

The Production of Potassium Chloride from the Dead Sea by Crystallization

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ABSTRACT

The Dead Sea contains 1% of potassium chloride, the extraction of which is made difficult by the presence of large amounts of magnesium, sodium and calcium. In the new processing plant of the Dead Sea Works, crystallization is effected by evaporation, common-ion effect and cooling corresponding to the enrichment of KCl, removal of impurities and growth of large, homogeneous crystals.

The process has five crystallization steps:

- 1. Crystallization of CaSO_4 in solar evaporation ponds;*
- 2. Crystallization of NaCl in solar evaporation ponds;*

These steps are simultaneous. The concentration of KCl in the solution increases from 1% to 2%; the solution becomes sulphate-free and poor in sodium.

- 3. Crystallization of Carnallite (with some NaCl) in solar evaporation ponds;*

This step raises the KCl concentration in the crystal mixture to 23%.

- 4. Simultaneous dissolution of Carnallite and crystallization of KCl, due to common-ion effect (carnallite decomposition);*

MgCl_2 is removed; the remaining mixture (Sylvinite) contains 50%-60% KCl.

- 5. The KCl-NaCl mixture is leached by a hot solution and filtered, then cooled in a vacuum crystallizer, thereby producing pure KCl.*

In this step NaCl is removed and the product acquires its desired physical properties.

Although this process is based on thermodynamic equilibrium, various irreversible phenomena occur in the system. Some of these phenomena, as well as equipment problems, will be discussed.

I. INTRODUCTION

Potash has been produced on the shores of the Dead Sea since 1932. Novomeysky¹ developed the basic process 40 years ago, utilizing the hot dry climate and the relatively simple system of ions in the Dead Sea.

The first potash plant operated at the northern end of the sea until the beginning of 1948, at a capacity of 40,000 t/a. The second plant, with a capacity of 60,000 t/a, operated at the southern

¹M. A. Novomeysky, Trans. Inst. Chem. Eng. 14, 60 (1936).

end of the sea from 1937, with an interruption of five years between 1948-53, until it was closed down at the end of 1956. The third plant, the capacity of which is 200,000 t/a, has been in operation since 1956. The new plant has operated since 1964. It is producing close to its nominal capacity of 400,000 t/a. A plant for another 400,000 t/a is planned.

The carnallite for each of these four plants is and was produced by solar evaporation. It is then decomposed by water into a mixture of sodium chloride and potassium chloride, i.e., into sylvinite. Sodium chloride was separated from the potassium chloride in the earlier plants by washing with cold water, thereby dissolving a considerable amount of potassium chloride.

The smaller plant operating today at a rate of 200,000 t/a, separates sodium and potassium chloride by flotation. In the new plant potassium chloride is leached with a hot brine, and recovered by crystallization, in the form of large, uniform crystals. The sodium chloride is left behind during the leaching.

II. THE DEAD SEA AS A SOURCE OF RAW MATERIAL

The Dead Sea is situated in the lowest part of the Jordan Valley, which is part of the Syrian-African Rift. Although the Dead Sea, in its present form and composition, is relatively young (less than 100,000 years), the rift valley formed slowly during millions of years of the Miocene and Pliocene periods. Its level was formed at the end of the Tertier period. It seems to have separated from the oceans since the Pleistocene period.

The high salt content of the sea can be attributed to the salt content of the River Jordan feeding it (approximately 1,000,000 tons salt per year) and to many salty springs along its shores.

The sea is divided into a larger, northern part (constituting about three-fourths of the total area and reaching a depth of 350 meters, and a shallow, southern part. Before part of the sea was closed off by dikes, its total area was about 1,000 sq. km. and its water content 150 cu. Km. (150 billion cu. m.). The average air temperature in the southern part of the Dead Sea area varies between 17°C. in January to 34°C. in August. Maximum day temperatures vary from 20°C. in January to 39°C. in August. Minimum temperatures in January are 11°C. and in August 29°C. The average relative humidity during daytime in April through September is 30%-40%.

Although the concept of an average annual rainfall in such arid zones is of little meaning, 50 mm. is considered correct for the southern end. There are about 300 cloudless days during the whole year. Cloudy days occur mostly during winter. Water evaporation from the whole of the Dead Sea area is calculated to be about 1.7 billion cu. m. /a. Assuming that the water is mixed, this means that about once every 100 years the whole of the Dead Sea water is replaced. Compensation for the evaporation comes mainly, about 65%, from the River Jordan, some 20% from other rivers, 5% from rains and the rest from floods and other sources. Dry winters, such as three to four years ago, will cause a decrease in the Dead Sea level. The diversion of the River Jordan and the use of its waters for irrigation will have the same effect.

The lowering of the water level is counterbalanced by the decrease in the area of the shallow southern basin: when the water level falls the sea retreats from its southern, shallow tip, thereby decreasing the surface area of the sea and diminishing evaporation.

The chemical composition of the Dead Sea is not constant: it changes with depth, with the season and with the humidity of the previous winter. Composition of the water from the southern end of the sea is given below:

Mg ⁺⁺	--	33	-	41	gr/l
Ca ⁺⁺	--	14	-	17	gr/l
Na ⁺	--	32	-	40	gr/l
K ⁺	--	6.0	-	7.5	gr/l
Cl ⁻	--	173.0	-	212.5	gr/l
Br ⁻	--	4.0	-	5.0	gr/l
SO ₄ ⁼	--	0.65	-	0.8	gr/l
sp. gr.	--	1,180	-	1,215	

The sea water contains only 1% by weight of potassium chloride, which has to be separated from large quantities of calcium, magnesium and sodium ions. On the other hand, there are only six components; the sulphate concentration is negligible and the ratio of the ions enables a relatively simple method of enrichment.

III. THE REMOVAL OF CALCIUM SULPHATE AND SODIUM CHLORIDE BY EVAPORATION AND CRYSTALLIZATION

In order to remove most of the calcium sulphate and sodium chloride, Dead Sea water is channelled into vast evaporation ponds, which cover an area of about 150 sq. km. Almost all of this area was separated from the deep sea by dikes built into the shallow southern part.

During the 1965 evaporation season the new large evaporation area reclaimed from the sea will be put into operation for the first time. However, since the sea in this area is relatively deep (4-6m.) it will contribute but little to the overall production. About 100 million cu.m. of sea water will be evaporated and 7-8 million tons of sodium chloride will crystallize.

The intense solar radiation available almost all the year-round supplies the heat necessary for the evaporation. Dry winds carry away the water vapour. Calcium sulphate crystallizes almost immediately after the sea water is conveyed into the ponds, but as its quantities are small, it does not seem to effect the further absorption of solar energy. When the salt concentration in the ponds reaches about 27%, which is equivalent to about 350 gr/l of total dissolved salts, sodium chloride begins to crystallize. At this stage the specific gravity of the brine, at 30°C., is 1.235 and a typical analysis is approximately as follows:

MgCl ₂	--	165	gr/l
CaCl ₂	--	48	gr/l
NaCl	--	105	gr/l
KCl	--	14.5	gr/l
CaSO ₄	--	1.0	gr/l

(Bromide is expressed as chloride)

The crystallization of sodium chloride continues during further evaporation until the volume of the water has diminished to about half of its original value. At this stage about 90% of the sodium chloride and more than 95% of calcium sulphate have crystallized. Sodium chloride crystallizes either as a hard white layer or as individual crystals, depending on whether the pond was shallow (20-30 cm.) or deep (80 cm. or more).

The water layers are transparent to visible light and behave almost as a black body towards infrared radiation. Therefore, only 5%-6% of the solar radiation is reflected from the surface of the ponds in which no sodium chloride crystallizes and settles. The remaining 94% of radiation is absorbed and transmitted to the bottom.

Ponds with a white salt layer at the bottom reflect 20%-30% of the solar radiation penetrating the liquid layer.² In order to minimize the reflection of visible light, about 5 gr./cu.m. of a green dye "Naphtol Green," is added. Following experiments carried out, this dye was chosen by the Palestine Potash Co. (Bloch) about 30 years ago. The use of this dye caused 15%-20% of the energy otherwise reflected and lost to be retained and raised the evaporation rate in approximately the same amount.

Part of the energy absorbed is lost to the atmosphere both as long-wave radiation at night and as sensible heat during the hours when the temperature of the brine is higher than the temperature of the air above it. As the concentration of the solution rises during the evaporation the vapour pressure diminishes, less energy is used for evaporation and more for heating the brines. Therefore at higher concentrations the use of the dye, which reduces the reflection, is relatively more effective.

² Bloch, Farkas, Spiegler: I. E. Ch. 1963,

In the southern evaporation ponds, which are further away from the sea and also slightly more elevated, the seepage is considerable. No exact data is available, but potassium chloride losses by seepage are estimated to be about 10%. Addition of the dye to the white-bottomed ponds, i.e., raising the evaporation rate, diminishes the relative seepage losses.

A study of the phase diagram of the Dead Sea shows that sodium chloride may crystallize in varying quantities during evaporation. At a specific gravity of 1.250 crystallization reaches a maximum of approximately 350 kg./1,000 kg. evaporated water. At higher concentration the crystallization rate is lower and close to a specific gravity of 1.300 only 100 kg. sodium chloride crystallize for every ton of water evaporated. This variation in the rate of crystallization may cause an uneven distribution of salt in the ponds. In order to produce even layers and avoid having to build higher dikes because of the natural elevations of the ground, the evaporation area is divided into smaller ponds. This, allows also for close control of the brine flow. Each of the southern ponds has an area of approximately 2-3 sq. km.; the areas of the new ponds are 6 sq. km. and 12 sq. km. and a very large one of 80 sq. km.

In order to prepare the salt ponds for a new evaporation season, the sodium chloride deposited during the previous season has to be removed. Each winter millions of tons of sodium chloride are dissolved by brackish water from drillings near the Dead Sea, and returned to the sea by channels.

For many hours during the day the concentrated solutions in the ponds are supersaturated with regard to sodium chloride. This supersaturation is usually 1-1.5 gr/l, but might reach 3 gr/l. Water is added during the pumping and conveying of these solutions through channels, in order to prevent crystallization and scaling which might interfere seriously with the brine flow.

IV. CRYSTALLIZATION OF CARNALLITE IN SOLAR PONDS

The concentration of the solution in the salt pans rises due to evaporation and when it reaches a specific gravity of 1.300, corresponding to a total salt content of 3% at 35°C., a new solid phase begins to separate. The composition of the brine at this stage is as follows:

MgCl ₂	--	295	gr/l
CaCl ₂	--	85	gr/l
NaCl	--	20	gr/l
KCl	--	27	gr/l
Br ⁻	--	9	gr/l
CaSO ₄	--	less than	0.1 gr/l

The new phase consists of carnallite (KCl·MgCl₂·6H₂O); sodium chloride and minute amounts of gypsum continue to crystallize together with the carnallite. The concentrated brine is conducted through a second series of ponds which are smaller than the first series. They serve as crystallization ponds and as storage for the carnallite before it is further processed.

While the brines flow through the carnallite pond system both the concentration and specific gravity rise as most of the potassium chloride which is in the brines crystallizes in the form of carnallite. The brines are disposed of when the ratio between evaporation and crystallization, i.e., quantity of carnallite crystallizing per unit of area, is most unfavourable. This condition occurs when the specific gravity of the brines is 1.350 and their composition is as follows:

MgCl ₂	--	360	gr/l
CaCl ₂	--	110	gr/l
NaCl	--	7	gr/l
KCl	--	5	gr/l
Br ⁻	--	12	gr/l (included in chlorides)

A small fraction of these brines is used for bromine production. They are also used as one of the raw materials in the production of table salt. Further evaporation of such brines to a specific gravity of 1.365 brings about the crystallization of bischofite (MgCl₂·6H₂O). In spite of the very low vapour pressure of the "End Brine," bischofite crystallizes by solar evaporation during two to three months every summer.

As in the sodium chloride evaporation system, the ratio between the quantity of water evaporating and of material crystallizing in the carnallite system is not constant. It reaches a high of 800 kg. for every ton of water evaporated at a specific gravity of 1.310, and a low of 150 kg. carnallite for every ton of water evaporated at a specific gravity of 1.350.

Since the quantity of sodium chloride crystallizing in the carnallite system changes slowly from 90 kg./ton water evaporated to 40 kg., the amount of sodium in the solid mixture is not constant. The carnallite crystallizing from the brines contains at first a high percentage of sodium chloride. The mixture then becomes poorer in sodium chloride, but during later phases the sodium chloride content rises again and approaches or sometimes passes the potassium chloride content. Furthermore, the changing ratio between carnallite and evaporation rate causes uneven crystallization in the different ponds.

An average analysis of the dry carnallite mixed with sodium chloride is given below:

KCl	--	22.7%
MgCl ₂	--	29.0%
NaCl	--	15.3%
H ₂ O	--	33.0%

About 4-4.5 million tons of carnallite will be produced in 1965. When the whole evaporation area of 130 sq. km. will be in operation it will supply carnallite for the production of 1,000,000-1,200,000 tons of potassium chloride. In order to process these quantities of carnallite further refining capacity is going to be added during 1966-1967.

In contrast to sodium chloride, carnallite tends to crystallize in separate crystals, not in continuous layers. The size of these crystals depends on several factors, such as supersaturation, the rate of crystallization and the viscosity of the mother liquor. Crystals formed during the hot hours of the day, when the rate of evaporation is high, are smaller than those formed during the night, when the brines cool down relatively slowly.

A solution evaporating during the day and cooling down during the night will be more concentrated at the surface, from where it gives off water vapour during the day and heat during the night. At the same time it becomes supersaturated. The heavy, supersaturated solution, sinks. When a layer of crystals is near the surface, the supersaturation is transferred to the existing crystals which thereby grow larger. If, however, the layer of brine is deep, nucleation starts during the sinking of the supersaturated layer, thus producing small carnallite crystals.

It seems also that the more concentrated solutions tend to produce smaller crystals. It is possible that the higher viscosity retards the flow of the supersaturated solution towards the growing crystals, thereby promoting nucleation. The carnallite crystals vary in size between 0.1 mm. and 12 mm.

The original carnallite ponds were relatively small and rectangular (200,000 sq. m. each). They were built for simple harvesting equipment. With the development of much more elaborate harvesting equipment, the new carnallite ponds do not differ in form or size from the smaller salt ponds (2-3 sq. km.) but only in the stronger dikes necessary for the anchoring of the harvesters.

V. HARVESTING OF THE CARNALLITE AND ITS SEPARATION FROM THE MOTHER LIQUOR

The harvester should supply an even quantity of carnallite of constant chemical composition and crystal size distribution, but this is actually impossible. However, close control of the brine flow and careful planning of the harvesting can minimize fluctuations. Control may be exercised by, e.g., harvesting at more than one pond simultaneously or by harvesting certain areas once in two years, whereas other areas may be harvested more frequently than once a year.

The carnallite mixture, in a 10%-20% solid slurry, is pumped by floating pumps called dredges or pontoons through a floating and a rigid pipe to thickeners. In the thickeners the carnallite mixture is concentrated to a slurry of 40%-50% solid content by weight. The thickened material is pumped to tilting-pan filters, where a carnallite filter cake of 85%-88% solid content is obtained. The solutions from the thickeners and filters are used as condensing medium for the

vacuum crystallizers in the later stages of production. From there they return to the evaporation ponds.

The floating pumps mentioned previously were developed by the Dead Sea Works Ltd. The first floating pumps, built by the Palestine Potash Co. Ltd. 35 years ago, had a capacity of 10-20 tons of solids per hour. About 10 years ago new, larger pumps with a capacity of 30-40 t/hr were installed. The capacity of the pumps used at present in the small carnallite ponds is between 70-100 tons, whereas in the new system a large dredge, with a capacity of 300-500 tons solid carnallite per hour, is operating. The dredges are equipped with scrapers for the heaping of the crystals at the mouth of the suction pipe. The dredge is fastened to cables which, in turn, are fastened to the dikes, enabling the dredge to move backwards and forwards by winches.

Three large thickeners collect the slurry which is then pumped to four tilting-pan filters. The thickeners and filters are intentionally oversized, in order to withstand the large fluctuations encountered in the harvesting process. In order to feed the plant with a constant quantity of carnallite mixture, there is a reserve, i.e., a stockpile, the capacity of which is 50,000 tons. This stockpile is equipped with a dragline for reclaiming the material.

VI. CARNALLITE DECOMPOSITION

An approximate analysis of the carnallite mixture from the filters and from the stockpile is given below:

KCl	--	19 %	--	20 %
NaCl	--	11 %	--	15 %
MgCl ₂	--	28 %	--	30 %
CaCl ₂	--	0.5%	--	1.0%
H ₂ O	--	37 %	--	40 %

The carnallite is very pure and contains less than 0.1% insolubles.

In order to obtain pure potassium chloride, magnesium chloride is removed first, by making use of the equilibrium which exists between carnallite, potassium chloride and sodium chloride in its saturated solution: such a solution is much richer in magnesium than in potassium chloride, the actual ratio at 25°C. being about 7.5. (Solutions of this system containing magnesium and potassium chloride at a lower ratio are in equilibrium with potassium and sodium chloride only and are able to decompose carnallite.)

In the decomposition process water is brought in contact with carnallite in such quantities that the resulting solution contains all the MgCl₂ which has been present in the carnallite.

The approximate composition will then be -- at 25°C.:

Specific gravity	--	1,280
MgCl ₂	--	330 gr/l
KCl	--	40 gr/l
NaCl	--	30 gr/l
CaCl ₂	--	10 gr/l

The total dissolved solid content of the solution is approximately 32%.

The quantity of water necessary for the decomposition is 400-450 kg./ton carnallite mixture, which produces 0.9-0.95 m.³ of so-called "equilibrium brine." Eighteen percent of the potassium chloride present in the carnallite is dissolved.

The remaining solid mixture of potassium and sodium chloride, i.e., the sylvinite, contains 50%-65% potassium chloride on a dry basis, the rest being sodium chloride.

The decomposition of carnallite is an example of incongruent dissolution. When water is brought into contact with the carnallite, the rhombic crystals dissolve and, because of the common ion effect, small cubic potassium chloride crystals form in the vicinity of the dissolving carnallite. Some time passes until the potassium chloride crystals appear and grow.

The crystallization of potassium chloride proceeds in two separate steps, i.e., dissolution of carnallite and crystallization of the potassium chloride, and is therefore difficult to control. When the carnallite crystals are small, dissolution is faster than crystallization. On the other hand, when the carnallite crystals are large dissolution is slower than crystallization. Thus the decomposition of small carnallite crystals usually gives rise to higher supersaturation and, consequently, to more nucleation and finer potassium chloride crystals. Because of both mechanical and marketing reasons, large, potassium chloride crystals, obtained by the decomposition of large, slowly dissolving carnallite crystals, are preferred. On the other hand large carnallite crystals (> 2 mm.) constitute only 10%-20% of the average material and in addition cause mechanical difficulties.

Furthermore, although according to the phase diagram only 30 gr/l of sodium chloride should dissolve during the decomposition of the carnallite, short periods of local undersaturation cause it to dissolve to a much higher extent. In order to arrive at an "equilibrium brine," it has to be recrystallized. In this case parallel growth of potassium chloride and sodium chloride crystals occurs.

The controlled decomposition of carnallite is of special importance in the flotation process, where the parallel growth of potassium and sodium chloride crystals hinders the separation. In this case the size and form of the potassium chloride crystal in the end product is determined during the carnallite decomposition. In the new plant, potassium chloride is recrystallized after the decomposition of the carnallite. Therefore, the parallel growth of sodium and potassium chloride crystals is of almost no importance.

In order to enable efficient separation from the mother liquor, both the potassium and sodium chloride crystals should be large. At the same time care has to be taken to dissolve the large carnallite crystals, in order to avoid unnecessary mechanical difficulties.

Decomposition is performed countercurrently in three stages. In each stage the carnallite mixture comes into contact with a solution containing magnesium chloride, sodium chloride and potassium chloride. Carnallite is dissolved potassium and sodium chloride crystallizes thereby arriving in the first stage at a solution the composition of which is similar to that of the aforementioned brine, i.e., containing magnesium and potassium chloride in a ratio of approximately 7.5.

The coarse carnallite (+2 mm.) crystals are separated on a D.S.M. screen and dissolved in water. The solution obtained thereby is used in the third decomposition stage.

Decomposition is performed in large mixing vessels equipped with agitators. The large volume of the vessels decreases supersaturation and facilitates crystal growth.

Between the first and second stage a thickener is installed for separating the solution from the solids. Between the second and third stage the solid is separated from the liquid in a row of hydrocyclones. After the third stage hydrocyclones concentrate the solids which are then fed to a tilting-pan filter.

This system is designed to decompose 350 t/hr of carnallite, yielding 110-130 tons of sylvinite.

VII. THE LEACHING OF POTASSIUM CHLORIDE AND ITS CRYSTALLIZATION

Potassium chloride can be separated from NaCl by making use of the difference in solubility in water of the two salts at high and low temperatures. Whereas the solubility of NaCl is almost constant, the solubility of KCl rises steeply with temperature.

Following is a typical analysis of the cool brine in equilibrium with potassium and sodium chloride (40°C.):

H ₂ O	--	1,000	gr.
KCl	--	187	gr.
NaCl	--	265	gr.
MgCl ₂	--	30	gr.
Specific gravity	--	1,238	gr.

The hot "equilibrium brine" with a similar magnesium chloride content has the following chemical composition (90°C.):

H ₂ O	--	1,000	gr.
KCl	--	316	gr.
NaCl	--	250	gr.
MgCl ₂	--	30	gr.

A cool solution containing 1,000 gr. water can dissolve 129 gr. potassium chloride when heated. This is equivalent to about 100 kg. KCl per m³ of solution.

A typical analysis of the filter cake from the sylvinitic filter is as follows:

H ₂ O	--	8.8%
KCl	--	53.0%
NaCl	--	37.0%
MgCl ₂	--	1.2%

By contacting sylvinitic with hot (105°C.) "equilibrium brine" saturated at 40°C., all the potassium chloride is leached and the sodium chloride is left behind. The hot, saturated "equilibrium brine," now at 90°C., is cooled by evaporation in vacuum, whereby the potassium chloride crystallizes. The cool solution is reheated and used again for leaching.

The sylvinitic added to the "equilibrium brine" increases its magnesium chloride content. According to the solubility data, an increase in magnesium chloride content lowers the solubility of both potassium and sodium chloride. In this case the sodium chloride might crystallize together with the potassium chloride. For this reason the magnesium chloride has to be removed from the crystallization system: More water is added than would be necessary to compensate for the evaporation losses in the crystallizers. As a result some potassium and sodium chloride is also dissolved and some of the circulating brine is bled off. The bleed is fed back to the decomposition stage and used again for decomposing part of the carnallite. In this way no potassium chloride is lost either in the hot-leach or in the crystallization sections. In this respect the operation at the Dead Sea has an advantage over other potash operations where mined sylvinitic is used as the raw material and where the brine has to be disposed because of its accumulated magnesium chloride content.

In order to crystallize one ton of potassium chloride, about 500,000 Kcal have to be withdrawn from the hot brine. Cold water is expensive near the Dead Sea, so other coolants have to be used. For instance, concentrated brines from the carnallite ponds are used. Although these brines are warmer than water, they have very low vapour pressures. At 40°C. the carnallite brines have a vapour pressure of about 20 mm. as compared to potassium chloride/sodium chloride "equilibrium brine" which has a vapour pressure of 38 mm. and water with 55 mm. By using a barometric jet condenser, these concentrated brines serve as excellent heat absorbers.

In order to produce separate, round, large, uniform crystals the forced Draft Tube Baffle Swenson crystallizers were chosen. This choice was made as a result of basic research on potassium chloride crystallization carried out by Dead Sea Works. This research proved that for uniformity -- magma circulation in the crystallizers is to be preferred to clear-solution circulation, as practiced in the Oslo crystallizers.

The two-stage, countercurrent hot-leaching is performed by agitators. Two thickeners are installed for liquid separation. Centrifuges filter the sodium chloride, which is stacked and partly sold for industrial uses.

The hot solution is passed through two rows of interconnected crystallizers, 15' in diameter. Magma density is up to 30% and is controlled by "on-off" valves equipped with timers. The temperatures in the four stages are approximately 75°C., 60°C., 50°C., and 40°C. respectively. The last stage has an elutriation leg for the final classification of the crystal size.

The cool potassium chloride slurry is thickened and conveyed to a basket type centrifuge, where it is filtered. The cool mother liquor is heated in the crystallizers of the second stage in

a barometric jet condenser, and transferred to heat exchangers heated by steam from a 12, 500 KW power station. The centrifuged material has the following approximate analysis.

H ₂ O	--	3.5 %
KCl	--	95.0 %
NaCl	--	2.4 %
MgCl ₂	--	0.1 %

VIII. DRYING, SCREENING AND STORING

The cake from the centrifuge is dried in two rotary driers, concurrently heated with natural gas (98% Methane). The dried product has the following average analysis:

H ₂ O	--	0.05%
KCl	--	97.0 %
NaCl	--	2.3 % -- 2.7 %
MgCl ₂	--	0.1 % -- 0.15%
(K ₂ O	--	61.0 % -- 61.5 %)
CaCl ₂	--	less than 0.02%

The fines, which constitute a small fraction, are separated in a cyclone, dissolved and sent back to the leaching section.

The product is separated on vibrating screens into a coarse product, and a standard product. By changing crystallization conditions, e. g., either the quantity of material passed in a unit of time or temperature gradient or magma density, changes in crystal size can be achieved. Tests are now under way to define precise conditions for desired crystal sizes.

While the material is being screened, its temperature falls from 200°C. to 130°C. At this temperature a long carbon chain amine is added to the final product, to prevent its caking.

The product is stored in two separate storehouses in bulk. In one the standard grade is kept; the capacity of this storehouse is 60,000 tons. The other, with a capacity of 15,000 tons contains the coarse material. From these stores the product is loaded onto 30 or 50 ton trucks, which bring the potash either directly to Eilat on the shore of the Red Sea for shipment to the East, or to the Beer-Sheva railway station, from where it is transported by rail to Haifa port.

The potash production process is an example of enrichment by crystallization. In the first step calcium sulphate and sodium chloride crystallize, thereby raising the potassium chloride concentration in the solution from 1% to 2%. In the second step the carnallite crystallizes. Here the concentration of potassium chloride is raised from 2% to 23%. In the third step the carnallite is decomposed and potassium chloride crystallizes. The concentration rises from 23% to 50%-60%. In the final fourth step potassium chloride is leached and recrystallized, raising the concentration to 97%. In the overall operation 60% of the potassium chloride is recovered from the total quantity present in the Dead Sea waters pumped into the evaporation ponds.