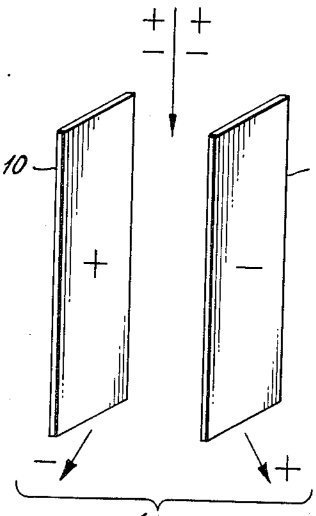


PRIOR ART Fig. 1.

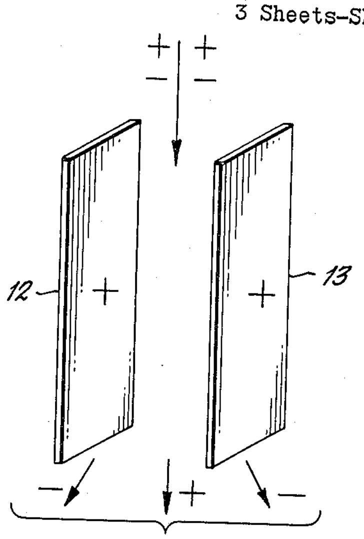


Fig. 2.

Fig. 3.

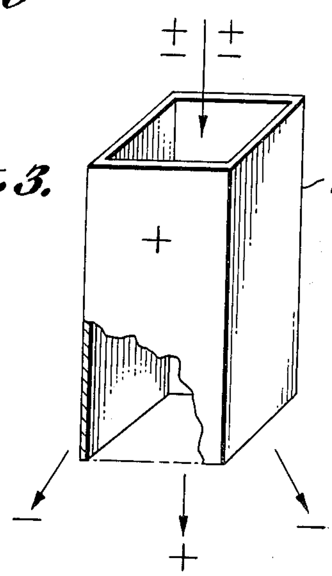
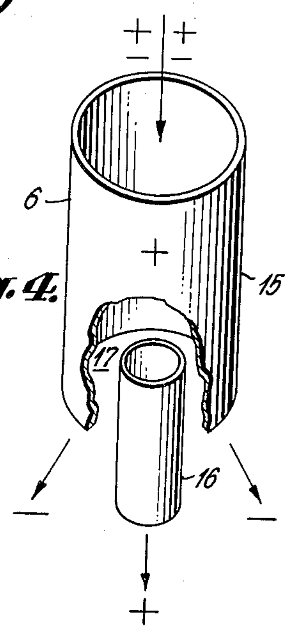


Fig. 4.



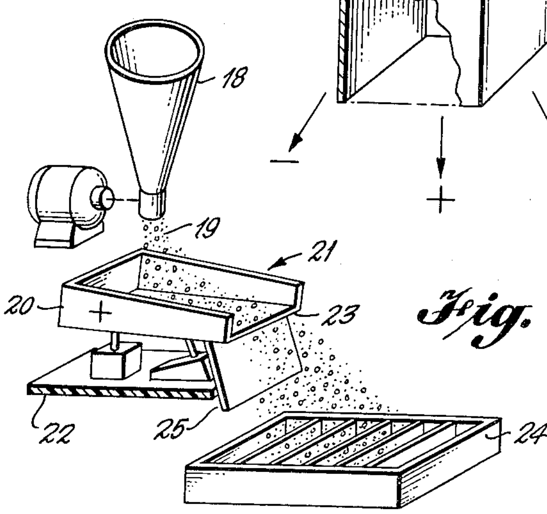


Fig. 5.

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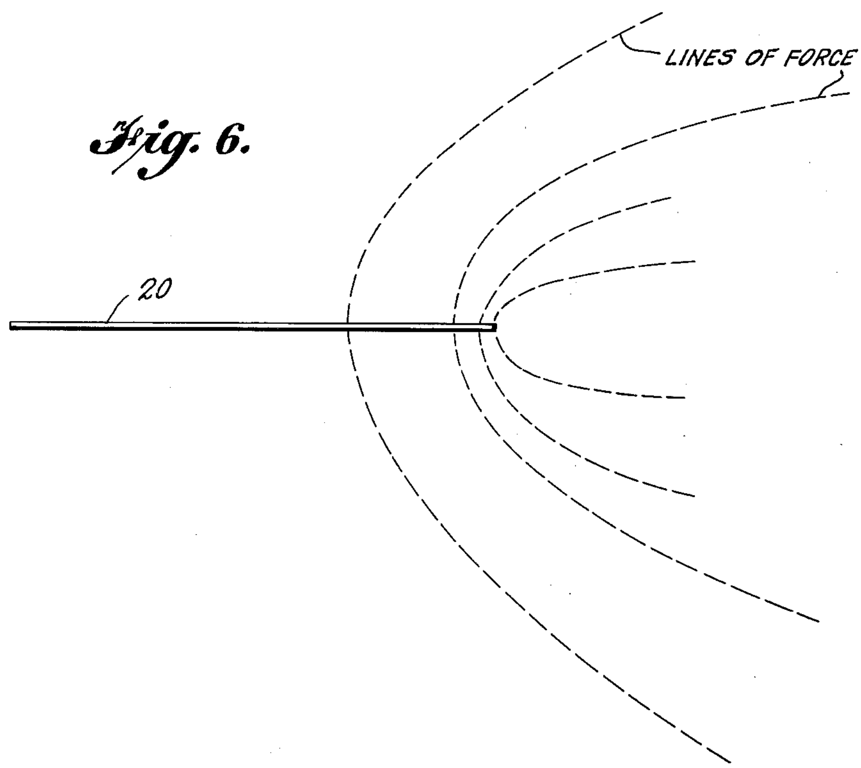
Fig. 6.



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Oct. 23, 1962 I. M. LE BARON 3,059,772
ELECTROSTATIC SEPARATION IN NON-UNIFORM FIELD
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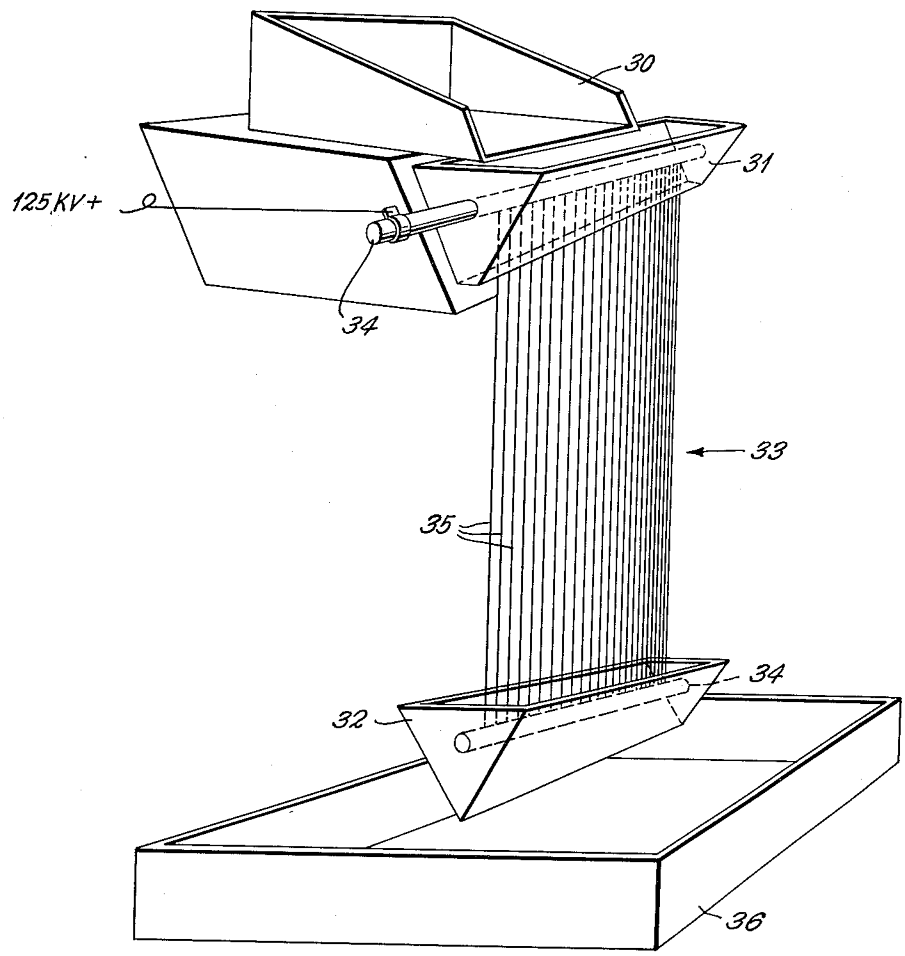
Fig. 7.



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3,059,772

ELECTROSTATIC SEPARATION IN NON-UNIFORM FIELD

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Filed Sept. 28, 1960, Ser. No. 59,013
17 Claims. (Cl. 209—127)

This invention relates to the electrostatic separation of materials. More particularly, the invention relates to novel techniques and apparatus for the electrostatic separation of particulate materials.

Conventional electrostatic separation procedure entails passing a mixture of differentially charged particles through an electrostatic field established between adjacent oppositely charged electrodes. While many aspects of such conventional procedure may be substantially varied, an electrostatic field established between a pair of oppositely or differentially charged electrodes is essential in all cases.

Apparatus utilized to effect the conventional electrostatic separation of particulate materials is appropriately classified in two basic categories differing primarily in respect to the structure and arrangement of the differentially charged electrode pair between which the requisite field is established. In one such basic category of electrostatic separation equipment the necessary field is created by a pair of stationary, differentially charged electrodes between which the differentially charged particulate materials to be separated are passed as free falling bodies. Typical stationary electrode apparatus is described, inter alia, in Cook Patent No. 2,706,044, Le Baron Patent No. 2,738,875 and Cook et al. Patent No. 2,782,923. No significant modification of the charge on the particles undergoing separation occurs during passage through the electrostatic field of conventional stationary electrode apparatus. Such equipment is therefore particularly appropriate for the separation of materials, such as non-conductors, which may be differentially charged, as by contact electrification, prior to introduction into the field.

A second basic type of electrostatic separation equipment, commonly known as a "roll-type separator," conventionally comprises a first electrode, normally at ground potential, in the form of a rotating material-conveying roll of comparatively large diameter and a substantially smaller charged electrode spaced from the roll electrode. Roll separators are frequently provided with means, such as an electron spray, to impart a differential charge to the particulate materials to be separated during passage into or through the field established between the electrodes. Such apparatus is particularly applicable to the separation of mixtures of conductors and mixtures of conductors and non-conductors the separation of which may be significantly improved by such charge modification. Such apparatus is described in detail in Taggart, "Handbook of Mineral Dressing" (1945), chapter 13, pages 45–46, and in Gaudin, "Principles of Mineral Dressing" (1939), page 465.

The provision of an electrostatic field established between a pair of differentially charged electrodes, as required by prior art electrostatic separation techniques has occasioned significant problems in respect to the efficient utilization of the electrical energy supplied to the system, effective differential charging of the particles to be separated, the nature of the materials which can be separated, and the like.

It is accordingly a primary object of this invention to provide a novel technique for the electrostatic separation of particulate materials which does not require an electrostatic field established between a pair of differentially charged, adjacent electrodes.

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It is an additional object of the invention to provide an electrostatic separation technique which involves principles of operation different from those which characterize two electrode separators of the prior art.

It is yet another object of the invention to provide novel electrostatic separation apparatus and procedures which achieve a superior result as compared with prior art techniques which contemplate an electrostatic field established between two differentially charged electrodes.

It is specifically an object of the invention to provide a novel electrostatic separation technique which entails the utilization of a single electrode structure charged either positively or negatively.

It is an additional object of the invention to provide a method and apparatus whereby a mixture of differentially charged particles is subjected to an electrostatic field created by a charged single electrode structure.

It is an object of a specific embodiment of the invention to provide a non-uniform field adjacent to a single electrode structure and to utilize such non-uniform field to effect the electrostatic separation of differentially charged particulate materials.

It is a particular object of the invention to achieve effective electrostatic separation of a mixture of differentially charged particulate materials by passage of such materials through a non-uniform electrostatic field inclined with respect to the horizontal.

It is yet another object of the invention to provide a process effectively to electrostatically separate particulate materials of all types.

It is an additional object of the invention to provide a novel electrostatic separation technique which is essentially independent of the specific mechanism by which the requisite differential charges are imparted to the materials to be separated.

In accordance with this invention, there is provided a process for separating a mixture of particulate materials which comprises establishing a field by imparting a substantial electrical charge to a single electrode structure, imparting a differential charge to the particulate materials to be separated from said mixture, introducing said mixture of differentially charged particulate materials into said field to cause the particles charged to the sign opposite that of said electrode structure to be attracted toward said structure and the particles charged to the same sign as said electrode structure to be repelled therefrom, and separately collecting said attracted and repelled particles.

The invention will be appreciated by reference to the drawing in which:

FIGURE 1 is a schematic representation of a conventional, prior art, electrostatic separation by use of an electrostatic field established between two adjacent oppositely charged electrodes;

FIGURE 2 is a schematic representation of an electrostatic separation in accordance with the present invention;

FIGURE 3 is a schematic representation of an electrostatic separation in accordance with an additional embodiment of the present invention;

FIGURE 4 is a schematic representation of an electrostatic separation pursuant to an additional specific embodiment of the present invention;

FIGURE 5 is a schematic representation of the separation achieved with one preferred form of apparatus for the practice of the present invention which entails utilization of a non-uniform electrostatic field;

FIGURE 6 is a schematic representation of the electrostatic field at the discharge edge of the apparatus as shown in FIGURE 5; and

FIGURE 7 is a schematic representation of another form of apparatus contemplated by the invention.

The conventional prior art, free fall apparatus represented by FIGURE 1 includes a positive stationary electrode **10** separated from a negative stationary electrode **11**. The electrodes **10** and **11** are charged to establish an electrostatic field having a gradient from about 15,000 to about 100,000 volts per inch therebetween. A mixture of particulate materials bearing differential charges, schematically represented by the positive and negative symbols in the figure, is passed through the field between the electrodes **10** and **11** and separated by the attractive and repulsive forces on the particles in the field.

The novel system of the invention as represented in one embodiment schematically represented by FIGURE 2 takes the form of a pair of stationary electrodes **12** and **13** both positively charged, although a negative charge would achieve a like result.

The mixture of particulate materials bearing differential charges as schematically represented by the positive and negative symbols in FIGURE 2 is passed between the positively charged electrodes **12** and **13**. As shown in FIGURE 2, the positively charged particles are repelled by both electrodes and hence tend to be moved toward the center of the space between the electrodes. Analogously, the negatively charged particles are attracted by both positively charged electrodes **12** and **13** and hence are diverted in the direction of such electrodes. Accordingly, as shown in the figure, the positively charged particles may be collected below the center of the space between the electrodes **12** and **13** whereas the negatively charged particles may be collected in the area below the electrodes. If the sign on the electrodes **12** and **13** were changed from positive to negative the negatively charged particles would move toward the center of the space between the electrodes, whereas the positive particles would be attracted toward the electrodes.

FIGURE 3 reflected a refinement of the techniques and apparatus shown in FIGURE 2 and, more specifically, schematically illustrates a single electrode in the form of a square tube **14** bearing a positive charge.

The positively charged materials are repelled from the walls toward the center of the space within the tubular electrode **14** whereas the negatively charged materials are attracted to the electrode walls with the result that the positively and negatively charged materials may be separately collected. While the electrode **14** is illustrated in FIGURE 3 as being square in cross section, such electrodes may take any peripheral configuration. Hence round, elliptical, rectangular and irregularly shaped tubes are contemplated. Moreover, various other configurations such as truncated cones and polyhedrons, either singly or in series may be employed.

FIGURE 4 is a schematic representation of a further refinement of the apparatus of the type illustrated in FIGURE 3. A cylindrical electrode **15** bearing a substantial positive charge is positioned concentrically above a smaller cylindrical collector **16** which extends a short distance into the lower end of the electrode **15**. As the differentially charged materials pass through the apparatus represented by FIGURE 4, those particles which are charged positively are concentrated near the center of the electrode and tend to pass into the separator **16**, whereas the materials of opposite sign pass through annular opening **17** between the electrode **15** and the separator **16** for separate collection.

In conventional free fall electrostatic separations between stationary electrodes as represented by FIGURE 1, the field established between the differentially charged electrodes is substantially uniform when the electrodes are of essentially the same configuration. In certain types of stationary electrode electrostatic separators of the prior art and in roll type separators where one of the electrodes is substantially smaller or of different configuration than the other, the field established between the electrodes is non-uniform. The prior art, however, has made no significant or practical utilization of non-uniform electrostatic fields to effect the separation of particulate materials. Accordingly, one embodiment of the present invention contemplates the separation of differentially charged particulate materials in a non-uniform field established by imparting a significant charge to a single electrode structure.

Referring for purposes of illustration to the electrode structures schematically illustrated by FIGURES 2, 3 and 4, it will be appreciated that electrostatic fields exist between the exterior of such structures and ground. The gradient of such fields is non-uniform and increases in intensity as the electrode structure is approached. The present invention contemplates, in an embodiment of particular significance, the separation of mixtures of differentially charged particulate materials by passage through such non-uniform fields created by charged single electrode structures.

Obviously neither a pair of spaced electrodes, as shown in FIGURE 2, nor a tubular electrode as shown in FIGURES 3 and 4 is essential to that embodiment of the invention in which a non-uniform field is utilized. A single element of any desired configuration such as a sheet, sphere, or irregularly shaped body can be utilized. The expression "single electrode structure" is accordingly used in this specification in a generic sense to embrace any electrode system charged either positively or negatively regardless of the configuration, number and arrangement of individual elements of which such a system may be composed. Accordingly, a single electrode structure may be effective to produce a non-uniform field as well as a field such as that utilized in the schematic illustrations constituting FIGURES 2, 3 and 4, or, particularly if comprised of a single element, effective to produce a non-uniform field only.

Inasmuch as non-uniform fields appropriate for the practice of the invention may effectively be established by imparting a proper charge to an electrode structure comprising only a single element, of any configuration, it is apparent that various types of standard apparatus may be suitably charged and utilized as electrodes. One preferred embodiment of the invention, which utilizes a conventional vibrating feeder as an electrode, is schematically represented by FIGURE 5. The arrangement represented by FIGURE 5 includes a means **18**, for uniformly feeding the particulate mixture **19** onto the charged metal tray **20** of a conventional vibratory feeder **21** which is supported on insulation means **22**. The electrostatic field pattern at the edge **23** of the tray **20** is that of a conducting sharp edge as schematically represented by FIGURE 6 from which it is apparent that the field gradient increases as the edge **23** is approached. Accordingly, the particulate materials, which become differentially charged, inter alia, by contact electrification prior to reaching the edge **23**, are discharged from the tray **20** into an electrostatic field of force inclined from the horizontal. Particles of the same sign as the tray **20** are repelled at the edge **23**, whereas particles of opposite sign are attracted, and may be separately collected in the various pans of the collector **24**. The attracted particles having a sign opposite that of the tray **20** tend to travel along the bottom thereof after discharge from the edge **23**. Wiping means **25**, which may be either a conductor such as a metal, or a non-conductor, is provided to cause such attracted particles to fall into the collector **24**.

Another form of apparatus contemplated by the invention is shown in FIGURE 7. Such apparatus comprises a vibrating feeder **30**, hoppers **31** and **32** formed of insulating material such as polystyrene, the upper hopper **31** being open at the bottom and the lower hopper **32** being closed, and an electrode **33** positioned between the hoppers **31** and **32**. The electrode structure includes rods **34** formed of metal such as iron and a plurality of parallel spaced metallic wires **35** extending between the rods **34**. Positioned below the lower hopper **32** is an insulated tray 36. The entire apparatus is insulated from the ground.

In analogous manner there may be utilized as an electrostatic separator in accordance with the invention a continuous, charged, horizontal belt. In such an arrangement, the particulate mixture to be separated is distributed near one end of the moving belt and is discharged at the opposite end. The materials which are of the same sign as the belt are repelled at the point of discharge, whereas the materials of like sign are attracted to achieve the desired separation.

The invention embraces separation of particulate mixtures of all types which can be differentially charged including, without limitation, mixtures of conductors of any degree of conductivity, mixtures of conductors and non-conductors, and mixtures of non-conductors. More specifically, the invention contemplates the separation of natural and artificial mixtures of particulate organic and inorganic materials of all types including elements, chemical compounds and natural and artificial mixtures thereof. By way of example, mixtures of metals such as particulate iron, aluminum, copper, zinc, brass, tin, lead, and the like are separated pursuant to the invention. Likewise, mixtures of metals with non-metals such as carbon, silicon, organic and inorganic compounds and minerals are separated by the invention. Typical mixtures of inorganic compounds include the various possible combinations of potassium chloride, iodide, bromide and fluoride with like compounds of the other alkali metals and alkaline earth metals, including calcium, barium and strontium chloride, bromide, iodide and fluoride and the various hydrates thereof. Analogously, the invention is useful to separate all mineral mixtures including natural and synthetic mixtures of silicate and non-silicate, metallic and non-metallic minerals. Specific mineral mixtures which may be so separated include mixtures resulting from the comminution to liberation of all of the various minerals which are described in the treatise entitled "Taggart's Handbook of Mineral Dressing" (1945). It will accordingly be appreciated that the particulate mixture to be separated forms no essential part of the invention which contemplates, without limitation, the separation of all such mixtures.

The invention also generically contemplates that the components of the mineral mixture to be separated may be differentially charged, either to opposite sign or to a different degree to the same sign, by any method, including, without limitation, contact electrification, inductive conduction, electron spray, and the like. It is essential only that the particles to be separated be characterized by such differential charge at the point of separation. The manner by which such charge is achieved is not material insofar as the generic scope of the invention is concerned.

The art is replete with the various techniques for the pretreatment of minerals and other particulate mixtures prior to electrostatic separation, inter alia, to increase the magnitude of the differential charge which ultimately is imparted thereto. Such techniques include elevated temperatures, chemical reagentizing, various types of surface modification, and the like. This invention contemplates, without limitation, the separation of particulate mixtures which have been subjected to any desired pretreatment. More particularly, all of the various expedients which are effective to render prior art electrostatic separations of any type more efficient are contemplated for use in conjunction with the present invention.

Those skilled in the art will appreciate that particle size considerations applicable to prior art electrostatic separation techniques are also applicable to the present invention. Accordingly, the mesh sizes of the particles of the mixtures separated constitutes no essential feature of the present invention. In general, the efficiency of any electrostatic separation is a function of the mesh size of the particles and of the force in the electrostatic field to which the particles are subjected. Generally, it is preferred that the particles be no larger than about 4 mesh and preferably not larger than about 8 mesh. Similarly, it is preferred that fines constitute only a minor proportion of the mixture of materials to be separated. In the preferred practice of the invention, particles smaller than 200 mesh are removed from the feed material. In respect to minerals, comminuation to a degree requisite to achieve substantial liberation of the desired mineral component affords a particulate mixture amendable to separation in accordance with the method of the invention. It is preferred, however, that such minerals be comminuted to liberation and be characterized by mesh size within the range from about 8 to 100 mesh.

The manner in which the particulate mixture to be separated is positioned in the effected field forms no essential part of the invention. For example, the material may be passed as freely falling bodies adjacent to a charged electrode structure as contemplated by the invention, or suspended by a liquid or gaseous fluid in the vicinity of such electrode structure in the manner contemplated, for example, by Le Baron 2,889,055. Similarly, the materials may be conveyed into the field by a roller, as in a roll separator.

It is contemplated that the single electrode structures utilized pursuant to the invention can be charged to any desired voltage requisite to achieve a desired separation. The only limiting factors are those inherent in the design of the apparatus. In general, positive or negative charges of from about 10,000 volts to the voltage at which air breaks down adjacent the charged electrode are preferred. A charge of at least about 15,000 volts, preferably from about 30,000 to about 250,000 volts is appropriate. The equipment with which the invention is concerned should be associated in all cases with an adequate isolation transformer.

The ensuing examples reflect the best mode, presently known for the practice of the invention:

EXAMPLE I

An apparatus corresponding to that schematically represented in FIGURE 5 was utilized to effect concentration of Florida pebble phosphate liberated by comminution to −14+100 mesh to provide a mixture consisting essentially of phosphate and silica particles containing 25.98 percent by weight BPL. The liberated phosphate was heated in an oven to about 350° F., fed at a constant rate into a commercial Syntron vibrating feeder, Typer FOO Style 1970 having a pan 8 inches wide and 12 inches long, positioned in a substantially horizontal position, vibrated at a frequency of several cycles per second and charged positively to an indicated 30,000 volts, the entire system being isolated from external circuitry by an isolation transformer. In the course of passage onto and over the feeder, the phosphate and silica particles are differentially charged, inter alia, by contact electrification. The discharge from the vibrating feeder was collected in a series of 6 contiguous pans, each approximately two inches in width, positioned about twelve inches below the discharge edge of the feeder in the manner schematically indicated in FIGURE 5.

The analysis of the products collected in the pans was as follows:

Pan 1—153 gr. 1.70% wt. BPL
Pan 2—606 gr. 6.10% wt. BPL
Pan 3—335 gr. 47.51% wt. BPL
Pan 4—103 gr. 69.4% wt. BPL
Pan 5–Pan 6—30 gr. 74.43% wt. BPL

EXAMPLE II

Example I was repeated utilizing spodumene ore analyzing 1.399% by weight Li_2O, reagentized with oleic acid, and heated to 350° F. Concentrate of 58 grams analyzed 1.66% by weight Li_2O, and the tail of 191 grams analyzed 0.431% by weight Li_2O.

EXAMPLE III

Example I was repeated with the exception that the feeder was charged negatively to 30,000 indicated volts and a mixture particulate heavy minerals heated to 350° F. was separated. The quantity and analysis of the feed material utilized and of the various fractions collected are reported in Table I.

Table I

Sample No.	Sample weight	Weight per-cent ilmen-ite	Weight per-cent leu-coxene	Weight per-cent zircon	Weight per-cent rutile	Weight per-cent phos-phate	Weight per-cent others
Pan 1	32.0	27	1½	11	2½	32½	25½
Pan 2	247.0	44½	1	22½	6½	5	21
Pan 3	171.0	34½	2	42½	5	1	15
Pan 4	12.0	15½	1½	73	4	1	6
Pan 5	2.0	15½	½	66	5½	2½	10
Calc. head	464.0	38½	1½	30½	5½	5½	18½

EXAMPLE IV

Example III was repeated with the exception that the vibrating feeder was charged positively to 30,000 indicated volts. The weight and analysis of the feed material and the various collected fractions are reported in Table II.

Table II

Sample No.	Sample weight	Weight per-cent ilmen-ite	Weight per-cent leu-coxene	Weight per-cent zircon	Weight per-cent rutile	Weight per-cent phos-phate	Weight per-cent others
Pan 1+	39.0	17	½	72½	2½	1½	6
Pan 2+	296.0	37	2½	24½	5½	4½	26
Pan 3+	102.0	28½	1½	14½	2½	19	35
Pan 4+	11.0	15	--------	7½	3½	63	11
Calc. head	448.0	33	2	26	4½	9	25½

EXAMPLE V

Example I was repeated with the exception that —100 mesh (Tyler) phosphate rock fines produced by passing the liberated phosphate ore described in Example I twice through a Braun Pulverizer were heated to 325° F. and passed through the apparatus. A concentrate analyzing 34.26% BPL and a tail analyzing 17.46% BPL were collected.

EXAMPLE VI

The vibrating feeder of the apparatus described in Example I was charged negatively to an indicated 30,000 volts. Potash ore containing primarily potassium and sodium chloride and analyzing 15.26% by weight K_2O was ground to —20 mesh, heated to about 845° F. in a muffle furnace for one hour, and passed through the apparatus to provide a concentrate analyzing 19% by weight K_2O and a tail analyzing 13.3% by weight K_2O.

EXAMPLE VII

The apparatus as described in Example I was utilized charged positively to an indicated 30,000 volts. There was employed as a feed material a mixture of equal parts by weight of chemically pure potassium chloride and sodium chloride containing 31.5% by weight K_2O and heated to 325° F. in an oven. The concentrate contained 46% by weight K_2O and the tail 14.3% by weight K_2O.

When the procedure was repeated with an indicated negative 30,000 volt charge on the vibrating feeder, the concentrate analyzed 51.2% by weight K_2O and the tail 31.47% by weight K_2O.

EXAMPLE VIII

Example VI was repeated utilizing as a head feed a

mixture of equal parts by weight of potassium chloride and barium chloride dihydrate heated to about 191° F. and containing 38.68% by weight K_2O. With the apparatus charged positively, the concentrate analyzed 53.2% by weight K_2O, whereas the tail analyzed 39.4% by weight K_2O. With the apparatus charged negatively, the concentrate analyzed 45.5% by weight K_2O and the tail 29.3% by weight K_2O.

EXAMPLE IX

Example I was repeated with the exception that the vibrating feeder was negatively charged to an indicated 30,000 volts, and was utilized to separate a mixture of equal parts by weight of chemically pure potassium iodide and sodium chloride heated to 350° F. prior to separation. The feed material analyzed 14.2% by weight K_2O, the concentrate 18% by weight K_2O and the tail 3.07% by weight K_2O.

EXAMPLE X

Example I was repeated with a feed material comprising a mixture of equal parts by weight of potassium sulfate and sodium chloride containing 34.5% by weight chloride and heated to 350° F. The concentrate analyzed 64% by weight potassium sulfate, whereas the tail analyzed 19% by weight potassium sulfate.

Repetition of the procedure with a mixture of equal parts by weight of potassium iodide and barium chloride dihydrate heated to about 191° F. prior to separation yielded a concentrate analyzing 12.83% by weight K_2O and a tail analyzing 4.5% by weight K_2O.

EXAMPLE XI

Finnish apatite was comminuted in a hammer mill and screened to remove +35 mesh material consisting mostly of mica. The —35 mesh material, which analyzed 13.9% BPL was heated to 350° F. and passed through the apparatus as described in Example I with the vibrating feeder charged positively to an indicated 30,000 volts to produce a concentrate analyzing 20.2% BPL and a tail analyzing 7.92% BPL.

EXAMPLE XII

Example I was repeated with the exception that the vibrating feeder was charged positively to an indicated 30,000 volts and impure mustard seed containing rat feces heated to a temperature of 212° F. for one half hour was processed.

The feed contained 2.59% by weight impurities, the concentrate 0.78% by weight impurities and the tail 3.42% by weight impurities.

EXAMPLE XIII

Example XII was repeated with the exception that a mixture of equal parts by weight of d-glutamic acid and l-glutamic acid heated to a temperature of about 202° F. for one half hour was processed. The concentrate contained 73% by weight l-glutamic acid and 27% by weight d-glutamic acid.

EXAMPLE XIV

Florida pebble phosphate comminuted to —14+100 mesh (Tyler) was heated to a temperature within the range from about 250° F. to 350° F., differentially charged by contact electrification, and passed between two aluminum electrodes each approximately 24 inches long, 7½ inches wide, and 1/16 inch thick, spaced about 6 inches apart and hinged at the top. The electrodes were each charged with approximately 10,000 to 15,000 volts positively. The feed material analyzed 25.98% BPL, the concentrate 35% BPL, and the tail 0.96% BPL.

EXAMPLE XV

Example XIV was repeated with the exception that the electrode structure utilized took the form of an 8½ inch square tube approximately three feet long. The feed material analyzed 25.98% BPL, the concentrate 28%

BPL, and the tail 15% BPL. Comparable results are obtained with round tubes, rectangular and truncated cones and polyhedrons, both individually and in series.

EXAMPLE XVI

This example reflects the separation of a phosphate ore with the apparatus as shown in FIGURE 7.

The electrode was charged to 125,000 volts positively. A feed material comprising a phosphate ore containing 25.98% BPL was utilized, preheated to a temperature in excess of 150° F. The feed material was discharged from the vibrating feeder 30 into the upper hopper 31 and passed downwardly under the force of gravity through the electrostatic field created adjacent the electrode 33. The tail was collected in the closed hopper 32 at the bottom of the electrode, whereas the concentrate was collected in the insulated tray 36. The concentrate contained 41.32% BPL and the tail 5.59% BPL. The electrode 33 is so constructed and arranged as to take advantage of the concentration of the electrostatic field adjacent each of the wires 35.

The foregoing examples are illustrative of the fact that the present invention is applicable without limitation in respect to feed material, feed material pre-treatment, electrode configuration, and the like; hence further exemplification is deemed unnecessary. The scope of the invention is defined only by the appended claims.

This application is a continuation-in-part of my copending application Serial No. 54,172, now abandoned, entitled "Electrostatic Separation," filed September 6, 1960.

I claim:

1. A process for separating a mixture of particulate materials which comprises imparting a substantial electrical charge of a single sign to a single electrode structure to establish a non-uniform electrostatic field the gradient of which increases as said electrode structure is approached, imparting a differential charge to the particulate materials to be separated from said mixture, introducing said mixture of differentially charged materials into said non-uniform field to cause the particles of said materials charged to the sign opposite that of said structure to be attracted toward said structure and the particles of said materials charged to the same sign as said electrode structure to be repelled therefrom, and separately collecting said attracted and repelled particles.

2. The process of claim 1 wherein said electrode structure is charged positively.

3. The process of claim 1 wherein said electrode structure is charged negatively.

4. The process of claim 1 wherein said mixture of particulate materials is a mixture of inorganic chemical compounds.

5. The process of claim 1 wherein said mixture of particulate materials is a mixture of organic chemical compounds.

6. The process of claim 1 wherein said mixture of particulate materials is obtained by the comminution of an ore to liberation to provide a mixture of mineral and gangue particles.

7. The process of claim 6 wherein said mineral is a non-metallic mineral.

8. The process of claim 6 wherein said mineral is a metallic mineral.

9. The process of claim 6 wherein said ore is a phosphate ore.

10. The process of claim 6 wherein said ore is a potash ore.

11. The process of claim 1 wherein said non-uniform field into which said differentially charged materials are introduced is inclined with respect to the horizontal.

12. The process of claim 1 wherein a charge of at least about 15,000 volts is imparted to said single electrode structure.

13. Apparatus for the electrostatic separation of particulate materials which comprises a vibratory feeder bearing a substantial charge of a single sign, said charge establishing a non-uniform field surrounding the discharge edge of said feeder, the gradient of said field increasing as said discharge edge is approached, means for depositing the particulate materials to be separated on said feeder and means for separately collecting the materials which are repelled from and attracted from said feeder upon discharge therefrom.

14. A process for separating a mixture of particulate materials which comprises imparting a substantial electrical charge of a single polarity to a horizontal single electrode structure having a discharge edge to establish a non-uniform electrostatic field the gradient of which increases as said edge is approached, introducing a mixture of particulate material to be separated into contact with said electrode structure, vibrating said electrode structure whereby the particles of said materials are differentially charged by contact electrification and the differentially charged particles are moved across said electrode structure to discharge from said discharge edge, said materials charged to the polarity opposite that of said structure being attracted toward said structure and the particles of said materials charged to the same polarity as said electrode structure being repelled therefrom, and separately collecting said attracted and repelled particles.

15. A process for separating a mixture of particulate materials which comprises imparting a substantial electrical charge of a single polarity to a spaced pair of stationary electrodes to establish a non-uniform electrostatic field between said spaced electrodes, imparting a differential charge to the particulate materials to be separated, introducing said mixture of differentially charged materials into said non-uniform field to cause the particles of said materials charged to the polarity opposite that of said electrodes to be attracted toward each of said electrodes and the particles of said materials charged to the same polarity as said structure to be moved toward the center of the space between said electrodes and separately collecting the oppositely charged particles.

16. A process for separating a mixture of particulate materials which comprises imparting a substantial electrical charge of a single polarity to an enclosing periphery of a central area to establish a non-uniform electrostatic field which converges from said enclosing periphery to said central area, imparting a differential charge to the particulate materials to be separated, introducing said mixture of differentially charged materials into said non-uniform field to cause the particles of said materials charged to the polarity opposite that of said periphery to be attracted toward said periphery and the particles of said materials charged to the same polarity as said periphery to be moved toward the central area and separately collecting the oppositely charged particles.

17. Apparatus for electrostatically separating mixtures of particulate material which comprises a single electrode structure, means for applying a substantial charge of a single polarity to said structure to establish a non-uniform electrostatic field about said structure, the gradient of said field increasing as said structure is approached, means for differentially charging the particulate materials, means for passing said mixture of differentially charged particulate materials into said field and means for separately collecting materials attracted toward and repelled from said electrode structure.

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