

**Potash Processing in Saskatchewan – A Review of Process Technologies.**

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## Abstract

Potassium is one of the three basic plant nutrients along with nitrogen and phosphorus. There is no substitute for potassium compounds in agriculture; they are essential to maintain and expand food production.

Potash is extracted from buried ancient evaporites by underground or solution mining. This accounts for most of the potassium produced. Another important source is brine from land-locked water bodies, such as the Dead Sea, Salar de Atacama or Great Salt Lake.

About 95% of potash produced worldwide is used in agriculture. The rest is found in several other industrial uses, including glass manufacturing, soaps, plastics and pharmaceuticals.

Currently, three producers: IMC, PCS and Agrium operate 8 conventional and two solution mines in Saskatchewan, five of which run froth flotation circuits, two run heavy media-flotation, two run forced crystallization and one runs natural crystallization.

## Potash in Saskatchewan

Potash was discovered in Saskatchewan in the early 1940's while drilling for oil. The deposits lie diagonally across the southern plains of Saskatchewan sloping southerly from a 1,000 m depth at Saskatoon to more than 1,600 m depth at Belle Plaine and up to 3,000 m in depth in North Dakota. The known deposits are massive, with total resourced estimated at 67 billion tones  $K_2O$ , accounting for more than 40% of the world's known reserves (The British Sulphur Corp. Ltd., 1984)

Table 1 shows the current operating mines in Saskatchewan.

**Table 1: Potash Producers in Saskatchewan**

<b>Company</b>	<b>Location</b>	<b>Mining</b>	<b>Processing</b>
Agrium	Vanscoy	Conventional	Flotation
IMC	Belle Plaine	Solution	Mechanical Crystallization
IMC	Colonsay	Conventional	Flotation
IMC	Esterhazy (K1 & K2)	Conventional	Heavy Media-Flotation
PCS	Allan	Conventional	Flotation
PCS	Cory	Conventional	Mechanical Crystallization
PCS	Patience Lake	Solution	Natural Crystallization
PCS	Lanigan	Conventional	Flotation
PCS	Rocanville	Conventional	Flotation

The first conventional mine started production in 1962, and in 1964 the first solution mine was started near Belle Plaine. By 1971, all ten existing mines in Saskatchewan were in operation.

According to the Canadian Fertilizer Institute, the world potash production for the year 2000 amounted to 42.3 Mt KCl. Saskatchewan's share of world's production for the same year was about 13.0 Mt KCl, about one-third of the total.

Potash mining in Saskatchewan generates \$1.6 billion dollars in gross revenues, equivalent to \$251 million dollars in wages and benefits, employing 3,400 workers directly or through contractors (Source: Saskatchewan Mining Association, 2000).

The major share of the potash produced in Saskatchewan goes for export. The US is the major consumer with 52% of the total, another 43% goes to overseas markets and only a mere 5% is used in Canada.

## **The ore and products**

The mines in the Saskatoon area: Agrium, PCS-Cory, PCS-Allan, PCS-Patience Lake, PCS-Lanigan and IMC-Colonsay extract the ore from the Patience Lake member. The mines in the southeast corner of Saskatchewan: IMC-K1 & K2, PCS-Rocanville extract from the Esterhazy member, while IMC-Belle Plaine, near Regina, solution mines potassium chloride from both potash bearing members.

Ore from the Patience Lake member is a medium-grained mixture of sylvite and halite, with a KCl content of 36%, insolubles averaging up to 5.5%, and little or no carnallite.

The ore from the Esterhazy member is a coarse-grained mixture of sylvite (KCl) and halite (NaCl) with a small amount of water insolubles, and some carnallite (a K-Mg chloride). Average run-of-mine grades are about 30% KCl.

Water insoluble minerals are normally coloured from gray to brownish-gray and are typically a mixture of non-clay minerals (-150 $\mu$ m; +2 $\mu$ m) such as dolomite, anhydrite, hematite and silica, and clay minerals (-2 $\mu$ m) principally illite, chlorite, and septechlorite. The insolubles had been compressed under the pressure and are cemented together by dried soluble salts and possibly anhydrite.

Liberation in the Esterhazy member ores is substantial at 9.5 mm, and for the Patience Lake member ores is 1.2 mm.

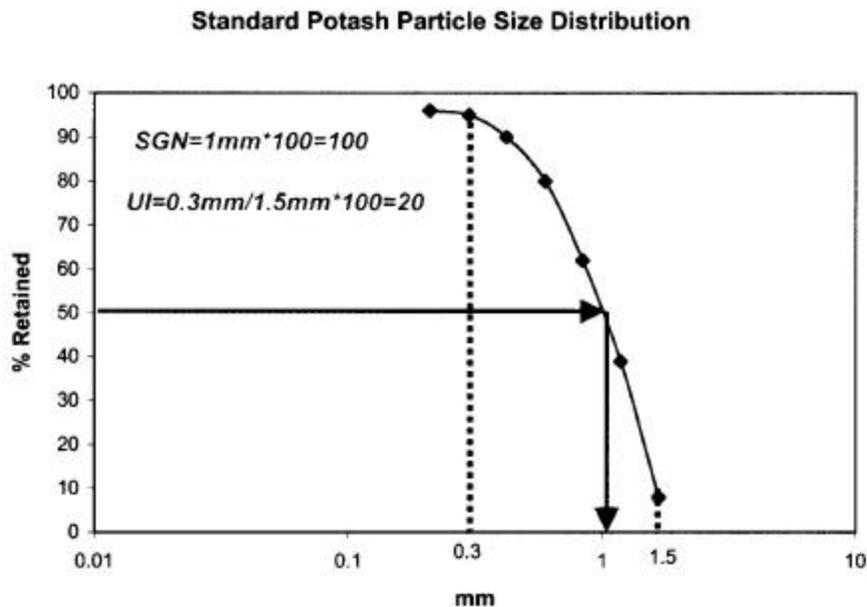
Potash, like most industrial minerals, is sold based both on its chemical composition as well as its size distribution. Fertilizer grade potash is marketed with a chemical composition of 60% K<sub>2</sub>O minimum. Various potash fertilizer products are marketed based on their size distributions.

The most common are Granular, Coarse, Standard and Fine. All four have exactly the same chemical composition, but differ on their particle size distribution specifications. The coarser products are sold at a premium. Potash prices are usually negotiated between suppliers and consumers based on delivery contracts. The “spot” price of Standard KCl f.o.b. Vancouver is considered a reference. This price has been fluctuating between \$ 100 to \$ 125 per metric tonne during the last few years.

**Table 2: Fertilizer Grade Potash Specifications**

Tyler Mesh	Opening [mm]	Typical (% cum.)			
		Granular	Coarse	Standard	Fine
6	3.360	25.0	17.5		
8	2.380	73.0	53.0		
10	1.680	97.0	88.0	7.0	
14	1.190	99.5	98.8	29.0	
20	0.841		99.5	50.0	0.2
28	0.600		99.7	78.0	1.0
35	0.420			87.0	16.0
65	0.210			98.0	77.0
100	0.149				93.0
<i>SGN</i>		285	245	85	30
<i>UI</i>		49	38	20	26

Particle size of fertilizer products is characterized by two parameters, the Size Guide Number (SGN) and the Uniformity Index (UI). Size guide number (SGN) is defined as the particle size in millimeters of which 50% by weight of the sample is coarser and 50% finer times 100.



**Figure 1:** Calculation of the SGN number and UI index.

The uniformity index (UI) is the particle size at which 95% of the material is retained, divided by the particle size at which 10% of the material is retained, multiplied by 100.

The UI is a measure of the uniformity of the size distribution of the product, when all the particles are exactly the same size, the size distribution curve is flat and the UI is 100%. Usual values of UI for premium products are about 40%.

Figure 1 describes the calculation of the SGN number and UI index.

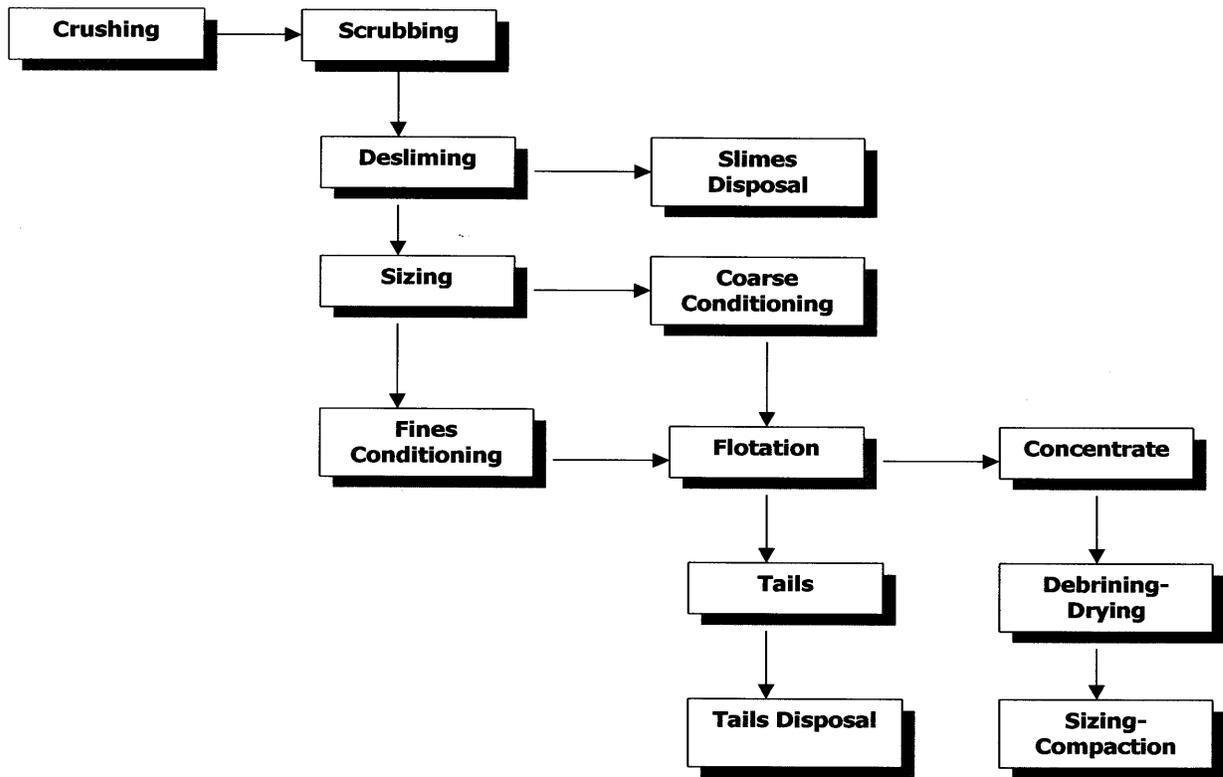


Figure 2: Schematic block diagram of a conventional potash flotation plant.

## Potash processing

About 70% of the total potash, and almost 90% of fertilizer grade potassium chloride is produced by conventional froth flotation, sometimes supplemented by heavy media separation. Crystallization is used mainly to produce industrial grade and specialty fertilizer grade (white muriate) potash.

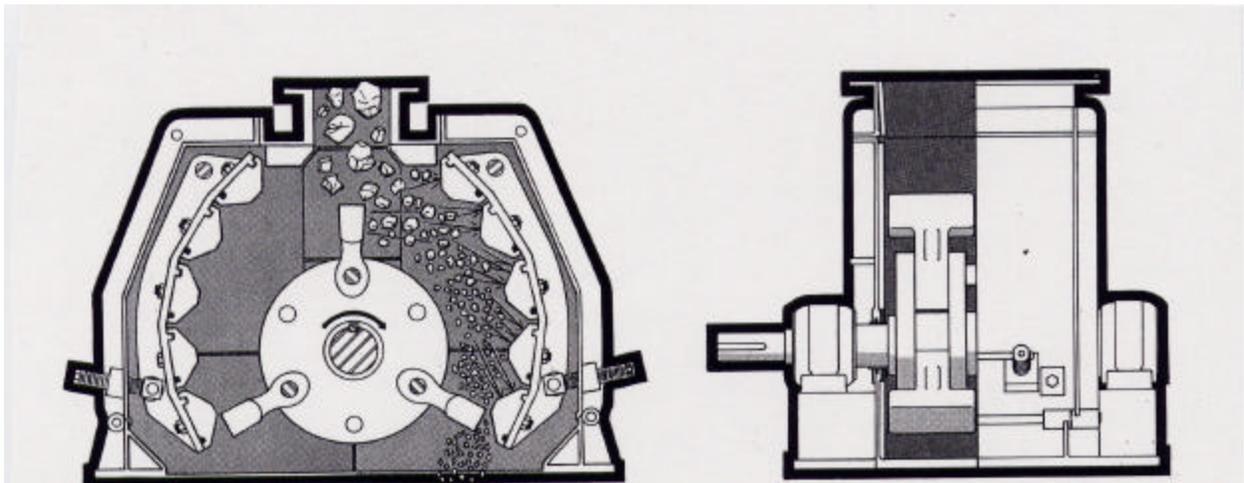
Figure 2 shows the conventional flotation route to obtain fertilizer grade potassium chloride.

### Comminution

The sizing of the mill feed ore is a compromise between maintaining the potassium chloride in as large a size as possible, obtaining a good liberation from the sodium chloride and facilitating the scrubbing of the insolubles released during the process.

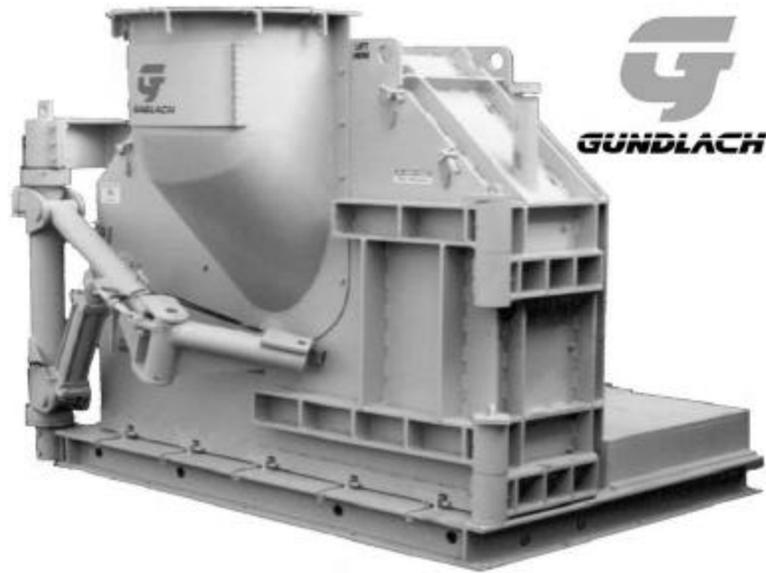
The run-of-mine ore is produced by continuous miners with a top size of about 1,500 mm, and is usually processed underground through a jaw crusher to reduce the largest lumps to the 150-200 mm range to minimize transportation problems underground and during skipping to surface.

Potash ore can be considered a soft rock, with typical Bond Work Index between 7 and 9. The simplest comminution circuits are single-stage dry crushing using impactors in closed circuit with vibrating screens. The more refined circuits consist of double-stage wet crushing in combination with wet screens and hydrocyclones. Dry crushing plants are simpler to operate, but as dust collection is difficult they are often dirty. Wet crushing plants are cleaner, the screening is more efficient and allow for improved insolubles release.



**Figure 3:** Primary crushers used in potash (Pennsylvania Crusher Inc. Catalog)

Rougher flotation tails are usually re-crushed in a secondary wet crushing stage. The older circuit designs used rod mills for this purpose. Recent expansions and retrofitting of existing plants are replacing the old roll mills for rotating cage impactors, which are cheaper to operate, use much less space, have more capacity and generate less fines (Figure 4).



**Figure 4:** Rotating cage impactor (Courtesy TJGundlach)

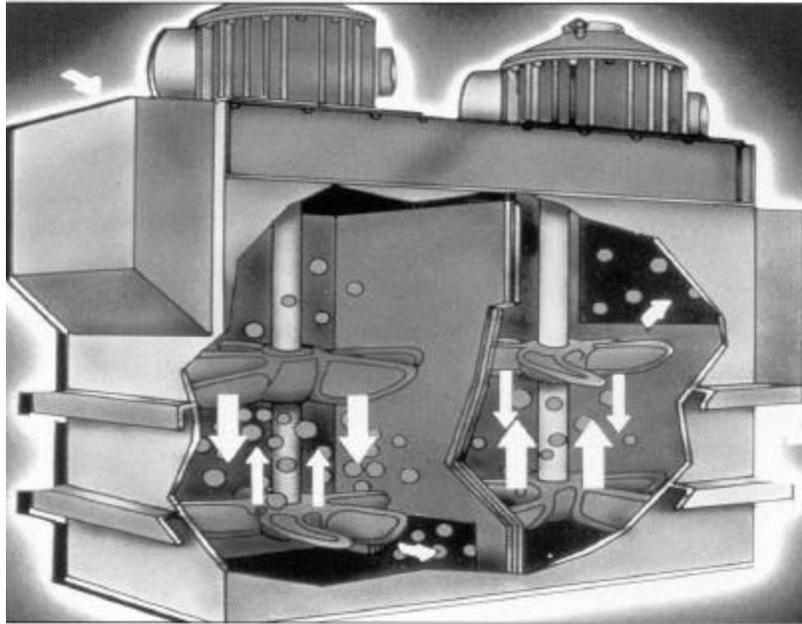
## **Scrubbing and Desliming**

In most potash ores there are liberated insoluble minerals which can be released by scrubbing the ore with saturated brine after crushing. During this stage, enough fresh water is added to the high carnallite ores to dissolve magnesium chloride.

Scrubbing is usually accomplished in a series of highly agitated cells, normally at high percent solids (60 to 70% solids in a KCl-NaCl saturated brine), designed to liberate the insolubles attached to the potash particles. Two-stage scrubbing is common in the mine areas with high insoluble ores.

After scrubbing, separation of the insolubles may be done with cyclones, siphon-sizers or wet screens, while the secondary separation is usually accomplished with hydro-separators, cyclones, and thickeners (Arsentiev and Leja, 1977).

Desliming by flotation of insoluble slimes from the ore in two stages is also practiced (Banks, 1976). This method has the advantage of reduced capital expenditures for desliming equipment but suffers the disadvantages of higher reagent costs (Banks, 1979). In this method, a flocculant is added to the minus 100-mesh fraction to increase the size of the slime particles prior to flotation. Slimes flocs are conditioned with a collector and floated in two stages in conventional flotation cells (Perucca and Cormode, 1999).



**Figure 5:** Attrition-scrubbing cells (Courtesy Metso Minerals)

The desliming stage is considered critical, as a virtually slime-free product is necessary to feed the potash flotation stage, in order to minimize reagent costs and to ensure good potash recovery.

### **Conditioning**

Coarse material is conditioned separately from fine material in order to optimize reagent usage and promote coarse particle flotation. Both coarse and fine material is conditioned with a depressant and a potash collector. An extender oil is added to the coarse conditioner. Alcohols are normally used to promote the froth.

Some conditioning is required for tailings scavenger circuits where large particles require optimum reagentizing, or flotation is preceded by secondary grinding to liberate the middlings. The cleaning, re-cleaning and centrifuge scavenging circuit require no further reagentizing.

Polyelectrolytes, usually referred as slime depressants, are applied to reduce the harmful effect of clays on sylvite flotation. The main mechanism involves blocking off the clay surfaces for amine adsorption. Therefore, collector conditioning is always preceded by conditioning with the polyelectrolyte modifier.

## Heavy Media

Heavy media separation using magnetite and cyclones is used by two operations mining the Esterhazy member. This process produces a separation of the rock at a very coarse size, of about 12 mm into three streams: tailings, product and middlings. Middlings are subsequently ground and subjected to conventional flotation; together with the fines generated in the initial crushing stages. Reagent costs are lower than with conventional flotation, but maintenance costs are high because of the abrasive properties of the magnetite.

## Potash Flotation

Since potash ores contain water-soluble salts, flotation has to be carried out in saturated brine, a highly concentrated electrolyte system. The properties of an aqueous system at such a high electrolyte concentration are very different from dilute aqueous solutions employed in conventional flotation processes.

Both coarse and fine material are floated using conventional Denver DR-type flotation cells, ranging from 100- to 300-ft<sup>3</sup>. Rougher concentrates are sized at 0.84 mm (20 mesh) which is usually final premium product. The minus 0.84 mm is sent to cleaner and recleaner flotation to separate the entrapped fine salt.

Potash rougher flotation tails usually consist of a coarse fraction (plus 1.41 mm (14 mesh)) that include liberated and non-liberated KCl particles that did not float due to their slow kinetics, and a fine fraction (minus 1.41 mm) which consist of fine salt with no potash left. Potash rougher tails are screened on Sieve Bend screens. The minus 1.41 mm (14 mesh) fraction is disposed of as tails and the plus 1.41 mm is re-crushed and floated in conventional or column cells (Figure 6).

Concentrates from rougher and scavenger potash flotation and re-cleaner flotation is centrifuged using screen-bowl type centrifuges down to 4 to 5 % moisture. Flotation tails are thickened in hydrocyclones and pipelined to tailings ponds.

Potash flotation plants are designed to deal with very coarse material when compared with conventional sulphide flotation plants. Besides, brine equilibrium is temperature dependent which causes salt crystallization when temperature either drops or increases. In order to cope with pumping problems derived from plugged lines or sanded-out pumps, potash plant are usually designed with a back-up set of pumps for each pump application. Back-up can be an extra full size pump sitting next to the operating pump, or in some cases, two pumps are operating in one application, each one with the capacity to pump at least 75 % of the total flow.

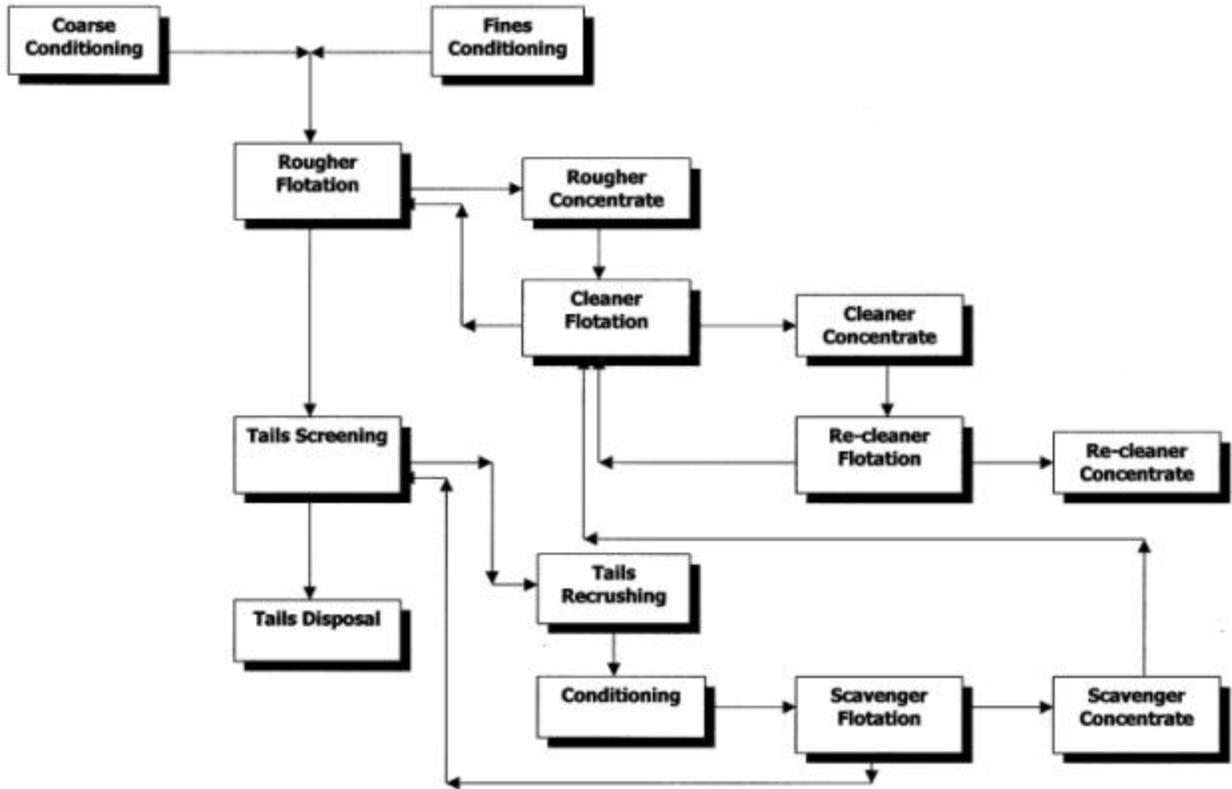
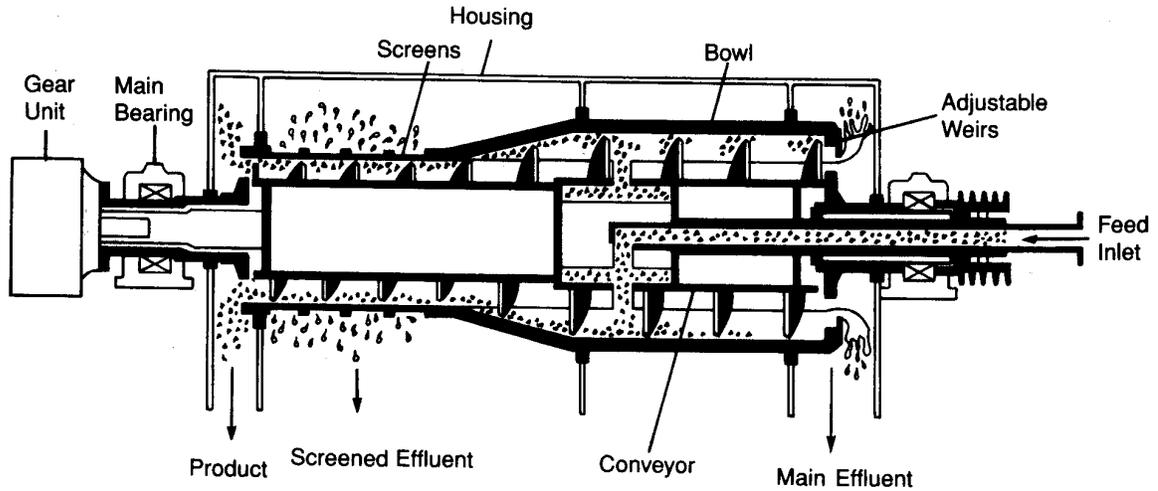


Figure 6: Simplified block diagram of a potash flotation circuit.

## Centrifuging and Product Drying

Screen bowl centrifuges are usually used to de-brine the flotation concentrates (Figure 7). Both co-flow gas-fired rotary and fluid bed dryers are common. In the case of rotary dryers most if not all have been converted to direct firing. Knockers have been removed from most dryers in an attempt to reduce noise levels.

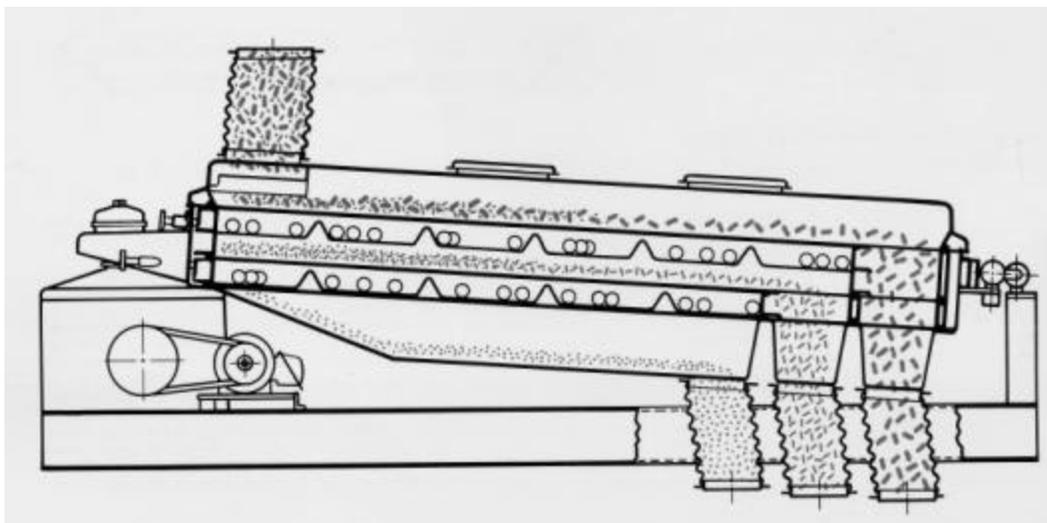
Dryer exhaust gases are subjected to cyclonic dust recovery usually followed by wet scrubbers. At one operation an electrostatic precipitator is used for final gas cleaning. Low pressure wet scrubbers are marginally successful in some cases, but more successful when combined with tall stacks.



**Figure 7:** Schematic diagram of a screen-bowl centrifuge (Bird Machine Co.).

### Classification and compaction

Potash obtained by flotation is usually Standard and Fine sizes, although some Coarse may be produced. In order to produce Coarse and Granular sizes, a compaction plant must be installed. The size of such a compaction plant is directly related to the amount of Coarse and Granular to be produced.



**Figure 8:** Schematic diagram of a double-deck rotary screen (Rotex Inc.).

After drying, product is screened on double deck rotary screens (Figure 8) into three products, 2.35 x 0.85 mm (8 x 20 mesh) Coarse; 1.18 x 0.30 mm (14 x 48 mesh) Standard; and 425 x 149  $\mu\text{m}$  (35 x 100 mesh) Fine. The meshes overlap the products due to operating requirements and screening efficiency. Screened product is stored in bins for dispatch to customers or to further processing.

Compactors (Figure 9) are fed with a well blended, hot ( $>130\text{ }^{\circ}\text{C}$ ) material, previously de-dusted. Two high pressure rolls compact the feed into flake, up to 16 mm (5/8 in.) thick. The flake is later crushed in impactors and screened into the premium Coarse and Granular products. Compactors vary in size from 610 x 610 mm x 181 t (24 x 24 in. X 200 tons); 710 x 710 mm x 270 t (28 x 28 in. x 300 tons); and 1,000 x 1,200 mm x 680 t (40 x 50 in. X 750 tons). Normal efficiency of a well operated compaction plant, measured as the conversion factor or tones of final product divided by tones of feed to the plant is 30 %.

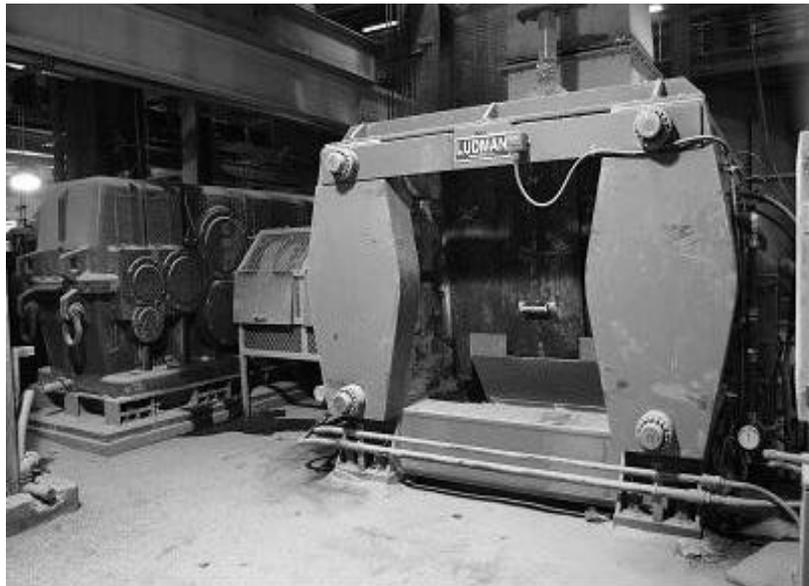


Figure 9: Ludman 40x40 compactor (Courtesy Agrium Inc.)

Coarse and Granular products are mixed with a small amount of water and are dried again in what is called the Glazing circuit. The objective is to fill cracks inside the particles and to eliminate sharp corners to reduce dusting problems during shipping and handling.

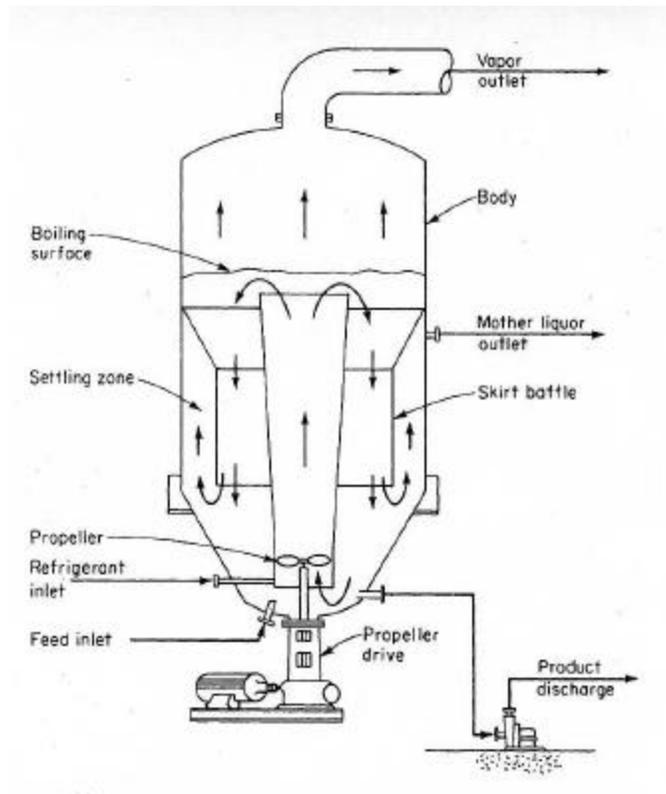
The product split depends on marketing strategy. Markets trend towards the Coarse and Granular products, which can be easily blended with other fertilizers for tailor-made formulations to suit almost any fertilizing requirement. Standard and Fine products are not used any more in North American or European markets, and are scarcely used in South American

markets. Only China and other Asian countries are still using these small particle potash products to mix with other fertilizers in fixed formulation fertilizer compounds.

## Crystallization

Crystallization is the process used to obtain industrial grade potassium chloride, also known as soluble grade muriate of potash with up to 62.5 %  $K_2O$ .

The process consists of mixing the potash with hot water while agitating at 100-110 °C to selectively dissolve sylvite from halite. Undissolved sodium chloride and insolubles are later removed in a clarifier.



**Figure 10:** Swenson Draft Tube Baffle (DTB) evaporative cooling crystallizer.

Clarifier overflow is fed to the crystallization circuit, consisting of four to five externally circulated vacuum units (Figure 10). Both gravity flow and pumping are used to transfer the

liquor between stages while the solids are pumped out. Inside the crystallizers, the brine liquor is cooled down to 20 °C and high purity KCl is obtained by differential crystallization.

Crystallization is also used as a side process to recover potash fines generated during crushing and scrubbing. These are usually too fine to be efficiently compacted and are therefore upgraded by crystallization to a Standard size material, amenable to be sold as white product or to be mixed with the Standard fraction from flotation concentrates and compacted to premium product.

On year 2000, nearly 180,000 tonnes were produced by crystallization, equivalent to 18 % of the total potash production.

## Recoveries

Table 3 shows typical recoveries achieved in some of the flotation plants in Saskatchewan, based on published data:

**Table 3: Published Potash Recoveries**

<b>Company</b>	<b>Recovery</b>	<b>Source</b>
Agrium	88%	Cormode (1985)
IMC-Colonsay	88%	Hrynewich (1983)
PCS-Allan	87%	Strathdee (1982)
PCS-Lanigan	85%	Eatock (1982)

## Conclusions

Potash mining in Saskatchewan is a well established, mature industry that generates an important contribution to the Provincial and Federal economies.

During the last few years, product quality has become an increasingly dominant factor for Saskatchewan's potash producers. Increased emphasis on coarser products has led to continuous improvements in key processing areas such as coarse particle flotation, product screening and compaction.

## Aknowlegment

The author thanks AMEC E&C Services for permission to publish this paper.

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