requires only a rougher float to meet quartz specification. However, some plants include one stage of cleaning to remove entrained quartz from the first stage froth to improve the feldspar product quality and enhance the yield.

Glass specifications usually limit the amount of minus 100 mesh to less than 5% in quartz and feldspar. The fines from the desliming and dewatering cyclones in the process usually represent a small fraction of feed material. This material can be discarded as waste and the losses are usually small. But rather than the fines being a waste product, at least one operator captures the material to make a fine sized feldspathic sand for the ceramic industry. At this point, a second, but smaller facility has been built using the same flotation scheme (a mica circuit and an iron removal circuit), but it has been designed to handle minus 150 mesh feed material.

The three products, mica-quartz-feldspar, are dewatered, dried, screened and sold. The quartz and feldspar are subjected to a final iron clean-up by high intensity magnetic separation. All three materials may be dry ground, depending upon the end use. Shipment to the customers is either by bags of bulk (rail or truck). Typical specifications are shown in Table 4.

**Table 4**
**Typical* Glass Grade**
**Quartz and Feldspar Specifications**

| | Feldspar | Quartz |
|---|---|---|
| Si02 | 63 - 69% | 93-99% |
| Al203 | 18 - 22% | 0.05 - 0.10% |
| Fe203 | 0.05 - 0.10% | 0.01 - 0.10% |

### High Purity and Ultra High Purity Quartz

The electronics industry requires pure quartz for numerous purposes, especially for the computer industry. The silicon chips used in all computers are formed in quartz crucibles made of very high purity quartz. Typical specifications of the quartz are shown in Table 5.

**Table 5**
**Typical* High Purity Quartz**
**Specifications**

| | Standard Grade | No. 4 Grade |
|---|---|---|
| Al | 15.2 - 22.0 ppm | 7.0 - 10.0 ppm |
| Ca | 0.4 - 1.5 ppm | 0.6 - 1.0 ppm |
| Fe | 0.3 - 1.5 ppm | 0.6 - 1.0 ppm |
| L | 0.7 - 1.5 ppm | 0.2 - 1.0 ppm |
| Na | 0.9 - 1.5 ppm | 1.0 - 1.3 ppm |
| K | 0.7 - 1.5 ppm | 0.4 - 1.0 ppm |
| B | 0.08 - 0.10 ppm | 0.04 - 0.05 ppm |

*Source: Industrial Minerals Handbook II

Very few deposits in the world have quartz of this quality. Even most of the single crystal quartz specimens have unwanted contaminants within their structure. Today the quartz found in the Spruce Pine pegmatites of North Carolina is the only commercial source in the world suitable for the computer industry. Here within a very small region are the only two suppliers of this material. The entire computer industry is dependent upon nature's quartz from here. This material is critical for the world's computer industry. The price of this quartz can be as much as $10,000 per ton. Definitely a hi-value product and definitely an important mineral to almost every industry in the world.

The quartz concentrates from the quartz-feldspar-mica flotation plants in Spruce Pine are further processed to produce the various grades of high purity grade quartz. Little is known about the process except the technology includes both flotation and chemical leaching. The technology is proprietary and unpublished.

### Quartz Flotation

Quartz is also produced as primary material of numerous plants throughout the country for the glass industry. These operations are located close to the glass plants and are sand type sedimentary deposits. Geologically these are very different from the North Carolina pegmatites but the flotation process used is essentially the same. Quartz is the predominant mineral in these deposits and flotation is used to remove the small amount of other contaminants.

Mining is open pit as with most industrial minerals. Depending upon the deposit, the ore will be crushed in jaw crushers and cones or sometimes the material is such that a rock breaker or hammermill will separate the sand down to rod mill feed size. The ore is ground to between 20 mesh and 30 mesh in rod mills that are in closed circuit with screens or hydrosizers. Prior to flotation, the ore is subjected to high-solids scrubbing to remove any iron coating or stains on the surface. After scrubbing, desliming and dewatering, the contaminating minerals are removed by flotation.

These plants have only one stage of flotation. This is the iron float. Mica usually is not contained in the feed. The small amount of contaminants in the feed is removed in the flotation froth using petroleum sulfonate collector in an acid pulp. The underflows from the float cells are the final quartz product ready for dewatering and drying. After a final stage of clean-up by magnetic separation, the product is screened or dry ground to meet size specifications, before being shipped to customers.

### Mica Flotation

The mica industry divides the mineral into two major groups according to size, sheet mica and flake mica. The United States is the largest producer and consumer of mica. Flake mica represents by far the largest tonnage.

The sheet mica used in this country comes from India and China. In these countries, the combination of high-grade deposits containing large mica sheets and the low cost of production makes importing economic. Most of the deposits containing sheet mica in the United States have already been depleted.

Mica (flake) in the United States is

usually produced as a by-product or co-product from plants such as described in the quartz-feldspar-mica section of the paper.Only a few domestic deposits contain sufficient quantities of the mica to be economic without producing another saleable mineral from the ore.

One plant in the Southwest is producing mica as its primary product. This plant uses the flotation reagent system as earlier described. The ore is crushed, ground in a rod mill, scrubbed and deslimed ahead of the amine flotation in an acid pulp. No other minerals are recovered from this operation except a minor amount of tailings that are used locally for construction material. This mica is sold to the western market, where it has the advantage of low transportation cost when compared to mica from the east.

Another mine, located in the Southeast, produced only mica, but it is for a specialty market. This plant uses a combination of gravity, sizing and flotation to produce two products, a coarse and fine mica. The coarse mica is recovered by gravity and screening only. It is marketed into the cosmetic industry where it received a high price but here they cannot use flotation because the reagents could cause skin irritation. Fine mica from this plant is recovered from the minus 40 mesh fraction by the standard acid-amine flotation scheme. The fine mica is a by-product and not used in cosmetics.

## Muriate of Potash (Sylvite) Flotation

**H. L. Huiatt**

The principal source of muriate of potash (KCL) is sylvinite ore which contains halite (NaCl) and Sylvite (KCl) and may contain minor amounts of soluble salt minerals such as carnallite (KCl,MgCl26H20), kainite (KCl MgS04-2.75 H20) and langbienite (K2S04MgS04). Other salts containing sulfates plus potassium, sodium, calcium, and/or magnesium may be present in small amounts. Fine insoluble materials containing clays are often found in these ores. These insoluble slimes cause considerable problems when present during potash processing. Other important sources include carnallite ore and solar evaporites.

The methods of treating sylvinite ore vary depending on how it is mined, e.g., conventional mining versus solution mining, type of salts present and the insoluble slimes content. Sylvinite ore from conventional mining is crushed to about 6 mesh to free mineral constituents; the mesh size may vary from plant to plant. It is then scrubbed with saturated equilibrium brine to liberate the insoluble slimes. Traditionally, the insoluble slimes are removed by hydroclassification employing screens, thickeners, classifiers, and/or, hydrocyclones.

The oversize material which contains the bulk of the potash values is conditioned with a polyelectrolite to block adsorption sites on residual insoluble slimes to prevent adsorption of potash collectors. Tallow amine potash collector is added; an extender oil is added in some operations to facilitate coarse potash flotation. Amine collectors have strong frothing characteristics: consequently frothers such as MIBC and hexanol are added to modify the concentrate froth. The potash rougher concentrate is cleaned and if necessary brine leached to the concentrate froth. The potash rougher concentrate is cleaned and if necessary brine leached to make market grade of 60% K20 (95% KCl). The final concentrate is dried, compacted and screened to product sizes.

Some fine sized potash plus halite will follow the insoluble slimes during desliming; therefore the hydrocyclone underflow is combined with the feed to the potash rougher circuit or floated in a separate circuit. An alternate procedure is to hot leach the thickened slimes and recrystallize the sylvite (1).

The process brine from the desliming circuit and the potash flotation tails and concentrates contains appreciable amounts of potash values and must be recovered and recycled back to the circuit. The plant brine can be recovered by thickening, and/or, filtering. The International Mining Corporation in Carlsbad, NM developed a method where the salt tailings from the potash flotation circuit is treated with flocculent, mixed with insoluble slimes from the deslime circuit and filtered through a continuous belt filter. The brine is collected and returned to the circuit. This technique is employed by Mississippi Potash in Carlsbad, NM (2).

Mechanical desliming is effective for sylvinite ores containing about 4% insoluble slimes or less. Ores containing large quantities, 5% or more, need to be treated by other methods to get rid of the insoluble slimes and recover potash. One method is to subject the ore to a hot leach, thicken the slurry, and recrystallize the KCL from the thickener overflow in vacuum crystalizes. Brine from the thickener underflow and the crystalizes is recovered in centrifuges and recycled. The final KCl product is sold as white potash. The Mississippi Potash East Plant (formerly Kerr McGee) is one of the operations that utilizes this technique (2).

Another method is to float the insoluble slimes prior to potash flotation (3,4). This method is employed by Agrium, Inc. (formerly Cominco) at Vanscoy (5.6). In this procedure the ore containing about 5.5% insoluble slimes is pulped to about 70% solids with saturated plant brine and subjected to high intensity scrubbing for a short period to liberate the insoluble fraction from the soluble salt. Prolonged scrubbing is avoided to prevent creating fine KCL crystals.

The pulp is conditioned gently in a step mixing launders with a high molecular weight non-ionicpolyacrilamide flocculent and then with a 12 to 15 carbon ether amine. Agrium now uses an ether amine instead of the Aero 840 because of cost considerations. No frother is required as the residual frother in the brine coupled with the frothing characteristics of the collector provides adequate froth. The insoluble slimes are floated in a primary and then a secondary stage. The tailings from the primary flotation are reagentized in a step launder prior to secondary flotation. The secondary stage was incorporated to remove the additional insoluble slimes liberated during primary flotation due to mechanical attritioning.

The insoluble slime concentrates from both stages are sent to the cold slimes thickener to recover brine. Potash values in the insoluble slimes concentrate are used to saturate make up brine. The tailings from the fine potash circuit are cycloned and the cyclone underflow combined with the coarse potash feed.

The coarse potash rougher tailings are screened at 0.7 mm. The oversize is treated in 4 ft. diameter by 8 ft. high flooded column cells to recover coarse potash. The columns have conical bottoms where the brine is injected tangentially. The feed is added to the top of the column and tailings are discharged out the bottom. Concentrates are flooded off the top of the columns. The column tailings are debrined on a vibrating screen and the screen oversize is crushed in cage mills which liberate additional insoluble slimes.

The regrind is operated in closed circuit where the mill discharge is screened and the oversize returned to the cage mill. The undersized material is reagentized and the insoluble slimes floated. The insoluble slimes product is sent to the cold slimes thickener. The insoluble slimes tailings are returned to the potash circuit for further upgrading.

Potash Corporation of Saskatchewan at Rocanville also uses flotation to remove insoluble slimes from sylvinite ore containing about 1% insoluble slimes. The ore is scrubbed to free insoluble slimes, thickened and the thickener underflow reagentized with flocculent Procol CK 910 insoluble slime collector and the slimes floated. The potash from the insol tailings is recovered by flotation. Flotation columns are to be installed at Rocanville to replace cleaner flotation cells (7).

The Moab Salt Company (now part of Potash Corporation of Saskatchewan) in Moab, Utah, employs solution mining to extract potash salts from the ore body (8,9). Fresh water is injected into the old underground workings to dissolve soluble salts. The resulting brine is pumped from the mine into solar evaporation ponds where water is evaporated and potassium chloride, sodium chloride and other salts are crystallized.

These evaporites are harvested, pulped with saturated plant brine, and sent to the flotation plant where they are crushed to liberate the potash salts from halite and other minerals, conditioned with a neutralized vegetable amine collector, Aerosurf MG 102H, and froth modifiers and the KCL floated. The use of a vegetable amine potash collector is fairly recent. The potash rougher concentrate is cleaned and given a light leach if necessary to produce an acceptable grade potash product. The brine recovered from debrining is returned to the head of the flotation circuit. Salt tailings are dissolved in water and injected into the mine workings to dissolve KCl.

IMC Kalium uses solution mining at Belle Plaine, SK and Hersey, Michigan (10). Heated water is injected through a series boreholes drilled to the orebody. The resulting brine is pumped to a refinery where sodium is separated from potash by evaporation and crystallization. Concurrently solution is pumped to a 130-acre cooling pond where additional crystallization occurs. Refined potash is dewatered, dried and sized. Apparently, froth flotation is not employed at these operations.

In the past, potash beneficiation at Kali and Salz Kielitz mine has been based exclusively on flotation (11). A new hot leach plant has been added to increase KCL production. The oversize material from fine grinding is sent to the potash flotation circuit; the fine sizes are sent to the hot leach plant where high purity KCL can be produced.

Solar evaporation is also used to concentrate surface and subsurface brines from the Bonneville Salt Flats by Reilly Chemical Co. near Wendover, NV. The brines are pumped to a series of evaporation ponds. In the first ponds halite is crystallized. The supernatant brine, which is rich in MgCl2, is transferred to a holding pond. The KCL/NaCl evaporite is harvested and sent to the potash flotation circuit where it is crushed to 6 mesh, conditioned with tallow amine flotation reagent and froth modifiers and floated. The cleaner flotation product is given a light leach to make product grade, filtered, dried and compacted and screened to produce acceptable size. Carnallite crystallized from the magnesium chloride holding pond is harvested periodically. This evaporite is leached with brackish water to remove MgCl2, leaving a crude KCl crystal product, which is blended with plant feed and upgraded in the potash flotation circuit. The insoluble materials in the potash evaporates are low and do not cause problems in the flotation circuit. Reilly is cooperating with the Bureau of Land Management and the State of Utah School and Institutional Trust Land Administration in restoring the surface of the Bonneville Race Track. NaCl brine is flooded back to racetrack surface where it is left to evaporate. The natural evaporation will thicken the surface at a rate of about 1.1 centimeters per year. This is a five year program, which began in September, 1995 (12,13,14).

Carnallite is present in large quantities at the potash deposit at Upper Kama, Russia. Solikamsh Potash has been produced by a thermal dissolution process which is energy intensive and uneconomical. Solikemsk has developed a reverse flotation process where a small amount of halite and sylvite are removed in the flotation froth and the carnallite is collected in the cell discharge. An alkyl morpholine collector reagent is used. Clay slimes are removed by a preliminary flotation step. The carnallite product is claimed to be a good fertilizer for many soils (11).

The treatment of sylvinite ores has not changed much over the years. Much of the new technology consists of improvements on established classical process methods. As mentioned above, flotation columns are being tested and installed in some potash operations. Also small scale testing was performed to remove insoluble slimes from sylvinite ore using air-sparged hydrocyclone flotation. Ore obtained from the Potash Corporation of Saskatchewan was dry crushed to minus 60 mesh, pulped to the desired percent solids with saturated brine, scrubbed to free insoluble slimes and conditioned first with Percol E-10 flocculent and then with Sherex MG-185-A3 (neutralized 12-15 Carbon collector). The slurry was then pumped to the air-sparged hydrocyclone and the insols separated. In these tests, salt recoveries in the underflow product ranged from 92 to 95%. The insolubles content was reduced from 6% to as low as 1% at recoveries exceeding 70%. Collector consumption (690 g/t) was higher than that for conventional flotation (15).

## Sulfate of Potash (K2S04)

**David Butts**

IMC Kalium, at Ogden, Utah, routinely floats schoenite from sodium chloride in a beneficiation step. Brine from Great Salt Lake is pumped into a 35,000 acre solar pond complex where a mixture of salts are crystalized. These salts are halite (NaCl), epsomite (MgS04·7H20), schoenite (MgS04·K2S04·6H20), kainite (MgS04·K2S04·3H20), and carnallite (MgCl2·KCl·6H20). The relative amounts of each mineral in the mixture depends on the brine concentration where they crystalize. Brine just entering into saturation of potassium minerals will also deposit large quantities of halite and epsomite. The resulting mixed salts are low in potassium bearing minerals. This low grade mixture will have 4 to 7 percent potassium and will have very low recoveries in the processing plant unless some of the impurities are removed.

Since 1977, an anionic flotation process is used to upgrade the low grade mixed salts to a concentrate having 12 percent or higher potassium. This beneficiated product is then combined with high grade ore fed directly to the plant where it is converted to sulfate of potash (potassium sulfate).

The flotation process is dependent on conversion of all potassium minerals to schoenite. This is done by mixing the salts with a liquid and temperature environment where only schoenite, epsomite and halite are stable. The schoenite is then floated off resulting in a high grade ore easily converted to potassium sulfate by the normal processing plant routine.

In the early years of the flotation operation, concentrates of 12 to 13 percent potassium were obtained. A short chained, saturated fatty acid collection derived from coconut oil was used to float schoenite away from halite. Later, flotation was improved after it was discovered more residence time was needed to convert potassium minerals to schoenite. Two large tanks were added at the beginning of the process to increase reaction time. These were added in addition to two smaller tanks already in the process. It was also found that the fatty acid needed more time to completely coat the particles. These particles were ground to less than 35 mesh. The collector was therefore added at the first reactor tank instead of the entrance of the slurry at the flotation cells. In 1981, the more expensive coconut oil collector was replaced with petroleum sulfonate. This proved to be a better reagent at lower cost.

IMC Kalium has been the only company using the anion flotation process producing sulfate of potash on a commercial scale. SQM's Minsal plant, coming on stream this year at Salar de Atacama, Chile, also produces sulfate of potash from schoenite with a process similar to IMC. They will float schoenite. This plant has a target capacity of 250,000 tons per year.

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