SOLUTION MINING OF POTASSIUM CHLORIDE
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This application is a continuation-in-part of commonly assigned co-pending application Serial No. 283,482, filed May 27, 1963 and now abandoned, and its parent application Serial No. 123,916, filed May 26, 1961, now U.S. Patent 3,096,969.

This invention relates to a novel method of mining potassium chloride. It more particularly relates to a method of extracting, with water, subterranean deposits containing potassium chloride.

Potassium chloride usually occurs in mineral deposits closely associated with sodium chloride. In many cases, potassium chloride exists in admixture or in combination with sodium chloride in the form of potassium chloride rich strata. Often, a potassium chloride rich stratum, i.e., a stratum containing up to 15 to 60 percent by weight of potassium chloride, based on the total weight of potassium and sodium chlorides in the stratum, is disposed immediately above another stratum lean as to potassium chloride, i.e., containing less than 15 percent by weight potassium chloride on the aforesaid basis or which contain no substantial amount of potassium chloride but which are preponderantly sodium chloride. These mineral deposits usually contain varying amounts of other minerals such as clay, calcium chloride, calcium sulfate, magnesium chloride, and magnesium sulfate.

The aforesaid deposits of potassium chloride and sodium chloride are frequently located very deep. For example, Canadian deposits of this character typically occur 3,000 feet or more below the surface of the ground. In the United States, such deposits are sometimes disposed from less than about 1,000 feet to 3,000 feet or more, typically at least 2,500 feet, below the surface of the earth.

Historically these deposits have been mined by shaft, room and pillar type mining techniques. The aforesaid U.S. Patent 3,096,969 discloses a method whereby they are extracted with water, including unsaturated aqueous solutions. Such extraction is accomplished by first developing a suitable cavity in the mineable deposit. Water is then circulated through the cavity, thereby dissolving the deposits to form an aqueous solution richer in potassium chloride than is the feed water. The enriched solution is then withdrawn from the cavity and the potassium chloride values are recovered therefrom.

Both the solubility of potassium chloride and the rate of dissolution of potassium chloride in aqueous solution increase with increasing temperatures. Thus, in solution mining potassium chloride in subterranean deposits, it is of decided benefit to maintain the aqueous solution in the cavity at as high a temperature as practicable. It is known that potassium chloride absorbs a considerable amount of heat when it is dissolved in aqueous solutions. It is therefore beneficial to feed water into the cavity at a temperature hotter than the aqueous solution within the cavity so that undue cooling of the cavity solution is prevented. This aims to be achieved although according to the preferred embodiment of this invention, the cavity solution is maintained at about, i.e., plus or minus about 5° C, preferably plus or minus about 3° C of the natural formation temperature.

By "natural temperature of the formation" is meant the temperature which exists in a subterranean formation prior to the formation's being disturbed by mining activities. This temperature can be determined by lowering a thermometer down a bore hole and allowing it to remain undisturbed in place until the temperature recorded by the thermometer is constant over an appreciable time. Normally, less than five hours residence of the thermometer in the bore hole is required to determine the natural formation temperature. If the formation has been disturbed by mining or other activities so that the natural formation temperature can no longer be directly measured, this temperature can be calculated from the geothermal gradient in accordance with recognized procedures. See, for example, the book Geology of Petroleum, Lever- sen (W. H. Freeman and Co., 1954), p. 398 et seq.

In practice, it may be impractical to measure the temperature of the aqueous solution within the cavity. When a normal rate of withdraw to the surface is maintained, e.g., in excess of 100 gallons per minute, it may be assumed that little or no heat transfer occurs between the ascending solution and the ground. Thus, under normal operating conditions of the process herein described, the temperature of the effluent, i.e., the aqueous solution as it reaches the surface of the earth, may be considered, in the absence of other factors which could influence its temperature, to approximate the temperature of the aqueous solution within the cavity. Of course, it is possible to heat from an external source the solution on its way up to the surface so that it is warmer as it reaches the surface than when it left the cavity.

References herein and in the accompanying claims to the effluent and feed temperatures may be assumed to be the temperatures of the effluent and feed, respectively, measured at the surface of the earth when heat is neither added to nor removed from the aqueous solution as it ascends from the cavity. When heat is added to or removed from the ascending solution, the temperatures stated herein must be adjusted accordingly.

In the practice of the invention herein contemplated, a plurality of cased bored holes is brought into communication with a suitable cavity in a subterranean potassium chloride deposit. Water, including unsaturated aqueous solutions of either or both sodium chloride and potassium chloride, is then fed to the cavity through one or more inlet holes. The water is fed at a temperature below its normal boiling point. The water dissolves the deposit to form an aqueous solution richer than the feed with respect to potassium chloride. Enriched aqueous solution is then withdrawn from the cavity through one or more outlet holes.

The inlet hole or holes are thermally isolated, typically by lateral separation, from the outlet hole or holes. In such an arrangement, the solution ascending from the cavity avoids heat transfer with the descending feed. If the contents of the inlet pipe were in heat exchange relationship with the contents of the outlet pipe, as, for example, in a concentric pipe arrangement, considerable heat transfer would occur between the incoming and outgoing streams. Mineable deposits are normally located at sufficient depth so that heat transfer in such a system occurs along a pipe length of up to several thousand feet. In flowing along this long pipe length, the streams come in indirect heat exchange relationship across a very large surface area. Thus, where the inlet is not thermally insulated from the outlet, the feed enters the cavity at approximately the temperature of the solution within the cavity. Heat added to the feed under these conditions of heat exchange relationship between the feed and the effluent is readily transferred to the ascending solution.

According to this invention, the feed is maintained at a hotter temperature than the effluent. Because the inlet piping is disposed so as not to be in heat transfer relationship with the outlet piping, the solvent enters the cavity
at a temperature above the temperature of the solution within the cavity. Under normal conditions of operation, it may be assumed that the temperature differential between the feed and the effluent approaches closely the temperature differential between the water entering the cavity and the bulk of the solution within the cavity.

Some of the heat in the feed is absorbed by the potassium chloride dissolved from the deposit, thus cooling the solution in the cavity. To offset too great a cooling effect on the cavity solution by the dissolution of KCl by the solvent, the feed is introduced at an elevated temperature. Cooling is evidenced by decreasing effluent temperature. By raising the feed temperature still higher, the cavity solution temperature is caused to increase. This fact is evidenced by an increased effluent temperature.

The most advantageous temperature differential between the feed and the effluent depends upon the nature and depth of the deposit, residence time of the solution in the cavity, the cavity solution temperature desired, sur- fates, and other factors. Typically, this temperature differential is no greater than 30° centigrade.

This invention is further illustrated in the accompanying drawings:

FIG. 1 illustrates two small cavities undergoing initial development in the mineable strata.

FIG. 2 is a diagrammatic view of a typical cavity and pipe arrangement. Identical numbers indicate identical features in the two drawings.

As illustrated in FIG. 2, a cavity 28 is developed in a subterranean deposit containing potassium chloride. Cavity 28 can be developed in accordance with any suitable technique. The preferred technique is that disclosed in the copending application, Serial 277,853, filed May 3, 1963, the disclosure of which is hereby incorporated by reference. Thus, as illustrated in FIG. 1, two cavities 8 and 18 are developed near the bottom of the mineable strata. These cavities are developed horizontally until they communicate to form cavity 28 (FIG. 2).

Typically, the mineable deposit is located at a depth of 3,000 feet or more. This invention is useful in extracting from a subterranean cavity at any depth. Usually, such cavities will be at least 1,000 feet below the surface of the earth. They often will be located more than 5,000 feet deep and will sometimes be at considerably greater depths, i.e., 10,000 feet or more.

A typical mineable deposit will have the following approximate composition:

<table>
<thead>
<tr>
<th>Composition</th>
<th>Percent by weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potassium chloride</td>
<td>15</td>
</tr>
<tr>
<td>Water insoluble clay</td>
<td>1-5</td>
</tr>
<tr>
<td>Calcium sulfate</td>
<td>1-2</td>
</tr>
<tr>
<td>Water soluble calcium and magnesium salts, such as MgCl₂, MgSO₄ and CaCl₂</td>
<td>About 2</td>
</tr>
<tr>
<td>Sodium chloride</td>
<td>Remainder</td>
</tr>
</tbody>
</table>

The development of cavities 8 to 18 is accomplished by first sinking cased bored holes 1 and 11 down into the mineable strata. Inner pipes 2 and 12 are located concentrically in their respective casings. Water (i.e., water per se or unsaturated aqueous solutions of either or both sodium chloride and potassium chloride) is fed to the deposit near its base through the casings 1 and 11. The deposit is dissolved by the water to form cavities 8 to 18. As water is fed into the cavity, the resulting aqueous solutions are withdrawn by pipes 2 and 12, thereby developing cavities 8 and 18.

The horizontal growth and ultimate communication of cavities 8 and 18 is typically encouraged by the formation of protective layers 6 and 16 at the roof of the cavities. These protective layers are formed by injecting along with the feed to the cavity an inert fluid lighter than, and mutually insoluble with, water at the temperature of the cavity solution. The fluid may be a gas but is preferably a liquid. Typical liquids suitable for this purpose include mineral oil, refined and non-refined petroleum oil and similar liquid hydrocarbons. Even after cavities 8 and 18 have interconnected, a protective layer of inert fluid 26 is often maintained at the roof of cavity 28. In this fashion, the cavity is encouraged to enlarge in a horizontal direction. When vertical growth is desired, the quantity of inert fluid introduced to the feed is reduced. Thus, the water is allowed to extract from the roof of the cavity.

During the initial development of cavities 8 and 18, casings 1 and 11 are typically located about 25 feet apart at the surface of the earth. They may be spaced at considerably greater distances, up to several thousand feet. Usually, casings 1 and 11 will be separated by distances of about 50 to about 500 feet.

The initial diameter of cavity 28 will rarely be less than 25 feet. Typically, its initial diameter will be considerably larger. As the cavity grows, the inlet and outlet casings or pipes are frequently located at greater lateral separations from each other. It is believed that the major diameter of a cavity can be essentially infinite. Typically, however, because of the difficulty in maintaining proper roof control in larger cavities, maximum cavity size rarely exceeds about 400 to about 1,000 feet in diameter.

After cavity 28 has been developed, pipes 2 and 12 are removed from casings 1 and 11 respectively. Casings 1 and 11 are thermally insulated from each other because of their lateral separation. The descending feed is thereby kept out of heat exchange relationships with the ascending solution. The inlet casing 1 is adjusted so that the water enters near the top of the cavity. The outlet casing 11 terminates at a level below the termination level of inlet 1, usually near the floor of the cavity. Outlet 11 terminates above the level where crystals and insoluble material tend to accumulate to an appreciable degree.

Solvent is introduced to cavity 28 through inlet 1. It enters near the top of the cavity and is thought to flow radially outward and down along the sides of cavity. The solvent dissolves the deposit, thereby forming an aqueous solution richer than the feed with respect to potassium chloride. Enriched aqueous solution is withdrawn through the outlet 11. The feed is maintained at a temperature hotter than the temperature of the effluent.

For economic reasons as well as to facilitate handling, the feed is introduced at a temperature under its boiling point, typically between about 50 and about 100° C. The preferred temperature range for solvent feed to a cavity located about 2,500 feet or more beneath the earth is between about 65 to about 80° C. The precise temperature differential which is maintained between the feed and the effluent depends in large measure on the cavity solution temperature which is desired. The cavity solution temperature, as hereinbefore explained, is considered to approximate the effluent temperature. In general, the higher the effluent temperature, the higher the productivity of the cavity in terms of dissolving rate and potassium chloride content of the effluent. However, significantly more economical operations result when the effluent temperature approximates, i.e., is within about 5° C, preferably 3° C. of the natural formation temperature. For typical cavities located, at least about 2,500 feet beneath the earth, the effluent temperature should usually be in the range of 40 to 90° C. Effluent temperatures between about 50 and about 60° C. are preferable in such cavities. It is generally desirable, for the effluent temperature to vary from the natural formation temperature by more than about plus or minus 10° C. Where the cavity is located in a shallow deposit, i.e., significantly less than 2,500 feet deep, the effluent may sometimes be plus or minus 15° C. from the natural formation temperature although a smaller variation is preferred.

According to this invention, it has been found of significant economic benefit to maintain the feed temperature up
to about 30 degrees or more hotter than the effluent temperature. Normally this temperature differential will exceed about 2° C. Preferably, the differential between the feed and the effluent temperatures will range from about 5° to about 20° C.

By the practice of this invention, the quality of the solution produced from the cavity at a given rate is significantly improved over the quality obtained by methods heretofore practiced. The residence time of the aqueous solution in the cavity at typical flow rates, i.e., 200 to 300 gallons per minute, is usually sufficient to produce effluents which contain from about 10 to about 24 p.p.h. (parts by weight per hundred parts of water) potassium chloride and from about 25 to about 35 p.p.h. sodium chloride.

It is apparent that this invention may be practiced in a variety of situations. For example, more than two cavities may be interconnected as hereinbefore described. Geological considerations may make a special arrangement or spacing of bore holes desirable in a particular case. The number of inlets to a cavity need not correspond to the number of outlets. An abandoned cavity may be economically productive by the practice of this invention.

Although the present invention has been described with reference to specific details of certain embodiments thereof, it is not intended that such details should be regarded as limitations upon the scope of the invention, except insofar as they are included in the accompanying claims.

We claim:

1. A method of mining potassium chloride from a subterranean sodium chloride containing deposit which contains at least 15 percent by weight potassium chloride which comprises bringing a plurality of cased bore holes thermally isolated from each other into communication with a cavity in the deposit, feeding solvent at less than 100° C. through at least one of the cased holes to the cavity, dissolving potassium chloride and sodium chloride from the deposit to form an aqueous solution richer in both potassium chloride and sodium chloride than the feed water, and withdrawing enriched solution through at least one of the remaining cased holes while maintaining the temperature of the feed water up to 30° C. hotter than the temperature of the effluent thereby avoiding undue cooling of the cavity solution.

2. A method of mining potassium chloride from a subterranean sodium chloride containing deposit which contains at least 15 percent by weight potassium chloride and is located at least 3,000 feet beneath the surface of the earth which comprises bringing a plurality of cased bore holes thermally isolated from each other into communication with a cavity in the deposit, feeding water at less than 100° C. through at least one of the cased holes to the cavity, dissolving potassium chloride and sodium chloride from the deposit to form an aqueous solution richer in both potassium chloride and sodium chloride than the feed water, and withdrawing enriched solution through at least one of the remaining cased holes while maintaining the temperature of the feed water up to 30° C. hotter than the temperature of the effluent thereby avoiding undue cooling of the cavity solution.

3. A method of mining potassium chloride from a subterranean sodium chloride containing deposit which contains at least 15 percent by weight potassium chloride and is located at least 3,000 feet beneath the surface of the earth which comprises bringing a plurality of cased bore holes thermally isolated from each other into communication with a cavity in the deposit, feeding water at less than 100° C. through at least one of the cased holes to the cavity, dissolving potassium chloride and sodium chloride from the deposit to form an aqueous solution richer in both potassium chloride and sodium chloride than the feed water, and withdrawing enriched solution through at least one of the remaining cased holes while maintaining the temperature of the feed water up to 30° C. hotter than the temperature of the effluent thereby avoiding undue cooling of the cavity solution.

4. A method of mining potassium chloride from a subterranean sodium chloride containing deposit which contains at least 15 percent by weight potassium chloride and is located at least 3,000 feet beneath the surface of the earth which comprises bringing a plurality of cased bore holes thermally isolated from each other into communication with a cavity in the deposit, feeding water at less than 100° C. through at least one of the cased holes to the cavity, dissolving potassium chloride and sodium chloride from the deposit to form an aqueous solution richer in both potassium chloride and sodium chloride than the feed water, and withdrawing enriched solution through at least one of the remaining cased holes while maintaining the temperature of the feed water up to 30° C. hotter than the temperature of the effluent thereby avoiding undue cooling of the cavity solution.