Sept 10, 1957 J. E. LAWVER 2,805,768

METHOD FOR BENEFICIATING POTASH MATERIALS

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Fig. 1

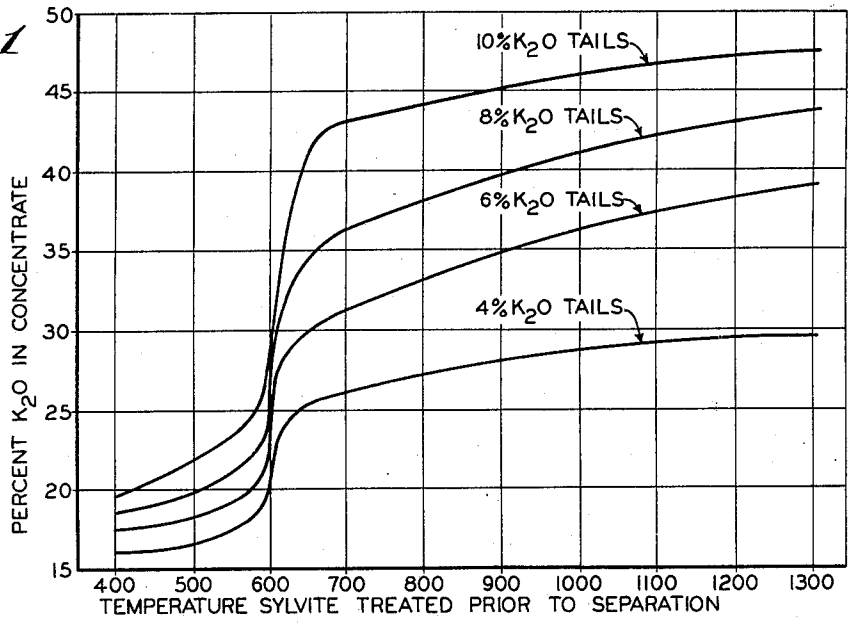


Fig. 2

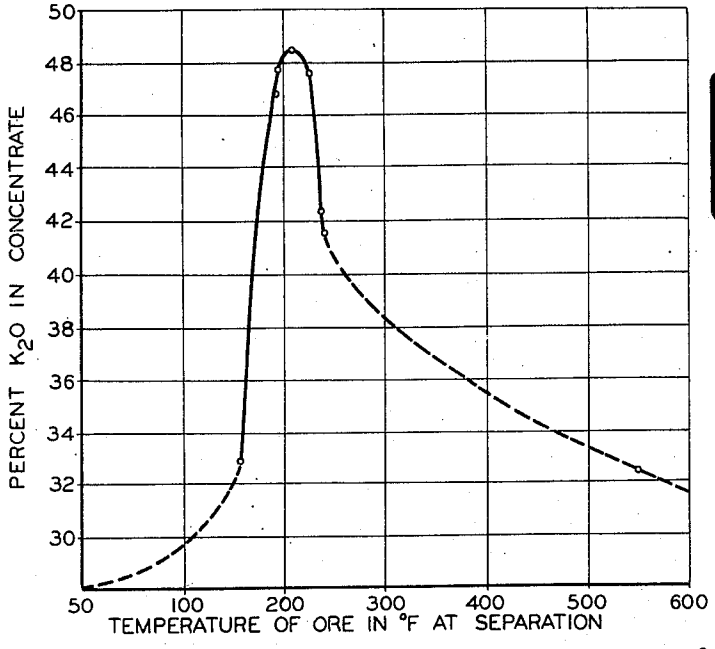
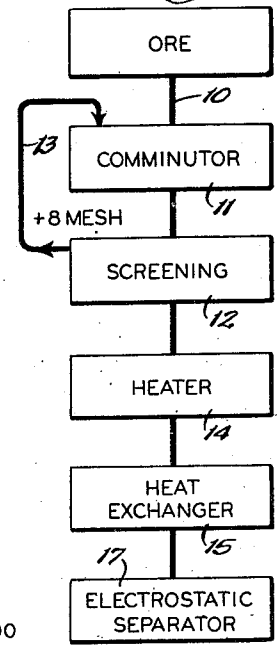


Fig. 3



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METHOD FOR BENEFICIATING POTASH MATERIALS

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25 Claims. (Cl. 209—11)

This invention relates to a method of beneficiating potash minerals. More particularly, it relates to a method of electrostatically separating dry particles of potash from the gangue of the ore. Still more particularly, it relates to a method of electrostatically separating sylvite values from the halite values with which they are found associated.

It has been long known that it is possible to beneficiate minerals by electrostatic methods. However, up to the present time, electrostatic methods have been successful from an economical and practical standpoint only in isolated instances.

Two general problems confront those interested in electrostatic methods of beneficiation. The first problem concerns the nature of the apparatus employed to create the electrostatic field. The second problem concerns the methods by which the feed material is advantageously rendered susceptible to the forces exerted in an electrostatic field.

At the present time, the most important methods that have been dealt with in this art are methods involving the phenomenon of "conductance" and the phenomenon of "contact potential." These and other phenomena of minor importance are disclosed in vol. 32, No. 35, of Industrial and Engineering Chemistry, beginning at page 600.

As distinguished from methods utilizing the phenomenon of conductance, the present invention deals with methods utilizing the phenomenon of contact potential and, in utilizing such phenomenon, subjects the particles of ore to be separated to an electrostatic field while the particles are in a freely falling condition. In apparatus utilizing the contact potential phenomenon, the electrostatic field is maintained by suitable juxtaposition of electrodes between which substantial differences of potential are maintained. Differential electrification of the particles having taken place prior to their entry into the electrostatic field and as a result of the well recognized phenomenon of contact potential, the differentially charged particles are caused to be differentially displaced during their travel through the electrostatic field in order that a suitable split may be accomplished in the lower part of the apparatus.

It will be observed that the electrostatic apparatus utilizes no moving parts, and that the capacity of methods and apparatus utilizing the contact potential phenomenon is relatively high inasmuch as no dependence is placed upon contact of the charged particles with any part of the electrodes.

The differences between the "conductance" and "contact potential" methods of charging and electrostatic separation are thus fundamental and the problems confronted widely divergent. By the very nature of the different principle of operation involved in mechanisms utilizing these methods, those who employ conductance separation will face requirements and desiderata as to rate of feed, field separation mechanism and electrification thereof, as well as segregation mechanism that differ in kind and degree from those dealt with in contact potential methods of separation of the kind herein utilized. Because

the conductance method involves a surface phenomenon and the differential loss or retention of electrical charges to or from the rotating or other electrode, careful attention must be given to the problem of charging the particles and effecting a split therebetween prior to impairment of the charge by extraneous means and before the conductance phenomenon can be utilized with respect to the rotating electrode.

In the utilization of the contact potential phenomenon followed by a free fall separation in an electrostatic field, problems arise not only with respect to conditions compatible with effective electron transfer between the particles, as well as conditions which favor the maintenance or even enhancement of the resulting charge, but also with respect to the movement of the particles as freely falling bodies under influence, not only of gravity, but electrostatic forces that are simultaneously being exerted upon the particles while falling through the field. The above enumerated and other problems have caused a marked cleavage to exist between "conductance" and "contact potential" methods of electrostatic separation.

Various methods of suitably charging particles to effect electrostatic separation of different components are well known and include not only the imparting of charges to the particles by means of effecting intimate frictional contact thereof with a source of free electrons, such as a donor plate, but also include the differential charging of the particles as a result of exchange of electrons therebetween upon the effecting of contact between particles of different components of the feed material.

It will be clear from even a cursory review of the literature that the behavior of various ores is, in large measure, unpredictable in electrostatic separation methods. While it is known that, in the contact potential series, certain substances are relatively more positive than other substances, it cannot be predicted what behavior results when these pure substances are contaminated by the presence of other substances or are present in mixtures of other substances. It has been found by extensive study upon different ores having naturally occurring slimes thereon that the electrostatic separation of particles of ores is inhibited by the presence of such slimes upon the surfaces of such particles. The term "slime," as used herein, includes very fine particles in the form of dusts and other solid bodies as conventionally used in the art and also includes films of solid materials whether or not present as discrete particles. In the present process, slimes having the same chemical composition as one of the principal components of the ore, if present on only a small portion of the surfaces of all ore particles treated, sometimes are not detrimental; but slimes having chemical compositions like or different from those of the principal constituents of the ore, if they cover appreciably the surface of the particles to be separated, generally exhibit troublesome and deleterious effects, which effects must be overcome to obtain a successful beneficiation of the types of ore herein described.

Another factor of importance that determines the behavior of ore particles in electrostatic separation of the freely falling type is the character of the surface of the ore particles. While the exact effect of this factor is not known at the present time, it has been established that variations in this factor as between different ores reflect varying results in the electrostatic separation by the freely falling method in which the particles are charged by the contact potential phenomenon. Thus, each different type of ore presents special problems which must be solved in order to achieve good separations. Accordingly, this invention is restricted specifically to the electrostatic separation of potash ores.

It has been found that the presence of slime on the ore particles is extremely detrimental to the obtention of

good electrostatic separation. It has also been found that one method of avoiding the deleterious effects of slimes is to remove them by washing. However, in some cases the removal of slimes by washing is either incomplete, impracticable, prohibitively expensive, or otherwise undesirable. For example, in the case of potash ores, washing with water can result in the solution of part of the ore particles which, in itself, is wasteful or ore values. Again, washing with water may result in transfer of one of the ore components to the surface of the particles of another component, thus producing solid particles having poor electrostatic separation characteristics. Instead of water, other liquids can be used for washing the ore, but the cost of such washing is prohibitive.

In order that the precise nature of this invention may be more fully understood and certain of the important advantages thereof explained, reference will now be made to the accompanying drawings, wherein:

Figure 1 is a graph on which have been plotted preliminary heating temperatures against percent K_2O found in the concentrate when producing various constant percentages of K_2O in the tail product;

Figure 2 is a graph on which have been plotted the temperature of separation versus the percent K_2O in the concentrate;

Figure 3 is a flow diagram of a process utilizing my invention.

In my application entitled "Method of Beneficiating Alkali Metal Minerals," Serial No. 248,171, filed September 25, 1951, and now abandoned, and the continuation-in-part thereof, Serial No. 337,919, filed February 20, 1953, now abandoned, of which this application is a continuing application, a process was disclosed for the recovery of sylvite particles from sylvinite ore by electrostatic means. In accordance with the discovery of this invention, good electrostatic separation of potash ores may be obtained with or without the removal of slimes from the surface of the ore particles by a procedure such as washing. In carrying out the instant process to obtain high potassium chloride content products, the potash bearing material such as a slime bearing ore of relatively low sylvite content must be subjected to a preliminary heat treatment of the proper magnitude. It can be commercially advantageous to remove a large fraction of the tailing as a final product prior to heating the relatively low weight of concentrate to the elevated temperature required to produce 60% K_2O concentrates. Following this heat treatment the ore must be cooled to a temperature in the range of about 350° F. to about 125° F. with the optimum separating temperature between about 150° F. and about 250° F. (the separations falling off rapidly below and above this range) and electrostatic separation made while the ore remains substantially free of surface moisture. Differential electrification of the particles, i. e., including the comminuted material to accept an electric charge, may be effected during the cooling to the 350° F. to about 125° F. range or just before passage of the comminuted ore through the electrostatic field.

In this novel method, potash ore, for example, as received from the mine, is comminuted to economical liberation size to produce a granular feed material. This granular material is sized to produce a granular feed of a particle size in the range of about 8 mesh to about 200 mesh and preferably a feed consisting of −8 mesh +150 mesh particles. This comminution of the ore may be carried out in a ball mill, roller mill, hammer mill or any other type of grinding or crushing apparatus. When the ore is ground to the mesh size indicated above, the potassium values of the ore are substantially liberated from the halite values and the ore is ready for treatment in accordance with this invention.

Potash ores which may be beneficiated by this method are the natural ores such as sylvinite, mixed ore consisting of magnesium sulfate-potassium sulfate complex, potassium chloride, and sodium chloride; langebeinite, consisting of a magnesium sulfate-potassium sulfate complex, and potassium chlorides, and the like; natural salt mixtures and salt mixtures crystallized from naturally occurring brines as well as artifically created brine solutions.

Sized granular material is next heated to temperatures in excess of about 600° F. but not to temperatures sufficiently high to decompose the salts. Sylvinite ore is generally heated to temperatures in the range of about 600° F. to about 1300° F. At the present time it is not known exactly why the process of the invention is successful in obtaining good separation of potash ore values. However, it is known that the heating of the ore to temperatures of at least 600° F. for a period of 2 minutes' to 20 minutes' duration at the lower end of the temperature range results in conditioning the ore so that upon cooling it responds to the attractive and repulsive forces operating in an electrostatic field.

Following the heat treatment, granular feed material is cooled to a temperature in the range of about 425° F. to about 100° F. and preferably to a temperature in the range of about 140° F. to about 220° F., optimum separation temperatures, of course, varying with differences in ore composition. Cooling of the ore to a temperature in this range is critical and separations while the ore is hotter than 425° F. show no appreciable upgrading of the material removed at the point where a concentrate would normally be collected. It has been observed that the effectiveness of separation of sylvite from halite rapidly increases as the optimum temperature range of 140° F. to 185° F. is approached, indicating that the temperature of the particles at the time of being separated, particularly in the first rougher separation stage, should be in the range of approximately 150° F. to 185° F. for best separations of sylvinite ore.

In order to accomplish separation, the ore particles must be differentially electrified before passage through the electrostatic field, i. e., particles of sylvite, for example, must carry an electrical charge of different character or of different magnitude from that of the halite. Differential electrification may be created by utilizing the contact potential phenomenon such as by frictional or rubbing contact between the particles either when in contact with a grounded donor plate or not. When the quantities of different ore components are not widely disproportionate, the contact potential charging is effectively carried out by agitating or movement of the mixture and under such conditions a donor plate may be disadvantageous although not sufficiently so that elimination of the donor element is at all critical. When charging concentrates, particularly of relatively high purity, contact potential will give only weak charging and at this stage use of a donor element is generally advantageous. By "grounded donor plate" is meant an element of low work function which readily exchanges electrons with the ore particles when the plate is grounded to the earth, and for optimum charging would have a work function between the two components which it is desired to separate. Such donor plates may be of graphite, galvanized iron, zinc, aluminum and the like. This differential electrification may be created, for example, by passage down an inclined chute (preferably vibratory) during the cooling operation or after reaching separation temperature.

The criticality of this preliminary heating when applied to Carlsbad sylvinite ore is illustrated in Figure 1 which is a plot of preliminary heating temperature versus percent K_2O found in the concentrate when producing various constant percentages of K_2O in the tail product, K_2O being the analytical standard for determining the potassium content of a product. From observation of each curve, it is apparent that a marked increase in the effectiveness of separation occurs beginning at a preliminary heating temperature of about 575° F. to about 600° F.

In each instance, the separations illustrated in Figure 1 were made after cooling the material to a temperature of approximately 380° F. and delivering the material to a hopper for delivery to the charging chute and then through the electrostatic field. At the point of entry of the particles into the electrostatic field, the temperature of the particles was about 200° F.

Heating of slime-bearing potash ore to render it susceptible to electrostatic separation is an operation in which the temperature of treatment will be varied according to the time of treatment. Higher temperatures accomplish the desired result in a shorter period. In a kiln operation where the material enters at about 80° F. and is discharged at about 800° F., the entire holding period in the kiln is about 5 to about 30 minutes. Operating temperatures in the range of about 800° F. to about 600° F. are effective if the material is raised to this temperature and then held at the temperature for a period varying from about 3 minutes to about 10 minutes respectively. Treatment in the range of about 750° F. to about 850° F. is preferred in kiln operation with a holding time of between about 10 minutes and about 20 minutes in the kiln.

In one variant of the process slime-bearing potash ore may be subjected to electrostatic separation following heating to temperatures in the range between about 100° F. and about 425° F., for example, 400° F. to produce a relatively low potassium chloride content concentrate. This treatment is substantially incapable of producing a concentrate above about 65% (about 41% K_2O) potassium chloride as will be shown in Example I, but it provides a more concentrated ore for treatment in accordance with this invention. In order to produce potassium chloride concentrates of the order of 95% (60% K_2O) potassium chloride or higher, it is necessary to subject this initial concentrate to the preliminary heat treatment in the range of about 600° F. up to just below the melting point of the ore as above described.

Following preliminary heating, the granular feed material is cooled to a temperature in the range of about 100° F. to about 425° F. and preferably to a temperature in the range of about 140° F. to about 220° F. just prior to its entry into the electrostatic field. Cooling of the ore to a temperature in this range is critical, as can be seen from Figure 2 which is a plot of temperature of separation versus percent K_2O in the concentrates of a sample of Carlsbad sylvinite ore separated under the influence of an electrostatic field of approximately 12,000 volts per inch field gradient. The preliminary heat treatment in each instance was to a temperature of approximately 680° F. From observation of the curve, it is apparent that the effectiveness of separation of sylvite from halite rapidly increases as the temperature range of approximately 150° F. to about 185° F. is approached. It has been found that the temperature of the particles at the time of being separated should be in the range of approximately 150° F. to about 250° F. for best separations of sylvinite ore, considering not only the factor of purity of concentrate as shown in Figure 2, but also the factors of quantity of concentrate and economy of operation, neither of which last named factors is reflected in Figure 2. Separations may be effected below about 150° F., for example between about 100° F. and about 150° F., and above about 250° F., for example, between about 250° F. and about 425° F.; but it will be recognized that separations effected in these ranges will make a somewhat poorer separation (from the standpoint of quantity of recovery or purity of concentrate), thus entailing a greater number of separation steps to reach the same grade of purity of final concentrate as is accomplished when the separations are made within the optimum range.

Mixtures of potassium chloride and sodium chloride, including mixtures formed by crystallization from solutions created by dissolving salts in aqueous media or from natural brines such as are found in the Bonneville, Utah, and Searles Lake, California, areas, need not be heated to the high temperatures required to render natural occurring potash ore susceptible to electrostatic separation; but the mixtures must be at temperatures in the range of about 125° F. to about 350° F. at the time of passage through the electrostatic field.

Where ore particles are subjected to a series of separations, the feed to subsequent stages often exhibits progressively reduced response to the electrostatic fields. This reduced response is probably due to loss or leakage of charges from the granular particles. Such weak responding concentrates may in one form of treatment be restored or induced to activity by passage through an impactor to create new surfaces and again recharging by frictional or other forces giving rise to differential electrification, which recharging may include a reheating in accordance with the treatment hereinabove described.

The strength of the electrostatic field which will effectively alter the path of ore particles varies with the average particle size and the type of material. The field gradient or strength may vary from about 1,000 volts to about 5,000 volts per inch of distance between electrodes in separating materials of relatively fine particle size and from about 3,000 volts to about 15,000 volts per inch for beneficiating of coarser particles. In all such discussion of field strenegth it must be borne in mind that corona discharges which ionize air are to be avoided. In general, it is preferred to operate with a total impressed difference of potential in the range of about 30,000 volts to about 250,000 volts. This voltage should be maintained in the form of a direct current potential substantially free of alternating current components, i. e., filtered direct current low in the so-called alternating current ripple. A steady supply of direct current may also be obtained with less expensive filtering apparatus by the use of such equipment as a rectified radio frequency power supply.

The process is outlined in general terms in Figure 3 which is a schematic flow sheet. In this flow sheet the numeral **10** indicates a conveyor which delivers ore from the mine. Ore is delivered to a comminutor **11** which may be of the thermal comminution type or standard grinding equipment. Comminuted ore is conveyed to a screening station **12** where +8 mesh size particles are separated from the −8 mesh to +200 mesh fraction. The oversize +8 mesh material is returned to the comminutor **11** for additional treatment by conveyor **13**. The −8 mesh to +200 mesh fraction is conveyed to a heater **14**, preferably of the hot air oven type where the ore is heated to a temperature in excess of about 600° F. From the heater **14** the hot ore is conveyed to a cooler **15**, which may be a heat exchanger or a unit wherein cooling air is blown through the granular hot ore. From the cooler **15** the ore is next passed, preferably as freely falling bodies, through one or more electrostatic fields of an electrostatic separator **17**.

When the material to be separated passes through a series of electrostatic fields, the preferred mode of operation provides for the collection of three fractions from each electrostatic field. The concentrate fraction from each separation unit becomes the feed to the next electrostatic field in series. A middling fraction is usually recycled to a point where the composition of the recycled middling corresponds roughly to the composition of the feed material to the separation unit. Tail fractions may or may not be combined and usually are passed to so-called scavenger electrostatic separations whereby additional values are separated from the final tail which is intended to be a throw-away product.

In a further novel embodiment of this invention, it has been found that certain variations in the separation temperatures of the initial ore body, the initial concentrate and the tail fractions from which scavenger recovery is made will produce a better final concentrate, i. e., higher in KCl, and a better tail, i. e., lower in KCl, than

is possible if the same separation temperature is used throughout. Thus, for example, if the initial feed is separated at a given temperature within the range of about 150° F. to about 300° F., preferably in the optimum range of about 175° F. to about 205° F., slightly better separations may be achieved if the rough concentrate from the first separation is passed through the electrostatic field at temperatures slightly higher than that employed in the initial separation, and if the rough tailings are separated in the scavenger recovery at a temperature about 20° F. lower than that employed in the initial separation.

Such high beneficiation is not accomplished in a single stage of electrostatic separation. The usual procedure is to separate a concentrate in a first or so-called rougher stage and to upgrade the concentrate by treatment in two or more so-called cleaner electrostatic separation stages. While the breadth of the range of temperature at the time of passage through the electrostatic field appears adequate to allow for cooling during passage through the stages necessary to make the desired grade of product, it frequently happens that this is not the case. One of the primary reasons for this failure is that in order to reduce the number of separation stages, it is necessary to make the first or rougher separation at or near the optimum separation temperature of about 175° F. to about 200° F., depending upon the character of the ore. Concentrate from the rougher separation thus will cool more or less rapidly depending upon the difference in temperature between 200° F. and the atmospheric temperature. After passage through one or more concentrate upgrading stages, it is found that sometimes the potash material has cooled below a temperature at which a measurable degree of upgrading will occur. When the potash ore has become too cool or picked up too much surface moisture, it sometimes happens that neither the concentrate nor the tail product will respond to further passes through electrostatic fields of the same, lower to higher potential gradient.

By grade is meant 50% or better K_2O content material (higher than 80% potassium chloride). Some product is sold as 50% K_2O granular muriate and appreciable quantities are sold as 60% K_2O content muriate (about 95% potassium chloride content).

Cooling conditions at times may be such that between about 50% K_2O and about 55% K_2O products can be secured in three consecutive quick passes through electrostatic fields without reheating the solids. On the other hand, cooling of solids as during winter seasons when atmospheric temperatures range, for example, between about 20° F. and about 45° F. may be so fast that precautions must be taken in the handling of a rougher concentrate to obtain satisfactory separation in a first cleaner stage without reheating between the rougher and first cleaner operation. When conditions prevail such that substantial cooling of the ore particles takes place during the operation, reheating is found to be beneficial in order to make products of acceptable commercial grade; i. e., consistently to obtain about 55% K_2O products, and such reheating is indispensable in the production of 60+% K_2O products.

In general it has been found that secondary heat treatment, i. e., treatment whereby the temperature of the solids is maintained at or raised to or above 200° F. between separation stages following the first or rougher separation, not only produces products meeting grade specifications, but also reduces the number of separation stages to obtain products meeting such grade specifications.

Secondary heat treatment as by blowing hot gases through or over the comminuted material so that the temperature of the solids is brought to between about 200° F. and about 500° F. to 600° F. appears to permit the upgrading of 18% to 20% K_2O content ore to about 55% K_2O concentrate, but no higher, irrespective of the number of separation stages. On the other hand, and in accordance with this invention, products analyzing 60% K_2O or better or readily attained (in one or two electrostatic separation stages) by suitable heat treatment of products from a rougher or subsequent stage, or products of a 55% K_2O content which products would not otherwise upgrade. Generally, after two stages products analyzing as high as 62+% K_2O are obtained.

The point at which heat treatment is utilized is generally determined by economics as reflected in a comparison of costs of material handling through various stages with the cost of heating a given quantity of material. To illustrate by a specific example, at a feed rate of 100 tons of ore per hour to a rougher separation stage, a concentrate is obtained of about 33 tons per hour and analyzes approximately 46% K_2O. By heating this 33 tons per hour of concentrate from about 150° F. back up to about 850° F., and then letting it cool to the separation temperature range, a product may be obtained in one additional separation stage analyzing approximately 60% K_2O. On the other hand, if the 33 tons per hour of concentrate is subjected to one additional stage of separation, the second concentrate recovered will be about 20 tons per hour of a material analyzing about 54% K_2O. Clearly it is more economical to pass the rougher concentrate through a second stage of separation before heating, since it saves the cost of fuel for heating approximately 13 tons of solids per hour, i. e., the difference between heating 33 tons per hour of rougher concentrate or 20 tons per hour of first cleaner stage concentrate.

When the material to be separated passes through a series of electrostatic fields, the preferred mode of operation provides for the collection of three fractions from each electrostatic field. How these fractions are further treated depends upon whether the emphasis is on a recovery of a relatively pure tail, a relatively pure concentrate, or both. For example, if emphasis is on the concentrate fraction, the operation of the first or rougher separation stage may be such that a throwaway tail is taken in this very first step. Under such circumstances the middling fraction is treated in one or more scavenger sections, in which event the tail product from the scavenger section is likewise a throwaway material and the desired component concentrates of the scavenger section are recycled to a point where the composition of the material corresponds roughly to the composition of the feed material to a separation unit. In another mode of operation the rougher concentrate and rougher tail are not final products, and then each will be subjected to one or more stages of separation to segregate, for example, sylvite from halite. In such scavenger and cleaner operations when the temperature of the feed material to the first stage was only about 185° F. to begin with, the fraction desired to be recovered, say between the first and second cleaner stage, is subjected to one or the other of the heat treatments hereinbefore described. In most instances a middling fraction is recycled either to the feed unit in which it is prepared, or to a point where the composition of the middling corresponds roughly to the composition of the feed material to a separation unit. Thus, it can be seen that there are many variations, when there are four or more separation stages, upon the exact processing order.

The invention will be more fully illustrated by the following examples.

Example I

Natural sylvinite ore from the Carlsbad section of New Mexico was comminuted in a roll crusher and then in a hammer mill. The comminuted ore was screened to produce a fraction containing particles in the range of —14 mesh to about +200 mesh size. The comminuted slime-bearing material was heated to approximately 400° F. and passed in a layer of between about

¼ inch and about ½ inch in depth through a zinc-coated vibratory trough grounded to the earth by an electrical conductor, and then dropped as freely falling bodies through an electrostatic concentrator. This sylvinite ore contained approximately 27% potassium chloride. The results of the passage of this material through six electrostatic fields in series, all of the fields being maintained at a field gradient of approximately 12,000 volts per inch, were as follows:

	Concentrate	Middling	Tail
1st Pass:			
Percent Wt.	89.6	----------	10.4
Percent Assay (KCl)	21.5	----------	7.0
2d Pass:			
Percent Wt.	30.0	38.8	31.2
Percent Assay (KCl)	43.0	16.5	7.0
3d Pass:			
Percent Wt.	20.6	65.4	14.0
Percent Assay (KCl)	49.0	45.0	25.0
4th Pass:			
Percent Wt.	24.2	36.5	39.3
Percent Assay (KCl)	64.0	48.0	33.0
5th Pass:			
Percent Wt.	57.5	4.2	38.3
Percent Assay (KCl)	67.0	59.0	60.0

At this point it is obvious that concentration has stopped. In order to determine if merely passivation of the comminuted ore had occurred, the material from the fifth pass was ground to 100% passing 20 mesh in a hammer mill. This material was heated to approximately 370° F. and subjected to the stage of electrostatic concentration under identical conditions maintained previously. Results were as follows:

	Concentrate	Middling	Tail
Percent Weight	32.1	32.1	35.8
Percent Assay (KCl)	66.0	65.0	65.0

This material, after six passes through electrostatic fields, and which had reached the ultimate of concentration under the conditions as shown, was then heated to approximately 700° F. in a hot air oven, cooled to approximately 380° F. before delivery to the feed hopper, and then passed over a grounded zinc-coated chute during delivery of the material as freely falling bodies to the electrostatic separation unit again maintained at a field gradient of approximately 12,000 volts per inch. Results from one pass through the field were as follows:

	Concentrate	Middling	Tail
Percent Weight	26.5	49.9	25.4
Percent Assay (KCl)	82.7	61.5	37.0

The foregoing example illustrates that potash ore grown nonresponsive to electrostatic forces is not appreciably upgraded by grinding and low temperature reheating, but the inactivated potash concentrate can be further beneficiated without grinding by heating to 600° F. or higher.

Example II

Sylvinite ore from the Carslbad section of New Mexico was comminuted as in Example I to produce a granular feed material of a particle size in the range of —14 to +200 mesh size. This granular slime-bearing sylvinite feed was heated to approximately 750° F. in a hot air oven. Heating was continued for approximately five minutes. The material was removed from the oven and the particles cooled by agitation in air having a temperature initially of about 80° F. When the particles cooled to approximately 400° F., the particles were delivered to a cold feed hopper and cascaded downwardly through a vibratory cast-iron trough which was grounded to the earth by an electrical conductor. The granular material differentially charged, halite positively charged, and sylvite negatively charged, was cooled to about 250° F. during delivery and was allowed to drop between vertical electrodes at a rate of approximately 2,000 pounds per hour, per foot of horizontal electrode width. The electrodes consisted of a spaced row of three inch diameter aluminum tubes arranged with approximately one inch of space between said tubes. The tubes were straight for approximately six feet of their vertical length, and then were curved smoothly on a radius of curvature of about ten feet so that the bottom end of the tubes were approximately 18 inches further apart than the straight sections of said electrodes. The electrodes were spaced approximately ten inches apart over their perpendicular length. The voltage impressed upon the electrodes was approximately 100,000 volts, giving a field gradient of approximately 10,000 volts per inch of distance between oppositely charged electrodes measured as distance between parallel sections of the electrodes. Analysis of the feed and the products after a series of passes between the electrodes and the products obtained from passage of the concentrates through additional electrostatic fields of the same intensity as that for the initial separation, is as follows:

	Percent KCl	Percent Weight
Raw Ore	24.6	100
1st Pass:		
Concentrate	65.0	22.6
Middling	27.8	24.5
Tail	5.9	52.9
2d Pass (Rougher Concentrate Treatment):		
Feed	65.0	----------
Concentrate	87.0	45.4
Middling	63.5	38.6
Tail	7.0	16.0
3d Pass:		
Feed	87.0	----------
Concentrate	95.0	43.2
Middling	89.6	39.4
Tail	62.5	17.4
4th Pass:		
Feed	95.0	----------
Concentrate	98.0	72.0
Tail	87.0	28.0
1st Scavenger Pass (Rougher Tails Treatment):		(1)
Feed [1]	5.9	----------
Concentrate	20.0	15.0
Middling	4.0	37.3
Tail	2.9	47.7
2d Scavenger:		
Feed	2.9	----------
Concentrate	7.0	20.0
Middling	2.6	25.0
Tail	1.6	55.0

[1] Material from 1st Pass.

By this method, tails or throwaway halite products of approximately 1.6% KCl are obtained by two scavenger passes through electrostatic fields. The sylvite or potassium chloride product of approximately 98% purity was obtained by three-pass treatment of concentrates from the first pass with the sylvite recovery being approximately 95% of that contained in the original ore.

Example III

Sylvinite ore from the Carlsbad section of New Mexico was comminuted as in Example I to produce a granular slime-bearing feed material of a particle size in the range of —8 +200 mesh. This granular sylvinite feed was heated to approximately 700° F. in a hot air oven for about 5 minutes. The material, after removal from the oven, was cooled so that at the time of passing between the electrodes, the ore was at a temperature of approximately 175° F. The material, while cooling from a temperature of approximately 350° F. to the temperature of passage between the electrodes of approximately 175° F., was cascaded downwardly through a vibratory cast-iron trough which was grounded to the earth by an electrical conductor. The charged material flowed at a rate of approximately 2,000 pounds per hour per foot of horizontal electrode width. The electrodes were identical to the electrodes previously described as utilized in Example II and the impressed voltage upon the electrodes

was approximately 100,000 volts, giving a field gradient of approximately 10,000 volts per inch (calculated as in Example II).

Analysis of the feed and the products after a series of passes between electrodes and the products obtained from passage of the concentrates through additional electrostatic fields of the same intensity as that for the initial separation is as follows:

	Percent K_2O	Percent Weight
Raw Ore	19.3	100
1st Pass:		
Concentrate	50.1	27.7
Middling	22.4	14.8
Tail	3.78	57.5
2d Pass (Rougher Concentrate Treatment):		
Feed	50.1	27.7
Concentrate	56.7	82.7
Tail	27.7	17.3
3d Pass:		
Feed	56.7	82.7
Concentrate	60.6	[1] 57.3
Middling	59.1	24.5
Tail	45.8	18.2
1st Scavenger Pass:		
Feed [2]	3.78	57.5
Concentrate	9.65	18.9
Middling	3.78	27.4
Tail	0.54	53.7

[1] 13% of feed.
[2] Material from 1st pass.

It will be noted from the above example that a concentrate of approximately 95% purity (measured as potassium chloride) (60.6% K_2O) is obtained with an indicated recovery of approximately 98% of the sylvite present in the original ore.

Example III illustrates the fact that lower grade ore can be beneficiated to produce 60+% K_2O products (95+% potassium chloride) if the first or rougher separation is made near the optimum separation temperature.

Example IV

Langbeinite ore from the Carlsbad section of New Mexico was comminuted as in Example I to produce a granular slime-bearing feed of a particle size in the range of about 8 to about 200 mesh. The comminuted langbeinite was heated to approximately 700° F. in a hot air oven. The material, after removal from the oven, was cooled so that at the time of passing between the electrodes, the ore was at a temperature of approximately 175° F. The ore was allowed to cascade downwardly over a vibratory cast-iron trough which was grounded to the earth by an electrical conductor. The charged material passed between the electrodes at a rate of approximately 2,000 pounds per hour per foot of horizontal electrode width. The electrodes were identical to the electrodes previously described as utilized in Example II. The impressed voltage upon the electrodes was approximately 100,000 volts giving a field gradient of approximately 10,000 volts per inch.

Analysis of the feed and the products after a series of passes between electrodes, and the products obtained by passage of the concentrates through additional electrostatic fields of the same intensity as that for the initial separation is as follows:

	Percent Langbeinite	Percent Weight
Raw Ore	70–75	100
1st Pass:		
Concentrate	97–98	46.1
Middling	90	21.2
Tail	25–30	32.7
2d Pass:		
Concentrate	96.5–98.5	89.4
Middling	87–90	4.9
Tail	55–60	5.7
1st Scavenger Pass:		
Concentrate	65–69	33.8
Middling	17–18	26.7
Tail	3–6	39.5

Example IV illustrates that potash ore other than sylvinite can be beneficiated by the process of this invention.

Example V

Mixed ore (i. e., potassium magnesium sulfate, potassium chloride, and sodium chloride) from the Carlsbad section of New Mexico was comminuted as in Example I to produce a granular feed of a particle size in the range of about 8 to about 200 mesh. The comminuted mixed ore was heated to approximately 700° F. in a hot air oven until there was a noticeable evolution of gas. The material, after removal from the oven, was cooled so that at the time of passing between the electrodes, the ore was at a temperature of approximately 175° F. The ore was allowed to cascade downwardly over a vibratory cast-iron trough which was grounded to the earth by an electrical conductor. The charged material dropped between the electrodes at a rate of approximately 2,000 pounds per hour per foot of horizontal electrode width. The electrodes were identical to the electrodes previously described as utilized in Example II. The impressed voltage upon the electrodes was approximately 100,000 volts, giving a field gradient of approximately 10,000 volts per inch.

Analysis of the feed and the products after a series of passes between electrodes, and the products obtained by passage of the concentrates through additional electrostatic fields of the same intensity as that for the initial separation, is as follows:

	Percent Potassium	Percent Weight
Raw Ore	14.0	100
1st Pass:		
Concentrate	19.5	49.8
Middling	16.0	12.6
Tail	5.6	37.6
2d Pass:		
Concentrate	20.4	38.9
Middling	19.4	51.1
Tail	15.9	10.0
1st Scavenger Pass:		
Concentrate	20.9	11.4
Middling	7.7	38.0
Tail	0.99	50.6

Example V illustrates that mixed ore can be beneficiated by the process of this invention and that the potassium chloride as well as the langbeinite is found in the concentrate, making an approximately 97% recovery of potassium salts, said salts having a purity of about 97.5% (corresponding to approximately 20.4% potassium). Potassium chloride differs in specific gravity from the langbeinite and, therefore, may be separated therefrom, if it is desirable, by any one of a number of methods, such as airtabling, or by such methods as flotation and the like.

Example VI

Sylvinite ore from the Carlsbad section of New Mexico was crushed in a jaw crusher and then comminuted in a hammer mill. The comminuted ore was screened to produce a fraction containing particles in the range of about −8 to about +150 mesh size. The granular sylvinite material was heated in a rotary kiln for a time necessary to bring the temperature of the solids to approximately 800° F. The heating time for this operation in this particular kiln was approximately 20 minutes. The heated ore upon discharge from the kiln was cooled by agitation in air having a temperature initially of about 65° F. When the particles cooled to approximately 250° F., the particles were conveyed to a feed hopper and cascaded downwardly through a vibratory trough. This trough was designated to impart to the granular material a horizontal shaking motion, thus creating differential electrification by intimate contact of halite particles with sylvite particles. The granular material differentially charged (halite charging positively and sylvite charging negatively), then passed between vertical electrodes of a rougher or first separator unit at a rate of approximately

2,000 pounds per hour per foot of horizontal electrode width. The electrodes consisted of a spaced row of 3 inch diamater tubes arranged with approximately 1 inch of space between said tubes. The tubes were straight for possibly 6 feet of their vertical length and then were curved smoothly on a radius of curvature of about 10 feet so that the bottom ends of the tubes were approximately 18 inches further apart than the straight sections of said electrodes. The straight sections of said electrodes were spaced approximately 10 inches apart. The voltage impressed upon the electrodes was 90,000 volts, giving a field gradient of approximately 9,000 volts per inch.

The feed material to this rougher concentrator stage analyzed approximately 18% K_2O. Concentrate from this first section analyzed approximately 45% K_2O, and the concentrate constituted approximately 39% of the weight of the material fed to this unit. Concentrate from this rougher unit was passed through a first upgrading or cleaner separation unit of identical construction and upon which was impressed the same voltage giving the identical field gradient. Following passage through this second electrostatic separation stage, a concentrate was produced the bulk of which analyzed about 55% K_2O and contained about 66% by weight of the feed to the cleaner section and a small fraction (about 5%) if separated would assay about 62% K_2O.

When attention was paid to maintenance of the temperature of the solids as by making the separations in a room heated to an average temperature of 190° F., passage of the concentrate from the above cleaner stage through two additional stages of separation resulted in the production of a product analyzing approximately 55% K_2O; i. e., passage resulted in no upgrading.

Example VI illustrates that potash ore can lose its response to electrostatic fields irrespective of maintenance of temperatures of the solids in the optimum separation temperature range during electrostatic separation, and that when reheating to temperatures of the order of 300° F. the maximum concentration of potash material which can be attained is about 55%.

Example VII

Sylvinite ore prepared as in Example I was passed through a rougher concentrate stage and a first cleaner stage of separation under the identical conditions of operation as in Example I except that the separations were not made in a room heated to 190° F. but were made in units surrounded by atmospheric conditions, the temperatures being approximately 65° F. Upon passage through the first cleaner stage of separation the concentrate temperature was approximately 88° F. Upon passage of this material through a second cleaner operation, no appreciable upgrading was accomplished. The concentrate was collected and passed through a small rotary kiln of adequate capacity and the solids passed countercurrently therethrough to gases which maintained the solids outlet temperature at approximately 250° F. The 250° F. temperature solids discharged from the kiln were conveyed to a hopper and cascaded by means of a vibratory cast iron trough grounded to the earth by an electrical conductor, between the electrodes of the unit originally used to make the rougher separation.

Concentrate from this separation stage analyzed approximately 43% K_2O and passage of this concentrate through another cleaner stage of separation failed to produce any appreciable upgrading of the product.

Example VII illustrates that if potash ore is reheated to temperatures generally in the separation range, products have no higher K_2O content than those obtained when no attempt is made to reheat.

Example VIII

Sylvinite ore from the Carlsbad section of New Mexico was comminuted as in Example I to produce a granular feed material in the particle size in the range of —8 mesh to +150 mesh. This granular sylvinite feed was heated to approximately 800° F. in a rotary kiln. After discharge from the kiln the material was cooled so that at the time of passing between the electrodes of the rougher separation stage the ore was at a temperature of approximately 190° F. The material was charged by cascading downwardly over a vibratory cast iron trough grounded to the earth by an electrical conductor. The charged material flowed at a rate of approximately 2000 pounds per hour per foot of horizontal electrode width. The electrodes were the same as described and as utilized in Example VI, and the impressed voltage gave a field gradient of approximately 9000 volts per inch. The raw ore analyzed approximately 16% K_2O. The concentrate from the rougher separation constituted approximately 28% of the weight of the feed and analyzed approximately 48% K_2O. A first half of this concentrate was passed through a first cleaner separation stage, and the product thereof was collected as a concentrate constituting approximately 75% of the feed material to this pass and analyzed approximately 52% K_2O. A second half of the material issuing from the rougher separation stage had a temperature of approximately 115° F. This material passed through a small rotary kiln countercurrent to gases which raised the temperature of the solids discharging from the kiln to approximately 700° F. This 700° F. material was cooled to approximately 200° F. at the time of passage through the next electrostatic field. Concentrate recovered in this next stage analyzed about 61.5% K_2O, and this product constituted approximately 13% by weight of the original feed.

Product from the first cleaner stage (from the first half of the rougher concentrate) was at a temperature of approximately 90° F. This material was passed through the small rotary kiln countercurrent to gases which raised the temperature of the solids to approximately 700° F. This 52% K_2O concentrate upgraded in one stage after heat treatment and cooling to approximately 195° F. to a product analyzing approximately 62.4% K_2O.

Example VIII illustrates that when processing potash ores it is necessary at some stage to heat the ore to a temperature in excess of about 575° F. to about 600° F. in order to obtain concentrates having in excess of 60% K_2O (95% KCl).

Having thus fully described and illustrated the character of the invention, what is desired to be secured and claimed by Letters Patent is:

1. A method of beneficiating a potash ore which comprises heating slime-bearing potash ore particles of a size in the range between about 8 mesh and about 200 mesh to a temperature in the range between about 600° F. and the melting point of the ore, allowing the said particles to cool to a temperature in the range between about 100° F. and about 425° F., inducing electrical charges on said particles, passing the charged particles as freely falling bodies through an electrostatic field, and recovering a concentrate.

2. A method of beneficiating sylvinite ore which comprises heating the raw ore particles of a size in the range between about 8 mesh and about 200 mesh to a temperature in the range between about 600° F. and the melting point of the ore, allowing said particles to cool to a temperature in the range between about 100° F. and about 425° F., inducing electrical charges on said particles, passing the charged ore particles as freely falling bodies through an electrostatic field, and recovering a potassium chloride concentrate.

3. A method of beneficiating langbeinite ore which comprises heating the raw ore particles of a size in the range between about 8 mesh and about 200 mesh to a temperature in the range between about 600° F. and the melting point of the ore, allowing said ore particles to cool to a temperature in the range between about 100° F. and about 425° F., inducing electrical charges on said

particles, passing the charged ore particles as freely falling bodes through an electrostatic field, and recovering a langbeinite concentrate.

4. A method of beneficiating a mixed potash ore which comprises heating the raw ore particles of a size in the range between about 8 mesh and about 200 mesh to a temperature in the range between about 600° F. and the melting point of the ore, allowing said ore particles to cool to a temperature in the range between about 100° F. and about 425° F., inducing electrical charges on said particles, passing the charged ore particles as freely falling bodies through an electrostatic field, and recovering a potassium salt concentrate.

5. A method of beneficiating a potash ore which comprises heating comminuted potash ore having a particle size of —8 +200 mesh to a temperature in the range between about 600° F. and the melting point of the ore, allowing said particles to cool to a temperature in the range between about 100° F. and about 425° F., inducing electrical charges on said particles, passing the charged particles as freely falling bodies through an electrostatic field, and recovering a potash concentrate.

6. A method of beneficiating a potash ore which comprises subjecting comminuted slime-bearing potash ore particles having a particle size of —8 +200 mesh to a temperature in the range between about 600° F. and the melting point of the ore, allowing said ore particles to cool to a temperature within the range of about 150° F. to about 250° F., inducing electrical charges on said cooled particles, passing the charged ore particles as freely falling bodies through an electrostatic field, and recovering a potash concentrate.

7. A method according to claim 6 in which the potash ore is sylvinite ore.

8. A method of beneficiating a potash ore which comprises heating comminuted slime-bearing potash ore particles having a particle size of —8 +200 mesh to a temperature in the range between about 600° F. and the melting point of the ore, inducing electrical charges on said particles, passing the charged particles as freely falling bodies when at a temperature in the range between about 150° F. and about 250° F. through an electrostatic field, and recovering a potash concentrate.

9. A method according to claim 8 wherein the potash ore is sylvinite.

10. A method of beneficiating a potash ore which comprises heating comminuted slime-bearing potash ore particles having a particle size of —8 +200 mesh to a temperature in the range between about 600° F. and the melting point of the particles, allowing said ore particles to cool to an initial separation temperature in the range between about 100° F. and about 425° F., inducing electric charges on said particles, passing the ore particles as freely falling bodies through an electrostatic field, collecting a concentrate fraction, passing said concentrate fraction as freely falling bodies at a temperature about 20° F. to about 30° F. higher than said initial separation through an electrostatic field, and recovering a final concentrate.

11. A method of beneficiating potash ore which comprises heating comminuted slime-bearing potash ore particles to a temperature in the range between about 600° F. and the melting point of the particles, allowing said potash ore particles to cool to an initial separation temperature in the range between about 100° F. and about 425° F., inducing electric charges on said potash ore particles, passing said potash ore particles as freely falling bodies through an electrostatic field, collecting a potash concentrate fraction and a tailing fraction, subjecting said tailing fraction to a scavenger electrostatic separation at a temperature about 20° F. lower than said initial separation temperature, and recycling the potash concentrate from the scavenger separation.

12. A method of beneficiating a potash ore which comprises heating comminuted slime-bearing potash ore particles having a particle size of —8 +200 mesh to a temperature in the range between about 600° F. and the melting point of the particles, allowing said ore particles to cool to an initial separation temperature in the range between about 100° F. and about 425° F., inducing electric charges on said particles, passing the ore particles as freely falling bodies through an electrostatic field, collecting a concentrate fraction and a tailing fraction, subjecting said tailing fraction to a scavenger electrostatic separation as freely falling bodies at a temperature about 20° F. below said initial separation temperature, subjecting said concentrate fraction to an electrostatic field as freely falling bodies at a temperature about 20° F. to about 30° F. higher than said initial separation temperature, and recovering a final concentrate.

13. A method according to claim 12 in which the potash ore is sylvinite ore.

14. A method of beneficiating potash ore which comprises heating comminuted slime-bearing potash ore particles to a temperature of between about 100° F. and about 425° F., passing said potash ore particles as freely falling bodies through an electrostatic field and recovering a rougher potash concentrate, heating the rougher potash concentrate to a temperature in the range between about 600° F. and the melting point of the particles, allowing said rougher potash concentrate particles to cool, inducing electric charges on the particles of said rougher potash concentrate, passing said rougher potash concentrate particles as freely falling bodies through an electrostatic field, and recovering a concentrate.

15. A method of beneficiating mixtures of particles of salts comprising chiefly potassium chloride and sodium chloride, which comprises heating the mixture of particles to a temperature above 125° F. but below the melting point of the particles, inducing an electric charge on said heated particles, and separating the potassium chloride particles from the sodium chloride particles by passage of the mixture of particles as freely falling bodies through an electrostatic field while the mixture of particles is at a temperature in the range between about 125° F. and about 350° F.

16. A method of beneficiating a slime-bearing potash ore which comprises dehydrating the slimes present with the comminuted potash ore particles, adjusting the temperature of the particles to a temperature in the range between about 125° F. and about 350° F., inducing electric charges on the ore particles, passing the material as freely falling bodies through an electrostatic field at a temperature in the range between about 125° F. and about 350° F. and recovering a concentrate.

17. In an electrostatic method of beneficiating potash bearing material, the steps comprising subjecting a potash-containing product of electrostatic separation of potash material at an elevated temperature which potash-containing product has cooled to a temperature below that for effective electrostatic separation in subsequent electrostatic steps to a secondary heat treatment to give said potash-containing product a temperature higher than about 200° F., and electrostatically separating said reheated potash-containing product when at a temperature between about 100° F. and about 425° F.

18. In an electrostatic method of beneficiating potash bearing material, the steps comprising subjecting a potash-containing product of electrostatic separation of potash material at an elevated temperature which potash-containing product has cooled to a temperature below that for effective electrostatic separation to a secondary heat treatment in the range of about 200° F. to about 575° F., electrostatically separating said reheated potash-containing product when at a temperature between about 100° F. and about 425° F., and recovering a potash concentrate.

19. In an electrostatic method of beneficiating potash bearing material, the steps comprising subjecting a potash-containing product of electrostatic separation of potash material at an elevated temperature which potash-con-

taining product has cooled to a temperature below that for effective electrostatic separation to a secondary heat treatment to raise said potash-containing product to a temperature in the range between about 575° F. and about 1300° F., electrostatically separating said reheated potash-containing product when at a temperature between about 100° F. and about 425° F., and recovering a potash concentrate.

20. In an electrostatic method of beneficiating potash bearing material, the steps comprising subjecting a potash-containing product of electrostatic separation of potash material at an elevated temperature which potash-containing product has cooled to a temperature below that for effective electrostatic separation to a secondary heat treatment to raise said potash-containing product to a temperature in the range between about 600° F. and about 800° F., electrostatically separating said reheated potash-containing product when at a temperature between about 100° F. and about 425° F., and recovering a potash concentrate.

21. A method of beneficiating potash bearing materials which comprises subjecting granular potash-bearing material to a preliminary heat treatment to raise said potash-bearing material to a temperature between about 575° F. and the melting point of the potash-bearing material, inducing said potash-bearing granular material to accept an electrical charge, subjecting the charged potash-bearing material to electrostatic separation when at a temperature in the range between about 100° F. and about 425° F., subjecting the partially beneficiated potash-bearing material which has cooled below a temperature for effective separation in subsequent electrostatic stages to a secondary heat treatment to raise the temperature thereof to a temperature higher than about 200° F., and passing the reheated potash-bearing material as freely falling bodies through at least one electrostatic field when at a temperature between about 100° F. and about 425° F.

22. A method of beneficiating potash bearing materials having particle sizes in the range between about 8 mesh and about 200 mesh, which comprises heating said potash material to a temperature in the range between about 600° F. and the melting point of the particles, inducing the differential electrification of the particles, passing the charged particles as freely falling bodies while at a temperature in the range between about 100° F. and about 425° F. through at least one electrostatic field, recovering a product which has cooled below the temperature for effective separation, giving said product a secondary heat treatment to raise said product to a temperature higher than about 200° F., passing the material over a donor element connected to the ground by an electrical conductor to re-establish differential electrification of the dissimilar particles, and subjecting the charged particles as freely falling bodies to further electrostatic separation when at a temperature in the range between about 100° F. and about 425° F.

23. The method of beneficiating potassium chloride-containing material which comprises heating potassium chloride-containing material having a particle size in the range between about 8 mesh and about 200 mesh to a temperature in the range of about 600° F. to about 850° F., inducing potassium chloride-containing material to accept an electrostatic charge, and subjecting the charged potassium chloride-containing material to electrostatic separation when at a temperature in the range between about 100° F. and about 425° F.

24. In a dry method of beneficiating potash ores wherein the potash ore particles are charged by movement in contact with a grounded donor element and passed as free-falling bodies through an electrostatic field, the steps comprising subjecting potash ore having a particle size in the range between about 8 mesh and about 200 mesh to heat treatment in the range between about 575° F. and 1300° F., and cooling the said potash ore particles to a temperature in the range between about 100° F. and about 425° F. prior to passage of the potash ore particles through the electrostatic field.

25. In a dry method of beneficiating potash ores wherein the potash ore particles are charged by movement in contact with a grounded donor element and passed as free-falling bodies through at least one electrostatic field, the steps comprising subjecting potash ore having a particle size in the range between about 8 mesh and about 200 mesh to heat treatment at a temperature in the range between about 600° F. and about 850° F., and cooling said potash ore particles to a temperature in the range between about 150° F. and about 200° F. prior to passage through the electrostatic field.

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