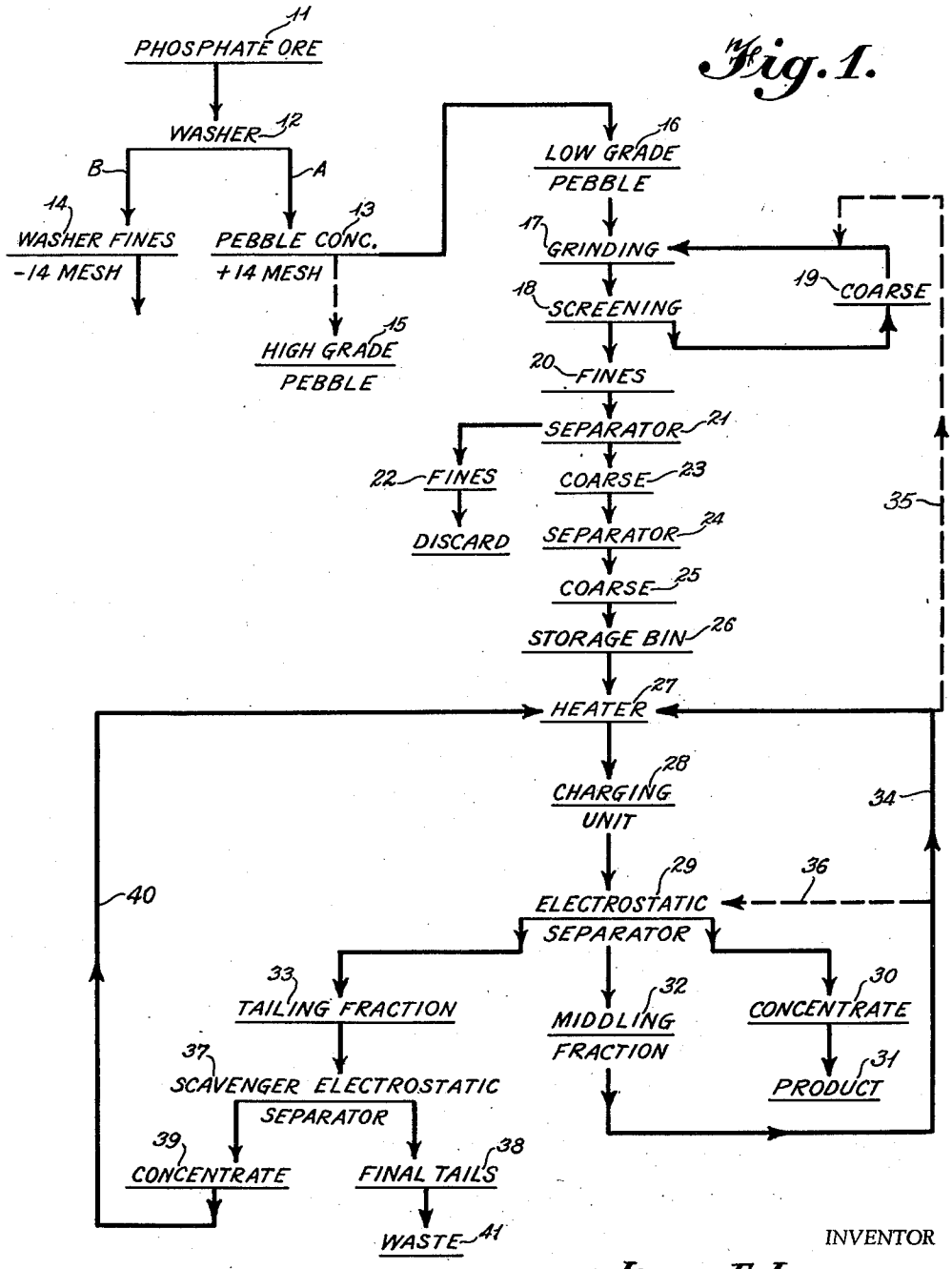
Sept. 10, 1957 J. E. LAWVER 2,805,769

BENEFICIATION OF NONMETALLIC MINERALS

Filed June 20, 1957 3 Sheets-Sheet 1

Fig. 1.



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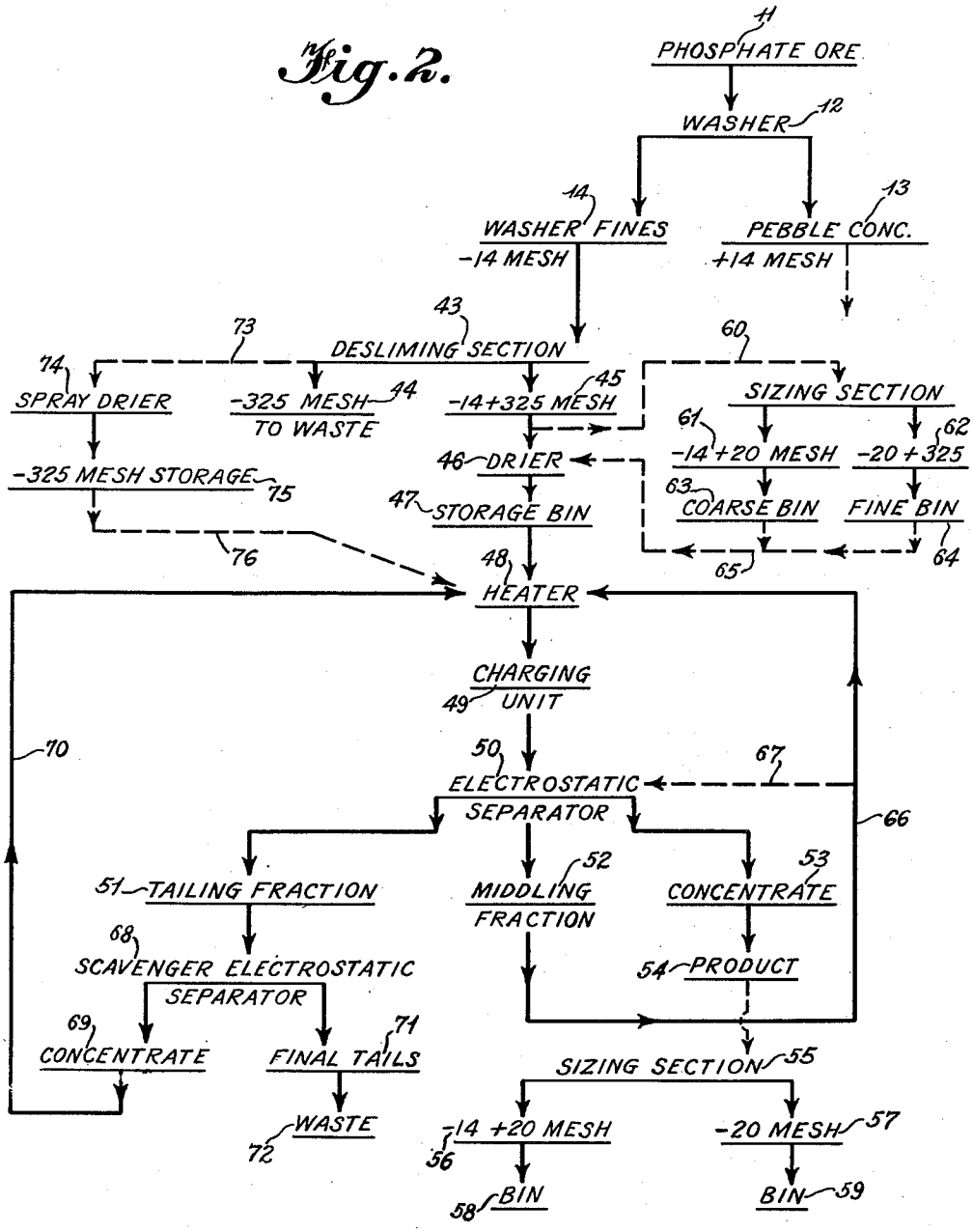
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BENEFICIATION OF NONMETALLIC MINERALS

Filed June 20, 1957 3 Sheets-Sheet 2

Fig. 2.



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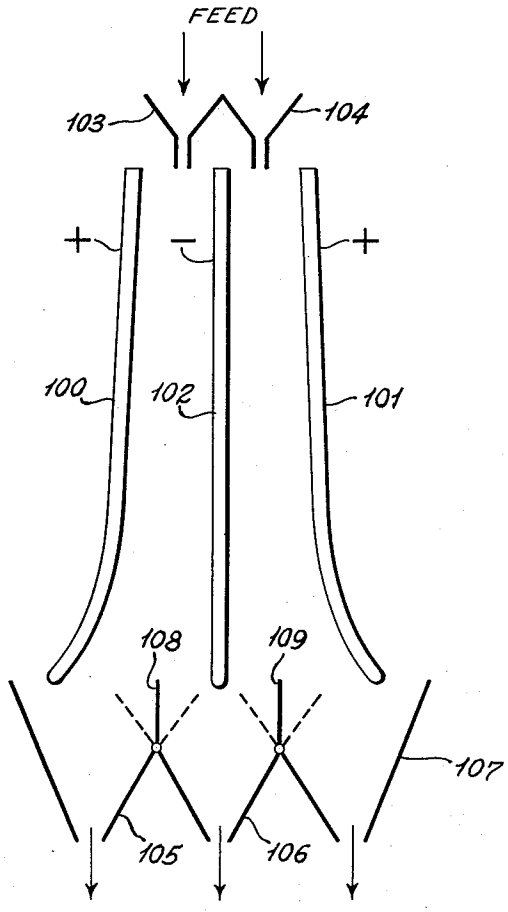
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Sept. 10, 1957 J. E. LAWVER 2,805,769

BENEFICIATION OF NONMETALLIC MINERALS

Filed June 20, 1957 3 Sheets-Sheet 3

Fig. 3.



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2,805,769

BENEFICIATION OF NONMETALLIC MINERALS

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Application June 20, 1957, Serial No. 666,284

13 Claims. (Cl. 209—11)

This invention relates to the dry beneficiation of non-metallic minerals and more particularly relates to a method for the electrostatic beneficiation of non-metallic minerals.

It has long been known to the art that it is possible to attain a mineral beneficiation of sorts by passing finely divided mineral through an electrostatic field. Despite a prodigious amount of research, however, and prolific patent and literature art reflecting that research, electrostatic beneficiation of minerals has to date been of little more than laboratory significance except for conductivity separations of lead sulfide from zinc sulfide and the conductivity beneficiation of beach sands. As a result of the problems encountered, both from the standpoint of designing suitable apparatus and from the standpoint of producing the necessary differential charges in the particles of the feed material, the art turned from electrostatic beneficiation to flotation procedures and other wet beneficiation processes despite the added cost of flotation reagents and the necessity for ample supplies of water. Thus, in arid regions where many of the available mineral deposits are located, it has been necessary to forego ore beneficiation close to the ore body and, in many instances where cost margins are close, otherwise valuable mineral deposits have gone undeveloped.

Apparatus developed by the prior art for electrostatic beneficiation of minerals falls into several categories. One type of apparatus utilizing particle charging by inductive conductance is disclosed in Johnson Patents 2,135,716 and 2,246,253. In this type of apparatus, the electrostatic separation effected depends upon the differences in surface conductivity and capacitance of the particles of comminuted mineral normally fed in a single layer to a revolving cylindrical electrode. The phenomenon of charging by inductive conductance is a function of the electric field, the time the particle is in contact with a metal in the electric field, particle capacitance, and net surface resistance. Net surface resistance, in turn, depends on particle history, particle purity, particle contact resistance, and particle moisture content. In apparatus wherein charging is effected by inductive conductance, mineral particles are caused to contact a conductive surface in the presence of an external electric field. The conductive particles become charged by induction much more rapidly than the non-conductive particles. Accordingly, by controlling the time and the field strength in relation to the surface resistance and capacitance of the particles, it is possible to control particle trajectories in the electrostatic field and to effect a separation.

In the mobile ion type of separator, such as the Sutton or Carpco machine, the particulate feed is usually delivered in a single layer to an earthed revolving cylindrical electrode which is spaced adjacent an oppositely charged second electrode. As the material is conveyed around the upper surface of the revolving cylindrical electrode it is in the normal operation, charged by bombardment with ions and/or electrons from the adjacent electrode or from any convenient source. The more conductive particles

rapidly share their charge with the earthed electrode, and fall into a first receptacle under the influence of gravity. The less conductive materials, on the other hand, are held to the revolving electrode by their image force until removed by a suitable means and allowed to fall into another receptacle. The charging mechanism used in the mobile ion type machine and the phenomenon of image force are adequately described by Sir James Jeans in the Mathematical Theory of Electricity and Magnetism, 1933. It is to be noted that in the normal operation of all of the above-described machines, the charging of the particles is always effected in the electrical field. A more detailed discussion of such apparatus and its mode of operation may be found in Taggart's Handbook of Mineral Dressing (1945), chapter 13, pp. 45–46, and in Gaudin Principles of Mineral Dressing (1939), p. 465.

Because each mineral particle must make metal contact with a metal electrode, the capacity of the Johnson, Sutton and Carpco type machines is necessarily limited. Moreover, such machines do not operate satisfactorily with materials which are substantially non-conductive and hence require an unduly long charging and/or discharging time.

A further type of prior art electrostatic beneficiation procedure is disclosed in O'Brien U. S. Patent 2,168,681 and may be characterized as a mineral-metal impact or wiping contact electrification procedure. In this method of beneficiation, electrification is effected by impact or wiping contact with a grounded, conductive metal surface in the absence of an external electric field. In such a procedure the charged particles enter an external electric field and if the charges on the mineral particle species are sufficiently different, either in sign or magnitude or both, a species concentration is effected as a result of the particle movement in the electric field. Again by necessity, such procedure is limited to a relatively low capacity since each particle must be subjected to the wiping or impact action on the metal surface. The O'Brien method, therefore, has not been developed to the point of commercial significance.

The basic objection to charging principally by wiping or metal donor action lies in the fact that most particles tend to become negatively charged by this mechanism. The negative charge that usually results due to mineral-metal contact in general follows Coehn's rule which states that the surface charge density $\sigma = 15 \times 10^{-6} (e_1 - e_2)$ coulomb/meter^2, where e_1 and e_2 are relative permittivities (Coehn Handb. der Physik, 13, 332). This rule expressed in the modern theory of solids by Swikker in Physical Properties of Solid Materials, p. 256 (1954) states that "the material with the greater number of energy levels will have the higher permittivity and will be more easily polarized so that it will give off electrons to the other contact material." . . . That is, "Electron-containing energy bands of the metal may be in equilibrium with the forbidden bands of the semiconductor or insulator. By wave mechanics, electrons pass from the metal to the boundary and are reflected with exponential return to the metal thus leaving the dielectric negative upon separation."

If all of the particles which are strongly negatively charged by wiping or metal donor action are either gangue or desired mineral components, a satisfactory separation may be achieved. If, as is almost always the case, both gangue particles and desired particles are strongly negatively charged, a satisfactory beneficiation is difficult to obtain. Further objections to wiper or donor plate charging lie in the excessive apparatus wear engendered by the continuous wiping contact and the low capacity imposed by the necessary contact of each particle with the metal donor plate.

With the exception of dielectric separations, differential charging is a surface phenomenon and, consequently, surface treatment of the mineral particles with chemical agents such as surface active agents, including known flotation collectors; mineral acids, organic acids, and the like, has been suggested. These reagents, however, are objectionable for a number of reasons including corrosion of apparatus, cost and deleterious effect on subsequent operations.

In view of the foregoing problems confronting the prior art with respect to electrostatic beneficiation of minerals, the primary object of the present invention is to provide an improved process for beneficiation of non-metallic minerals wherein electrostatic methods of separation are employed to produce commercially attractive yields.

It is a further object of this invention to provide an improved electrostatic beneficiation process wherein sufficient differences in electrical charge are maintained between the desired components of the feed material and the gangue to provide commercially satisfactory electrostatic separations.

It is an additional object of this invention to provide a method for electrostatic beneficiation of substantially non-conductive, non-metallic minerals which produces commercially attractive yields and which does not necessitate reagentizing the feed material.

Yet another object of the invention is to provide an electrostatic process for the separation of substantially non-conductive, non-metallic mineral particles from gangue when the various types of particles separated are relatively poor conductors characterized by a conductivity of substantially the same order of magnitude.

In accordance with the present invention, it has been discovered that eminently satisfactory dry beneficiation of ores and minerals can be achieved electrostatically by means of a series of critical and interdependent process steps. The process of the invention does not require reagentizing of the mineral feed and yet provides a different electrification of the particular components in the feed whereby a commercially attractive electrostatic beneficiation and separation of even substantially non-conductive components is achieved. Moreover, the through-put per lineal foot of electrode obtainable with the process of this invention is markedly greater than that possible with any other known electrostatic separation procedure.

Generally described, the present invention is an electrostatic process for beneficiating non-metallic minerals which comprises heating the mineral to a temperature of at least about 150° F. while in a state of subdivision sufficient to substantially completely liberate the desired components from the gangue, inducing the particulate mineral in the absence of an external electric field and while at a temperature of at least 150° F., to accept differential electrical charges and then subjecting the differentially charged particles as free falling bodies and while at a temperature of at least 150° F. to an electrostatic field to beneficiate the material without substantially altering the charge on the particles while in the electric field.

The mineral processed in accordance with the invention must be subdivided to a degree requisite to liberate the value components. The exact particle size necessary to liberation will vary with the crystal size of the different minerals. In general, reduction in particle size to less than about 14 mesh is sufficient to liberate the desired components from the gangue while reduction in particle size to less than 200 mesh generally provides a feed material too finely divided and dusty for preferred commercial operation. With some minerals, however, feeds containing substantial amounts of very finely divided material, e. g., —325 mesh, have proven commercially satisfactory. It will be apparent that material which is liberated at —14 mesh will be further subdivided by additional comminution to the smaller mesh

size. Such additional crushing of the individual, liberated particles is often beneficial to the electrostatic separation. The mineral material may be comminuted in any of the conventional apparatus of the art including, without limitation, jaw crushers, cone crushers, roll crushers, hammer mills, and the like.

It is essential both to satisfactory charging of the mineral particles prior to introduction into the electrostatic field and to commercially acceptable separations in the electrostatic field under normal atmospheric conditions, that the particles be maintained thoroughly dry and that the particle surfaces be kept hot. In order to effect the necessary drying of the mineral either before or after final comminuation, if comminuation is necessary, the mineral should be heated to dryness at a temperature of at least 150° F. and maintained at a temperature of at least 150° F. during the charging and up to the point of introduction as free falling bodies into the electrostatic field. Higher temperatures which do not deleteriously affect the mineral can be employed and in many instances are required in order to satisfactorily prepare the particle surfaces for optimum separations. In general temperatures of between about 200° F. and about 500° F. produce the most desirable results. Obviously, the use of temperatures higher than those resulting in optimum beneficiation cannot be justified economically. Preferred upper temperature ranges from some of the materials particularly amenable to electrostatic beneficiation are given below:

	° F.
Phosphatic ore or pebble	550
Sylvinite ore	550
Barite ore	900
Fluorite ore	550
Lithium bearing ores, such as lepidolite and spodumene	750
Pegmatite ore (feldspar)	750

The heating and drying of the particles, in accordance with the method of the invention, must be conducted in a drying apparatus such that the surface of the particles do not become deleteriously affected by the mechanical treatment during the drying operation. Rotary kilns, fluo-driers, hot gas conveying-type driers, indirectly heated rotary driers, and the like, may be employed depending on the requirements of the particular mineral or ore being processed.

Charging, in accordance with the invention, is attained through the medium of contact electrification. Contact electrification results from the movement of matter in response to such stimuli as differences in escape rate of positive or negative charges, or transfer of electrons or ions across an interface due to differences in energy levels and the like. It has been determined that real crystals never attain the static perfection of an ideal crystal lattice and that a real crystal may have distorted surfaces, displaced ions or atoms, interstitial sites and surface sites, and charge displacement due to separated anion-cation pairs of abnormal ionized atoms and trapped electrons. It is postulated that these traps are capable of acting as donors and acceptors of electrons and frequently it is these traps that are probably the controlling influences in contact electrification of minerals.

Particles of dissimilar materials, if the surfaces thereof do not exhibit differential electrification upon subjection to contact electrification operations, such as agitation, often can be caused to exhibit differential electrification by thermal, chemical, or electromagnetic methods. The differential charge may be acquired, for example, by rupture of an electrical double layer, by mechanical means, as, for example, from interparticle contact and separation or by transfer of electrons from a source external to the particles or any combination of these methods.

Basically, the desired contact electrification depends on temperature, impurity content, and mechanical history

of the various surfaces involved. Therefore, it is necessary to determine the precise conditions requisite to optimum selective charging. Under certain conditions the surfaces of the mineral species are such that it is possible to electrify by mineral-metal contact electrification. For example, if such contact causes high electrification with one mineral species and very low electrification with a second mineral species, a selective separation is possible. By way of specific example, quartz-metal contact electrification will result in a relatively high surface charge density on the quartz compared to the corresponding surface charge density on Florida phosphate after phosphate-metal contact electrification. However, even with these materials it is more desirable to employ quartz-phosphate contact electrification since this charging mechanism results in a surface charge density of opposite polarity on the two mineral species to be separated. A more complete discussion of charging mechanisms may be found in Fraas et al., Industrial and Engineering Chemistry, vol. 32, pp. 601–602 (1940).

Proper charging of the particulate mineral is an especially critical part of the present invention. It has been discovered that greatly improved differential charging of the particles is accomplished in accordance with the invention by essentially particle-to-particle contact while the dry comminuted material is maintained at a temperature of at least 150° F. Ideally, the particles would not contact a metal or grounded metal surface during the charging operation, since as previously indicated, contact with grounded metal surfaces usually causes all particles to accept a negative charge. On the other hand, where the charging of the particles is accomplished essentially by particle-to-particle contact while at a temperature of at least 150° F., the surface charge density found on the mineral species in the ore is equal and opposite in sign. Accordingly, the charged particles move in opposite directions in an electrostatic field. Thus, in the process of the invention it becomes possible effectively to separate non-conductive particles. The sign of the surface charge density to be expected in particle-to-particle contact electrification, depends on the probability of the particle making contact with surface A, B, C, etc. and the relation of the surface energies that control the sign of contact electrification of the particles against A, B, C, etc. For example, if quartz contacts Florida phosphate rock at about 150° F., the resulting surface charge density on the quartz will be negative while that on the phosphate rock will be equally positive. If quartz is allowed to contact silica gel, the quartz will become charged positively and the silica gel equally negatively. Accordingly, the charge to be expected on quartz in a mixture of phosphate rock and silica gel depends on the probability of contacting phosphate and the probability of contacting silica gel.

The desired particle-to-particle charging may be effected in numerous ways, such as by tumbling the particles down an elongated chute in such quantity that contact between the particles and the chute is at a minimum. Alternatively, the comminuted mineral, while maintained at the proper temperature, may be delivered from the drying apparatus to the electrostatic separator by means of a vibrating trough. At high throughput, the great preponderance of charging is engendered by particle-to-particle contact rather than by contact of the particles with the trough. Suitable charging also may be obtained by air agitation of the hot, comminuted mineral.

The beneficiation of the mineral feed and the separation of the mineral components is effected by passing the comminuted mineral as freely falling bodies through an external electrostatic field. It is essential to the satisfactory operation of the process that the particulate mineral, when delivered to and dropped into the electrostatic field, be dry and hot in order to achieve commercially acceptable beneficiation. It is further essential that the charge on the mineral be materially unaltered as it is delivered to and passes through the external electrostatic field. Any corona discharge causing bombardment of the feed with ions or electrons or any contact which materially will effect alteration of the charge on the individual particle as it is introduced into or passes through the external electrostatic field, must essentially be avoided. Otherwise, selectivity of charge on the respective particles resulting from the combination of steps preceding exposure to the external electric field will be deleteriously affected and the degree of beneficiation of the material will be correspondingly reduced.

In practicing the process of the invention, therefore, it is necessary to employ an apparatus which minimizes the possibility of altering the previously acquired charge with corona discharge or of charging by inductive conduction such as is employed in the roll-type conductive electrostatic separators such as the Johnson, Sutton and Carpco machines. It is desirable to employ either flat plates or relatively large rolls or cylinders as electrodes, which are specifically designed to minimize corona and to avoid metal contact in the presence of the external electrical field which results in inductive conduction and/or alteration of the charge on the particles.

The surfaces of the oppositely charged electrodes of the electrostatic separator desirably will be positioned or formed at an angle to the normal path of flow of the material if undiverted by the electrostatic forces. Such arrangement of electrodes is provided to make the angle of divergency as great as possible, thus permitting the separation of materials with dividers to be more readily accomplished. Although a variety of electrostatic apparatus may be employed in the process of the invention, it is preferred that the electrostatic field be created by one or more pairs of spaced, oppositely charged electrodes, the lower portions of which curve outwardly from the perpendicular. The paired electrodes are desirably secured in place by members with smooth, convex surfaces. Although the field gradient may vary considerably, it has been found that field gradient of from about 6,000 to about 15,000 volts per inch is sufficient for most separations.

The process of the invention may be employed to beneficiate a wide variety of minerals and ores heretofore deemed unsuitable for commercially acceptable electrostatic separations. The process of the invention is especially adapted to beneficiation of ores or minerals, the liberated particles of which are substantially non-conductive. Such materials include, without limitation, phosphatic ore, pebble phosphate, sylvinite, fluorspar, feldspar, barite, lepidolite, spodumene, kyanite, beryl, brucite-magnesite, wollastonite and cinnabar.

The beneficiation process of this invention is characterized by materially greater capacity than the electrostatic separation procedures of the prior art. Previously, the highest capacities have been achieved with Carpco type machines in the separation of conductors from non-conductors, viz, feed rates of about 1 to about 1.5 tons per hour per lineal foot of electrode. With the process of this invention, however, an operating capacity up to about 10 tons per hour, per lineal foot of electrode may be obtained depending upon the particular material being treated.

Since electrostatic separations depend on surface properties, it is imperative that the surfaces of the mineral species being differentially electrified be discrete. Accordingly, it is sometimes necessary to remove undesirable surface films by known desliming operations or other known physical methods for preparing surfaces for treatment.

Having generally described the process of the invention, more specific and detailed description will be given with reference to the accompanying drawings in which Figures 1 and 2, taken together, are flow sheets illustrating the general application of the process of the invention and in which Figure 3 shows a preferred type of electrode ar-

rangement for electrostatic separators usable in the invention.

Figs. 1 and 2, taken together, are flow-sheets of a complete process for beneficiating silica-containing phosphatic ore. They are intended merely as one illustration and not as a limitation of the instant invention. Modification of the process illustrated by these flow-sheets, while employing the principles of the instant invention, will be apparent to those familiar with electrostatic beneficiation processes in general.

Referring to Fig. 1, phosphate ore **11**, as mined, is slurried with water and pumped into a washer **12** where phosphate pebble concentrate **13** of +14 mesh is separated from washer fines **14** of −14 mesh. The −14 mesh fines **14** are processed as shown in Fig. 2; line B of Fig. 1 being the same as line B of Fig. 2. If the pebble is of high-grade, it need not be further processed and may be shipped as a product concentrate **15**. If the pebble concentrate comprises essentialy low-grade pebble as shown at **16**, it is subjected to a grinding process at **17** to substantially liberate the phosphatic values from the gangue comprising essentially quartz, feldspar and chert. The ground material is subjected to a screening operation at **18**, to separate particles of −24 mesh and the +24 mesh material **19** is recycled to the grinding process **17**. The −24 mesh fines **20** are subjected to an air classification at **21** to remove −200 mesh material **22** which may be discarded. The coarse material **23** is again subjected to classification at **24**, and the resulting fines (not shown) also may be combined with the previously obtained fines **22** and sent to discard. The coarse material **25** of −24 +200 mesh is placed in storage or surge bin **26**. (Although preferably removed and discarded, the −200 mesh material may be retained or may be subjected separately to electrostatic separation if desired.) From the storage bin, the material is passed into heater **27** which may take the form of a vertical type heat exchanger, a rotary kiln, a tunnel kiln, a multiple hearth furnace or other suitable heating device. It is preferred, though not essential, to avoid an open flame as a direct source of heat for the comminuted ore to preclude an environment conducive to a concentration of mobile ions or electrons. The particles at a temperature of at least 150° F. and preferably from 300 to 350° F., are passed from the heater **27** into charging unit **28**. The charging unit may be heated to supply heat to the comminuted ore therein. However, it is preferred first to heat the ore as in heater **27** and then pass the hot ore into the charging unit. The ore must be at a temperature of at least 150° F. during charging to insure a satisfactory separation. The optimum charging temperature for commercial operations lies between about 200° and about 225° F.

The charged ore is then introduced as free falling bodies into a suitable electrostatic separator **29** while at a temperature of at least about 150° F. and prefearbly slightly below the temperature to which the material was heated where the lower operable temperature limit will permit.

As a result of the passage of the material through the electrostatic field, a phosphatic concentrate **30** is separated which is saleable as product **31**. A middling fraction **32** and a tailing fraction **33** also are obtained. The middling fraction **32** is recycled to the heater **27** as shown by line **34**, or alternatively to the grinding step at **17** as shown by the dotted line **35**. The amount of middling fraction, a continuously circulating load, is dependent upon the grade of feed material and the amount of middling that the operator desires to carry. Since the middling recycle circuit is closed, in starting the operation the middling circuit must be filled before equilibrium is reached between the amount of feed material introduced and the amount of product and tails removed. If the middling fraction is found to be within the required temperature range, and if the particles surfaces have been maintained in a dry condition, it may be resubjected to electrostatic separation at **29** without repassage through the heater **27** or the grinding step at **17**, as shown by dotted line **36**.

The tailing fraction **33** is subjected to a scavenger electrostatic separation **37** in which tailings **38** and a phosphatic concentrate **39** are produced. The concentrate **39** is conveyed to heater **27** as shown by line **40** or alternatively to the grinding step at **17**. The concentrate **39** is again passed through the charging unit **28**, and again passed as free falling bodies through the electrostatic separator **29**. The final tails **38** are sent to waste **41**.

The tailing concentrate **39** produced as shown in Figure 1 is normally produced of lower B. P. L. content than the primary concentrate **30**. If it is desired further to upgrade the tail concentrate **39**, it may be recycled to washer **2** to cleanse the surfaces and/or to pulverizing or grinding operation **17**. Alternatively, the tail concentrate **39** may be passed through a separate grinding stage and thereafter subjected to further electrostatic beneficiation.

Referring to Fig. 2, the washery fines **14**, which are −14 mesh, are deslimed at **43** and material of −325 mesh **44** is separated from material of −14 +325 mesh **45**. The −14 +325 mesh material **45** is sent to a dryer **46** and then to the dryer storage bin **47**. From the bin **47** the material is then passed through a heater **48**, a charging unit **49** and dropped as free falling bodies into the electrostatic separator **50**. The fractions produced include a tail fraction **51**, middling fraction **52**, and concentrate **53** which constitutes a product **54** of the process. This product may be sent to a sizing operation **55** where a product **56** of +20 mesh size is separated from a product **57** of −20 mesh size. Each product is separately stored in bins **58** and **59**, respectively.

Alternatively, as shown by dotted line **60**, the −14 +325 mesh material **45** may be sized into +20 mesh material **61** and −20 +325 mesh material **62** and stored in coarse and fine storage bins **63** and **64**, respectively. Materials from bins **63** and **64** may be separately processed by separately passing them through line **65**, as described.

The middling fraction **52** is returned to heater **48** by means of line **66**, as in the case of the process shown in Figure 1. Similarly, if the temperature of the middling fraction is within the desired range and the particle surfaces are dry, it may be directly passed as free falling bodies through the electrostatic separator **50** as shown by dotted line **67**.

The tails **51** are subjected to a scavenger electrostatic separation at **68** and the concentrate **69** is returned to the heater **48**, by means of line **70**, with the final tails **71** going to waste **72**.

The −325 mesh material **44**, instead of being sent to waste **73**, may, as shown by dotted line **73**, be sent to a spray dryer **77** and then to storage **75** from which it may be conveyed, as shown by dotted line **76**, to heater **48**, and raised to the proper temperature for electrostatic beneficiation, charged by particle-to-particle contact, and dropped through the electrostatic field as in the case of the coarser sized material. However, the further processing of the −325 mesh material is not commercially attractive and it is preferred to discard this fraction and prevent any deleterious effect from the presence of such finely divided and dusty material in the system.

The processes as shown in Figs. 1 and 2 may be modified in a number of ways depending upon the character of the feed and the B. P. L. content desired in each of the products. Feed material, for example, may be introduced into the system at the heater **27**, as shown in Fig. 1, and after heating, be subjected to the grinding operation shown at **17** and sizing operations shown at **18**, **21** and **24** of Fig. 1. Two stages of electrostatic separation are shown in Figs. 1 and 2. A third stage may be added to afford means for further removal of the high silica fraction to thus produce a lower B. P. L. tail having a B. P. L. content in the range of 15 to 30%.

Thus, the aforedescribed process illustrates one method

by which phosphatic ore may be completely processed dry without the use of costly or corrosive reagents.

In the modified form of electrostatic separator shown in Fig. 3, electrodes **100** and **101** are disposed in spaced relationship on opposite sides of electrode **102**. Electrode **102** is a straight member formed by a flat, smooth-surfaced plate and is preferably of the permeable type, i. e., an electrode composed of spaced, vertical elements at the same potential and having spaced openings therebetween. The member **102** thus furnishes a common, oppositely charged electrode for electrodes **100** and **101** and provides two parallel electrostatic fields at a considerable saving in space.

Electrodes **100** and **101** are parallel to electrode **102** throughout most of their length but are curved smoothly outwardly from the central electrode **102** adjacent the lower extremities. In the preferred ten foot electrode, the curvature preferably begins at a point about four feet from the lower ends of the electrodes and sweeps smoothly outwardly on a radius of between about ten and about fifteen feet.

Feed hopper **103** is centrally disposed above electrodes **100** and **102** and delivers differentially charged feed material to the electrostatic field therebetween. Feed hopper **104** is similarly disposed above electrodes **101** and **102** for delivery of differentially charged feed material to the second electrostatic field between electrodes **101** and **102**. Hoppers **105**, **106** and **107** are disposed beneath the electrodes **100**, **101** and **102** for collection of separated fractions. Adjustable-angle dividers **108** and **109** are provided between hoppers **105** and **106** and **106** and **107**, as shown.

In the apparatus as shown, one fraction is collected in hoppers **105** and **107** while a second fraction is collected in hopper **106**. It is apparent that additional hoppers may be employed if desired to recover a middling fraction under each electrostatic field.

The following examples are given to illustrate specific applications of the instant novel process and are not to be construed as limiting the invention thereto.

EXAMPLE I

Enough low-grade pebble of a B. P. L. content of between about 59.5 and 63.5% B. P. L., was comminuted and air sized to produce 1400 pounds of an electrostatic feed material of —35 +325 mesh. This material was heated to a temperature of between about 225° and about 250° F. About 200 pounds of the hot material was placed in a grounded galvanized iron hopper. By means of a vibrating feed trough, the heated feed material was differentially charged essentially by particle-to-particle contact and fed from the hopper to fall freely through an electrostatic field created by a series of eight pairs of stationary, vertically arranged electrodes having smooth, curved surfaces opposed and providing an electrical field having an essentially uniform intensity of about 10,000 volts per inch.

The feed material was dropped through the electrostatic field at a rate of about 200 pounds per hour. The hopper was continuously filled with material from the heater. Three fractions were separated; a phosphate concentrate, a middling fraction, and a tailing fraction. The middling fraction was continuously recycled to the heater by means of a bucket elevator and chute, and the phosphate and tailing fractions were separately collected. The process was run for about five hours until the concentrate and tailings, totaling about 1000 pounds, were obtained. The results are indicated in Table A.

Table A

Feed material	Low-grade phosphate pebble.
Rate of feeding	200 pounds per hour.
Time of operation	5 hours.
Pounds feed material	1,000.
Pounds of concentrate	833.
Pounds of tails	165.
B. P. L. feed	62.5%.
B. P. L. concentrate	72.2% (3.0% insoluble).
B. P. L. tails	15.0%.
B. P. L. recovery	96.0%.

EXAMPLE II

About 1400 pounds of unreagentized deslimed Florida pebble phosphate ore washer debris of 14+35 mesh was subjected to an electrostatic field created by the same apparatus as indicated in Example I and under substantially the same conditions as indicated in Example I. The results are indicated in Table B.

Table B

Feed material	—14+35 phosphate ore.
Rate of feeding	200 pounds per hour.
Time of operation	5 hours.
Feed material	1,000.
Pounds of concentrate	722.
Pounds of tails	278.
B. P. L. feed	57.2%.
B. P. L. concentrate	77.0% (2.9% insoluble).
B. P. L. tails	5.8%.
B. P. L. recovery	97.3%.

EXAMPLE III

Florida pebble phosphate of —3/8" +1 mm. size, and having a B. P. L. content of approximately 70.3%, was comminuted and sized to produce feed for electrostatic separation of —14 +35 mesh. This feed material is the undersized material for treatment in accordance with the flow-sheet illustrated in Figure 1. The +14 mesh material was recycled to the hammer mill. The undersized material was heated to a temperature of approximately 350° F. in a heat exchanger of the cascade type. Hot material from the heat exchanger was delivered to a vibrating trough feeder which delivered the material as a comparatively thin ribbon between the electrodes of a first electrostatic separation stage. At the time of drop through the electrodes, the temperature of the material was in the range between about 300° F. and about 325° F. The material was fed between the electrodes at a rate of approximately one ton per hour per lineal foot of electrode length. The electrodes were of the type described in Figure 3 and were approximately 10' in vertical dimension and about 10' long and had impressed thereon, a potential difference of approximately 40,000 volts giving a field gradient of approximately 4,000 volts per inch of distance separating the electrodes.

In this first electrostatic separation, a number 1 concentrate was produced of 75.3% B. P. L., 2.5% insolubles, and the concentrate constituted approximately 37% by weight of the feed. The balance of the feed was fed directly to a second stage electrostatic separation of substantially identical design and field strength, but adapted to recover three products. The middling fraction recovered from the second separation stage had approximately 57.9% B. P. L., 22.9% insolubles, and constituted approximately 17.3% by weight of the original feed. This middling fraction was recycled to the comminution operation. The tail fraction recovered assayed about 30% B. P. L., about 60.2% insolubles, and constituted approximately 10.6% by weight of the original feed. The concentrate fraction had 74% B. P. L., 4.2% insolubles, and about 35.1% of the weight of the original feed. The combined concentrates constituted a recovery of 80.7% of the total B. P. L., the middling accounted for approximately 14.9% of the B. P. L., and the tail fraction accounted for approximately 4.5% of the total B. P. L.

EXAMPLE IV

Fluorite-quartz ore analyzing approximately 53.4%

CaF_2 was ground and sized to recover a −20 +150 mesh standard screen size fraction.

This sized material was heated to approximately 350° F. in an electrically heated oven. The heated material was transferred to the hopper of an iron chute vibrated by an electrical vibrator. Material ran through the chute to give a depth of about one-eighth inch at the discharge lip.

The contacted material when passing into the electrostatic field was at a temperature of approximately 160° F. The feed rate was approximately 1.1 tons/hour/linear foot of electrode width. The field gradient of the electrostatic field was 9,000 volts per inch of distance separating the electrodes. The electrodes were 10 feet long.

The results obtained utilizing a single pass through the electrostatic field are indicated in Table C.

Table C

Material	Percent Weight	Percent CaF_2
Feed	100	53.4
Concentrate	42.8	87.5
Middling	13	44.7
Tail	44.2	27.8

EXAMPLE V

A barite-fluorite ore upon analysis showed 38% barite, 58% fluorite, 4% quartz, 7–8% clay and other gangue material. The ore was crushed and screened to recover a −14 +200 fraction. This fraction was deslimed by slurrying in water at 75% solids content.

The deslimed and washed ore fraction was dried and heated to approximately 500° F. in an electrically heated oven. The heated material was transferred to the hopper of a Syntron feeder grounded to the earth by an electrical conductor. Material ran through this chute to give a depth of about ⅛ inch at the discharge lip.

The contacted material while within the temperature range of between about 250° F. and about 300° F. was fed through the electrostatic field at a rate of approximately 1 ton/hour/linear foot of electrode width, the field gradient being 9,000 volts per inch of distance separating the electrodes.

Table D

Material	Percent Weight	Percent $BaSO_4$	$BaSO_4$ Dist.	Percent CaF_2
Feed	100	42.1		
Tail	48.8	6.6	7.8	78.5
Middling	9.0	36.8	7.7	50.1
Concentrate	42.2	84.5	84.5	4.2

EXAMPLE VI

Spodumene ore analyzing Li_2O 1.7%, K_2O 2.8%, Na_2O 3.8%, CaO 1.1%, Al_2O_3 16.5%, SiO_2 73.5%, Fe_2O_3 0.2%, was cone crushed and sized on a Sweco screen to recover a −35 +325 mesh feed material. This sized material was heated to approximately 500° F. in an electrically heated oven. The heated material was transferred to the hopper of a Syntron feeder having a cast iron chute grounded to the earth by an electrical conductor. Material ran through this chute at a depth to give about ⅛ inch at the discharge lip.

The contacted sample while within the temperature range of between 500° F. and 400° F. was fed to the electrostatic field at a rate of approximately one ton per hour per linear foot of electrode width, the field gradient being 9,000 volts per inch of distance separating the electrodes.

The results obtained utilizing a single pass through the electrostatic field are indicated in Table E.

Table E

Material	Percent Weight	Percent Li_2O
Feed	100.0	1.6
Concentrate	49.4	2.5
Middlings	15.2	1.9
Tails	35.4	1.1

Inspection of Table E shows clearly that the spodument HK–5 is substantially beneficiated with respect to Li_2O by this process.

EXAMPLE VII

Lepidolite ore containing about 45% feldspar, 30% quartz and 24% micas and assaying approximately 1.02% Li_2O was cone crushed and sized on a Sweco screen to recover a −35 +325 mesh feed material. This sized material was heated to approximately 500° F. in an electrically heated oven. The heated material was transferred to the hopper of a Syntron feeder having a cast iron chute grounded to the earth by an electrical conductor. Material ran through this chute to give a depth of about ⅛ inch at the discharge lip.

The contacted sample while within the temperature range of between 500° F. and 400° F. was fed to the electrostatic field at a rate of approximately one ton/hour/linear foot of electrode width, the field gradient being 9,000 volts per inch of distance separating the electrodes.

The results obtained utilizing a single pass through the electrostatic field are indicated in Table F.

Table F

Material	Percent Weight	Percent Li_2O
Concentrate	23.5	2.1
Middlings	24.5	1.0
Tails	52.0	0.4

Inspection of Table F shows clearly that the lepidolite is substantially beneficiated with respect to Li_2O by this process.

EXAMPLE VIII

Lepidolite ore containing about 30% feldspars, 45% quartz, about 20% mica and assaying approximately 1.42% Li_2O was cone crushed and sized on a Sweco screen to recover a −35 +325 mesh feed material. This sized material was heated to approximately 500° F. in an electrically heated oven. The heated material was transferred to the hopper of a Syntron feeder having a cast iron chute to give a depth of about ⅛ inch at the discharge lip.

The contacted sample while within the temperature range of between 500° F. and 400° F. was fed to the electrostatic field at a rate of approximately one ton/hour/linear foot of electrode width, the field gradient being 9,000 volts per inch of distance separating the electrodes.

The results obtained utilizing a single pass through the electrostatic field are indicated in Table G.

Table G

Material	Percent Weight	Percent Li_2O
Concentrate	25.0	3.0
Middling	47.0	1.8
Tail	28.0	1.3

EXAMPLE IX

Barite-fluorite analyzing 21.9% F, 35.4% CaO, and 24.7% BaO was wet screened on a Sweco screen to recover a −35 +325 mesh feed material. This sized material was heated to approximately 500° F. in an electrically heated oven. The heated material was trans-

ferred to the hopper of Syntron feeder having a cast iron chute grounded to the earth by an electrical conductor. Material ran through this chute to give a depth of about ⅛ inch at the discharge lip.

The contacted sample while within the temperature range of between 500° F. and 400° F. was fed through the electrostatic field at a rate of approximately one ton/hour/linear foot of electrode width, the field gradient being 9,000 volts per inch of distance separating the electrodes.

Table H

Material	Percent Weight	Percent $BaSO_4$	Percent CaF_2
Concentration	36.6	78.4	7.4
Middlings	7.5	50.6	35.6
Tails	55.9	4.7	74.0

Inspection of Table H shows clearly that the barite-fluorite is substantially beneficiated with respect to $BaSO_4$ by this process.

EXAMPLE X

A barite-bearing ore from South Carolina upon analysis showed a composition of approximately 17% barite, 51% quartz and about 30% sericite. The ore was crushed and screened to produce a feed 100% of which passed 30 mesh standard screen. This minus 30 mesh material was deslimed by slurrying in water at 75% solids content and a feed produced whose particles were of a size −30 +200 mesh.

The −30 +200 mesh was dried and heated to approximately 500° F. in an electrically heated oven. The heated material was transferred to the hopper of a Syntron feeder grounded to the earth by an electrical conductor. Material ran through this chute to give a depth of about ⅛ inch at the discharge lip.

The contacted material while within the temperature range of between about 250° F. and 300° F. was fed through the foot of electrode width, the field gradient being 9,000 volts per inch of distance separating the electrodes.

Fractions obtained in a rougher and a cleaner pass through the electrostatic field were as follows:

Table I

Material	Percent Weight	Percent $BaSO_4$
Rougher concentrate	51.2	54.4
Rougher tail	48.8	6.0
Cleaner concentrate	51.6	91.6
Cleaner middling	11.2	40.5
Cleaner tail	37.2	6.9

EXAMPLE XI

A barite-fluorite ore upon analysis showed 38% barite, 58% fluorite, 4% quartz, 7–8% clay and other gangue material. The ore was crushed and screened to recover a −14 +200 mesh. This fraction was deslimed by slurrying in water at 75% solids content.

The deslimed and washed ore fraction was dried and heated to approximately 500° F. in an electrically heated oven. The heated material was transferred to the hopper of a Syntron feeder grounded to the earth by an electrical conductor. Material ran through this chute to give a depth of about ⅛ inch at the discharge lip.

The contacted material while within the temperature range of between about 250° F. and about 300° F. was fed through the electrostatic field at a rate of approximately one ton/hour/linear foot of electrode width, the field gradient being 9,000 volts per inch of distance separating the electrodes.

The results obtained utilizing a single pass through the electrostatic field are indicated in Table J.

Table J

Material	Percent Weight	Percent $BaSO_4$	Percent $BaSO_4$ Dist.	Percent CaF_2
Feed	100	42.1		
Tail	48.8	6.6	7.8	78.5
Middling	9.0	36.8	7.7	50.1
Concentrate	42.2	84.5	84.5	4.2

The generic concept of this invention was first disclosed and exemplified in Lawver application Serial No. 142,982, filed February 8, 1950, which presented examples illustrating the process of the invention. This disclosure was perpetuated in Lawver application Serial No. 312,730, filed October 2, 1952, as a continuation-in-part of application Serial No. 142,982, subsequently abandoned. The disclosure of the invention was amplified and further illustrated in application Serial No. 646,189, filed March 12, 1957, as a continuation-in-part of now abandoned application Serial No. 312,730. This application is a continuation-in-part of application Serial No. 646,189, filed March 12, 1957, and, inter alia, amplifies the disclosure of that application by the exemplification of additional species of the invention and by more detailed elucidation of the technical phenomena involved.

What is claimed is:

1. An electrostatic process for beneficiating a non-metallic mineral which comprises heating the mineral to a temperature of at least 150° F. while in a state of subdivision sufficient to substantially completely liberate the desired components from the gangue; causing the mineral particles without chemical pretreatment, in the absence of an external electrical field and while at a temperature of at least 150° F., to accept differential charges; and thereafter subjecting the differentially charged particles as free falling bodies and while at a temperature of at least 150° F. to an electrostatic field to beneficiate the mineral without substantially altering the charge on the particles while in the electric field.

2. An electrostatic process for beneficiating a non-metallic mineral which comprises heating the mineral to a temperature of at least 150° F. while in a state of subdivision sufficient to substantially completely liberate the desired components from the gangue; causing the mineral particles without chemical pretreatment, in the absence of an external electrical field and while at a temperature of at least 150° F., to accept differential charges essentially by particle-to-particle contact; and thereafter subjecting the differentially charged particles as free falling bodies and while at a temperature of at least 150° F. to an electrostatic field to beneficiate the mineral without substantially altering the charge on the particles while in the electric field.

3. An electrostatic process for beneficiating a non-metallic mineral which comprises heating the mineral to a temperature of at least 150° F. while in a particle size of between about 14 and about 200 mesh; causing the mineral particles without chemical pretreatment, in the absence of an external electrical field and while at a temperature of at least 150° F., to accept differential charges; and thereafter subjecting the differentially charged particles as free falling bodies and while at a temperature of at least 150° F. to an electrostatic field to beneficiate the mineral without substantially altering the charge on the particles while in the electric field.

4. An electrostatic process for beneficiating a non-metallic mineral which comprises heating the mineral to a temperature of at least 150° F. while in a particle size of between about 14 and about 200 mesh; causing the mineral particles without chemical pretreatment, in the absence of an external electrical field and while at a temperature of at least 150° F., to accept differential charges essentially by particle-to-particle contact; and thereafter subjecting the differentially charged particles

as free falling bodies and while at a temperature of at least 150° F. to an electrostatic field to beneficiate the minerals without substantially altering the charge on the particles while in the electric field.

5. An electrostatic process for beneficiating a non-metallic mineral which comprises comminuting the mineral to a particle size of between about 14 and about 200 mesh to substantially completely liberate the value components from the gangue; heating the comminuted mineral to a temperature of at least 150° F.; causing the mineral particles without chemical pretreatment, in the absence of an external electrical field and while at a temperature of at least 150° F., to accept differential charges; and thereafter subjecting the differentially charged particles as free falling bodies and while at a temperature of at least 150° F. to an electrostatic field to beneficiate the mineral without substantially altering the charge on the particles while in the electric field.

6. An electrostatic process for beneficiating a non-metallic, substantially non-conductive mineral which comprises comminuting the mineral to a particle size of between about 14 and about 200 mesh to substantially completely liberate the value components from the gangue; heating the comminuted mineral to a temperature of at least 150° F., causing the mineral particles without chemical pretreatment, in the absence of an external electrical field and while at a temperature of at least 150° F., to accept differential charges essentially by particle-to-particle contact; and thereafter subjecting the differentially charged particles as free falling bodies and while at a temperature of at least 150° F. to an electrostatic field to beneficiate the mineral without substantially altering the charge on the particles while in the electric field.

7. An electrostatic beneficiation process according to claim 6 in which the mineral treated is phosphatic ore.

8. An electrostatic beneficiation process according to claim 6 in which the mineral treated is fluorite ore.

9. An electrostatic beneficiation process according to claim 6 in which the mineral treated is lithium ore.

10. An electrostatic beneficiation process according to claim 6 in which the mineral treated is barite ore.

11. An electrostatic beneficiation process according to claim 6 in which the mineral treated is pegmatite ore.

12. An electrostatic process for beneficiating silica-containing phosphate pebble ore which comprises comminuting said ore to a particle size range of about —14 mesh to about +200 mesh, heating the comminuted ore to a temperature of from about 150° F. to about 550° F., causing the particles of the heated comminuted ore while at a temperature of at least about 150° F. to accept differential charges, subjecting the differentially charged particles as free falling bodies to an electrostatic field to effect beneficiation thereof without substantially altering the charge on the ore particles while said particles are in the electrostatic field.

13. An electrostatic process for beneficiating a non-metallic, substantially non-conductive mineral which comprises heating said mineral in a state of subdivision adequate to effect substantially complete liberation of the desired mineral components from the gangue to a temperature of at least about 150° F.; causing the particles of said mineral, without chemical pretreatment, in the absence of an external electrical field and while at a temperature of at least about 150° F. to accept differential charges by contact with a donor element, and subjecting the differentially charged particles as free falling bodies and while at a temperature of at least 150° F. to beneficiate said mineral without material alteration of the charge on the mineral particles while said particles are in said electrostatic field.

References Cited in the file of this patent

UNITED STATES PATENTS

959,646	Swart	May 31, 1910
1,110,896	Comstock	Sept. 15, 1914
1,422,026	Brown	July 4, 1922
2,135,716	Johnson	Nov. 8, 1938
2,168,681	O'Brien	Aug. 8, 1939
2,197,865	Johnson	Apr. 23, 1940
2,198,972	Peddrick et al.	Apr. 30, 1940
2,246,253	Johnson	June 17 1941
2,357,658	Johnson	Sept. 5, 1944

FOREIGN PATENTS

598,948	Germany	June 21, 1934

OTHER REFERENCES

"Milling Methods," American Institute of Mining and Metallurgical Engineers, volume 134, 1939, pages 411 and 412.

Taggart: "Handbook of Mineral Dressing," (1945), chapter 13, pages 45–46.

Gaudin: "Principles of Mineral Dressing," (1939), page 465.

Fraas et al.: Electrostatic Separations of Solids, Industrial and Engineering Chemistry, volume 32, No. 5, 600–605, May 1940.

Fraas et al.: Contact Potential in Electrostatic Separation, Bureau of Mines, R. I. 3667, November 1942.

Fraas et al.: An Electrostatic Separator for Fine Powders, Bureau of Mines, R. I. 3667, November 1942.

Fraas et al: The Electrostatic Separation of Several Industrial Minerals, AIMME, Technical Publication No. 2408, July 1948.

Fraas et al.: Notes on Drying for Electrostatic Separation of Particles, American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2257, November 1947.

Von Szanthe: Electrostatic Beneficiation in the Industry of Rocks and Earths, Tomindustrie-Etg und Keramische Rundschau, volume 77, 83–88 (1953).