March 30, 1943. G. W. HEWITT 2,314,940

ELECTROSTATIC ORE CONCENTRATION

Filed Oct. 30, 1940 3 Sheets-Sheet 1

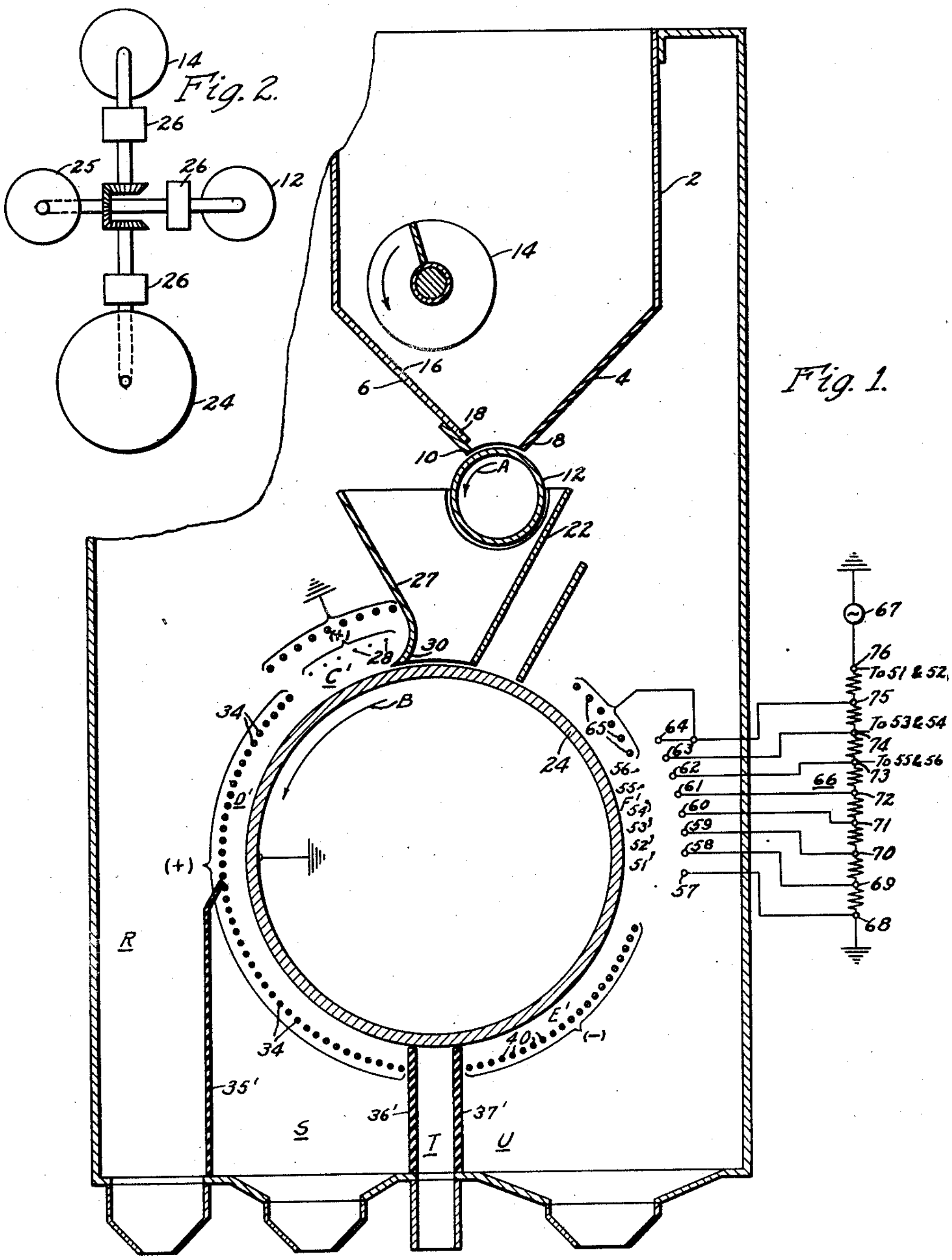

Fig. 2.

Fig. 1.

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ELECTROSTATIC ORE CONCENTRATION

Filed Oct. 30, 1940 3 Sheets-Sheet 2

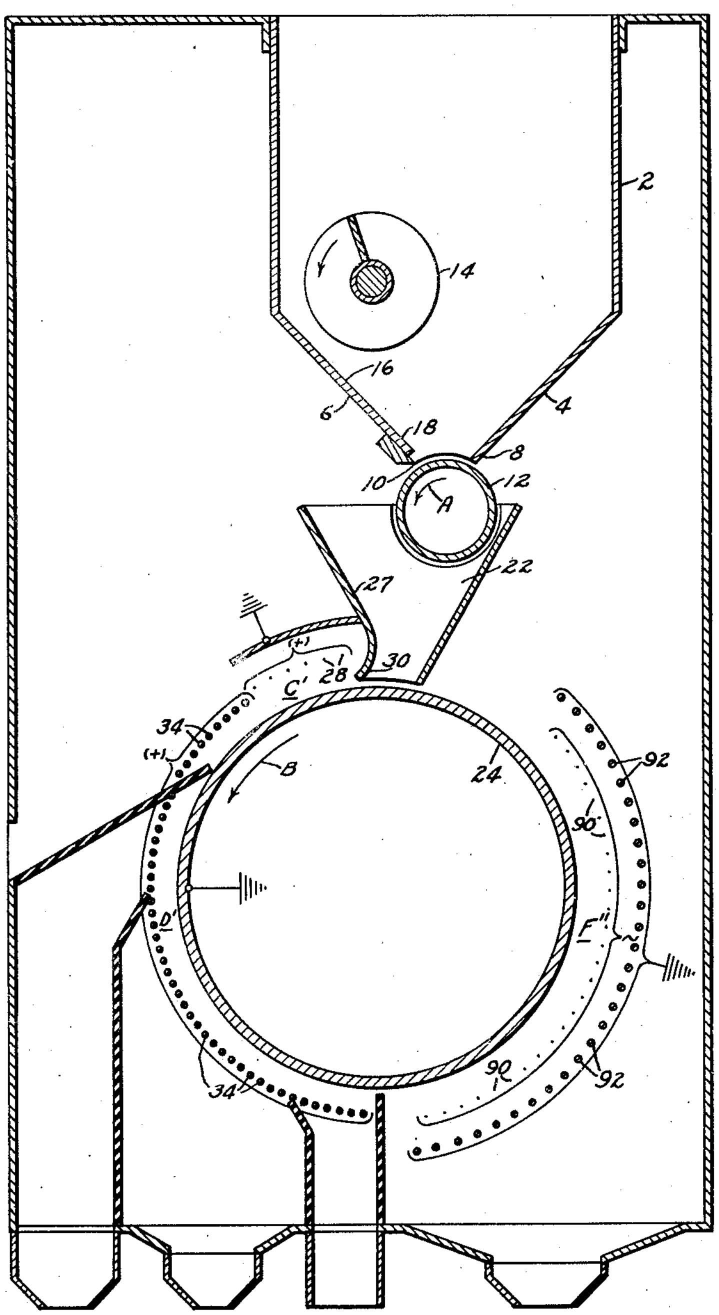

Fig. 3.

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ELECTROSTATIC ORE CONCENTRATION

Filed Oct. 30, 1940 3 Sheets-Sheet 3

Fig. 4.

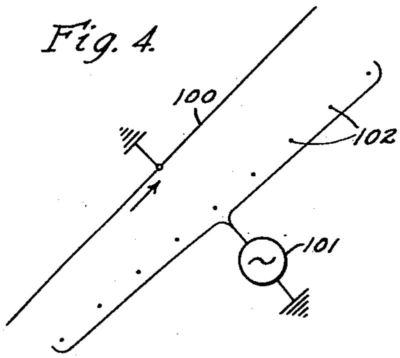


Fig. 5.

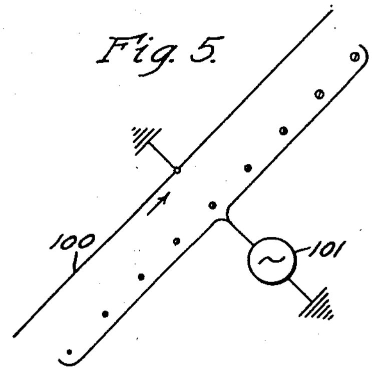


Fig. 6.

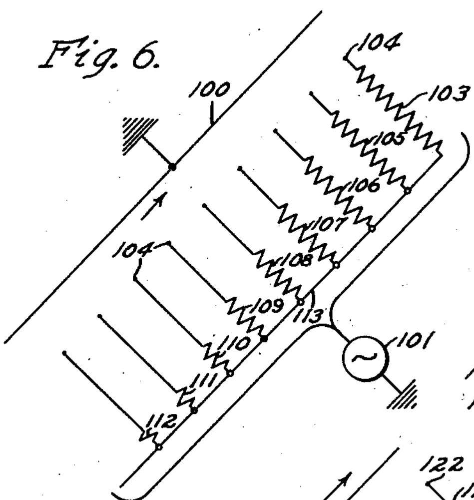


Fig. 7.

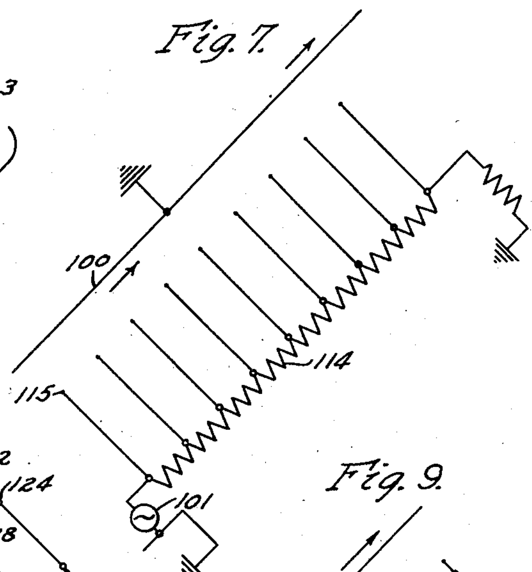


Fig. 8.

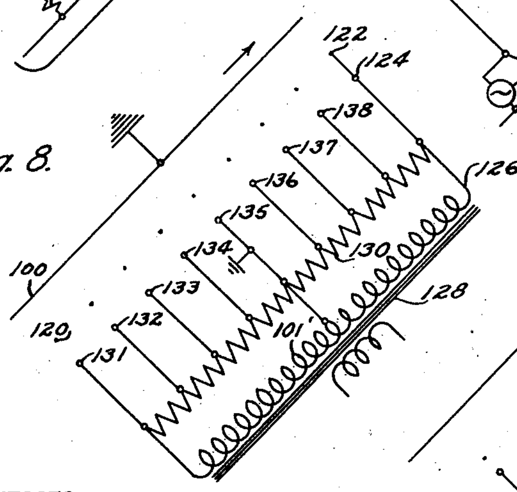
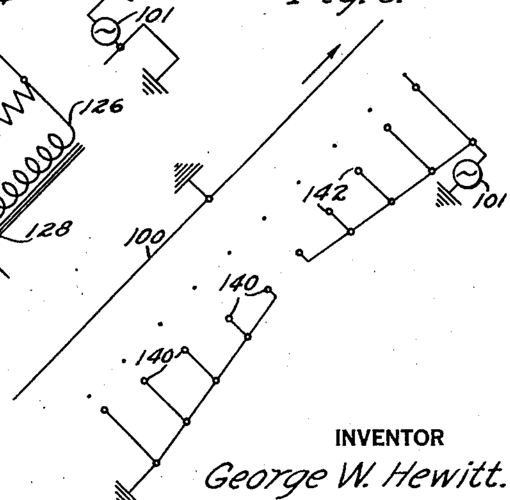


Fig. 9.



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Patented Mar. 30, 1943 2,314,940

UNITED STATES PATENT OFFICE

2,314,940

ELECTROSTATIC ORE-CONCENTRATION

George W. Hewitt, Forest Hills, Pa., assignor to Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa., a corporation of Pennsylvania

Application October 30, 1940, Serial No. 363,444

12 Claims. (Cl. 209—127)

This invention relates generally to means and methods for separating particles of certain physical characteristics from a mass of aggregated particles having similar physical characteristics but to different degrees, and, more particularly, relates to electrical apparatus for electrostatically beneficiating a finely divided or pulverized low-grade or lean metal-bearing ore.

It is an object of my invention to provide a practical low-cost electrostatic ore-treating device having small space requirements but having high ore-treating capacity together with exceptional operating efficiency for separating metal-bearing ore-particles from the intermixed gangue to the end that a commercially useable higher quality ore can be cheaply obtained from lower grade ores.

My invention hereinafter described is related to or in the nature of an improvement over the invention shown and claimed in the copending joint application of G. W. Penney and myself, Serial No. 363,443, filed concurrently herewith, and assigned to the same assignee as this application. The instant application has among its objects, features, and purposes many of the objects, features and purposes of the joint application.

In the specific forms of the invention described in the joint application a thin layer of ore particles is continuously fed to the top of a conducting cylindrical drum revolving about its horizontally disposed axis. The particles of the layer are substantially immediately subjected to an intense relatively extended ionized electrostatic field for charging the particles, the field being established between electrodes comprising a plurality of spaced ionizing wires and the drum, the wires being concentrically arranged about a portion of the drum for producing an extended, substantially uniform, dense field. In this region the particles, both those of relatively high resistivity and those of relatively low resistivity, are highly charged by the ion currents in the field and are attracted to the drum surface by the electrostatic forces produced. The layer of charged particles then passes into a non-ionized electrostatic field produced between extended non-discharging electrodes and the drum. This field has a high voltage gradient at the drum surface with substantially negligible ion current, and a general direction with respect to the surface of the drum which is the same as that of the ionized field, resulting in electrostatic forces on the charged particles on the drum which are in a direction tending to hold them on or repel them toward the drum surface. Charged particles tend to lose their charges by conduction to the grounded drum, the rate of loss of charge being dependent upon the resistivity of the particles and, consequently, in this second region the electric forces tending to hold or repel them to the drum diminish. Other things being equal, the higher the resistivity of the particles, the slower their rate of discharge and the longer the electrostatic forces persist with sufficient strength to hold such particles on the drum surface; and conversely, the lower the resistivity of the particles the higher the rate of discharge and the more rapidly the electrostatic force on them weakens. Ultimately a point is reached where either centrifugal forces or gravitational forces, or both, prevail over the electric forces, causing the particles to leave the drum. Accordingly, a good separation of particles of relatively lower resistivity is effected before the layer leaves this second region.

The two zones or regions above described together extend through about 180°, although they may extend through greater or lesser angles, and the remaining region about the treating drum is provided with means for removing any particles that still cling to the drum surface, these particles being for the most part particles of the higher resistivities. Still confined to the specific embodiments shown in the joint application, this subsequent region for removing the particles still on the drum comprises means for producing two electrostatic fields; the first, a unidirectional electrostatic field somewhat similar to that of the second region, but having a generally opposite direction to produce an opposite effect on the charged particles, that is, to produce a force on the charged particles tending to cause them to leave the drum; and the second, an ionized electrostatic field for neutralizing or counteracting the charge on the particles which still cling to the drum so that no electric forces act on these particles, thereby enabling mechanical forces to act on the particles for removing the particles from the drum before they are rotated back to the point of particle-feed.

My invention comprises an ore-concentrator having means in this last region for neutralizing or counteracting to proper degrees the charge on particles of some ores which tend to tenaciously stick to the drum subsequent to treatment in the first two regions, these particles usually being very fine particles of high resistivity such as extremely fine quartz or silica grains. These particles are very difficut to remove and stick to the drum even while subjected in the third region to the unidirectional electrostatic field described in the joint application for producing electric forces tending to pull them away from the drum, and to centrifugal forces and perhaps gravitational forces also tending to cause the particles to leave the drum. Unless such particles are removed they are continuously carried around with the drum, sticking on the drum surface and coating it with an insulating layer which decreases the efficiency of the ore-concentrator.

It is an object of my invention to provide an ore-concentrator for beneficiating ore, which concentrator has a rotary endless conveyor whose surface will at all times be maintained clean at the point of particle-feed.

It is an object of my invention to provide an ore-concentrator for beneficiating ore, having a cylindrical treating drum whose surface can be kept clean without increasing its speed of rotation beyond values adversely affecting the ore-treatment.

It is a general object of my invention to provide a means for discharging insulating surfaces which are electrically charged.

It is another general object of my invention to provide a means for cleaning dust or other particles adhering to a moving conveyor or belt or the like, because of electrical charges.

Many other objects, features, and advantages of my invention will be apparent from the following description thereof which is to be taken in connection with the drawings, in which similar reference characters indicate similar parts, and in which:

Figure 1 is a schematic vertical cross-sectional view of an electrostatic ore-concentrator embodying my invention;

Fig. 2 is a schematic view on a decreased scale of a driving means for rotating the parts of the ore-concentrator;

Fig. 3 is a view similar to Fig. 1 of a modified form of electrostatic ore-concentrator embodying my invention; and

Figs. 4 through 9 are developed partial views of modified forms of different means for producing attenuated ionized alternating fields for neutralizing or counteracting the charges on particles adhering to the drum after the separation of the relatively low resistivity particles.

Referring more particularly to the drawings, the finely divided or pulverized ore to be beneficiated is dumped or continuously fed into a storage hopper 2 having slanting bottom sides 4 and 6, slanting towards each other to provide an elongated rectangular discharge opening having lengthwise sides which are bounded by lower edges 8 and 10 of the bottom sides 4 and 6, respectively, these edges terminating close to a rotatably cylindrical feeding drum 12 of about four inches in diameter, for moving ore particles away from the discharge opening of the hopper. A rotating spiral agitator 14, within the hopper, and rotatably mounted in the ends of the hopper, agitates the ore particles to insure a steady and continuous flow to the feeding drum. The feeding drum 12 is somewhat longer than the discharge opening and its direction of rotation, as indicated by the arrow A, is such that the lower edge 10 of the bottom side 6 defines the trailing edge of the discharge opening.

The quantity of ore particles fed by the feeding drum 12 is determined by the speed of the feeding drum, which is adjustable, and the distance of the edge 10 from the feeding drum; the bottom side 6 being constructed so that this distance is also adjustable. To this end the bottom side 6 comprises an upper fixed member 16 terminating a relatively long distance from the feeding drum, and a lower slidable gate-plate 18, which includes the lower edge 10, extending across the length of the member 16 and adjustably positionable so that the lower edge 10 can be spaced any desired distance from the feeding drum.

The layer of mixed ore particles which is continuously fed by the feeding drum 12 falls through a guiding trough 22, which confines the spread of the layer, onto the surface of a grounded rotatable cylindrical treating drum 24 of about 12½ inches in diameter, and which rotates, in this case, in the same direction as the feeding drum, as indicated by the arrow B. The feeding drum 12, the agitator 14, and the treating drum 24 are preferably driven from a single power drive, such as a motor 25, through any common adjustable gearing 26 which permits their rotational velocities to be individually adjusted and relatively controlled. The thickness of the ore-particle layer on the drum 24 can be further controlled by controlling the relative speeds of the feeding and treating drums.

The treating drum 24 has a highly conducting outer surface which is obtained by making the treating drum in the form of a hollow metal tube, although an outer cloth belt with its surface treated with a liquid containing colloidal graphite to render the surface highly conducting has been successfully used. The other parts of the device thus far shown and described are also preferably made of metal and electrically grounded.

The guiding trough 22 has a spout shorter than the treating drum 24 located at the top of the drum, spanning only a few degrees of its periphery and immediately following the trailing side 27 of the guiding trough is an ionizing zone C′ for charging the ore particles fed on the drum 24.

In the embodiment shown in Fig. 1, this ionizing zone C′ starts at about 9° counter-clockwise from the vertical which is hereinafter assumed to be the reference line, and includes a plurality, in this case six, of relatively small ionizing wires 28 spaced 4½° apart along an arc concentric with, and about one inch from, the surface of the drum 24. 4½ mil tungsten wires have been found to be suitable, although other wires and other sizes can be used. The wires are conductively connected together and insulated from ground in any suitable way, and connected to the positive terminal of a source of unidirectional potential having its other terminal grounded, so that an ionized electrostatic field is established in conjunction with the grounded part of the drum within the angle subtended by the ionizing wires which constitute ionizing electrodes.

In order to dispose the ionizing zone C′ close to the depositing point of the ore particles on the drum 24, the trailing side 27 is curved concave toward the zone so that the leading end of the arc of the wires 28 can be disposed over the lower trailing edge 30 of the side 27 and still be sufficiently well insulated from the side 27 to prevent flashover and undue current leakage.

It is desirable to have the ionization in the zone C′ dense and uniform on the surface of the drum 24 and to this end the ionizing wires are backed by a plurality of grounded spaced 63 mil copper wires one inch away, the wires beginning at the guiding trough 22. These copper wires comprise a field-modifying means which causes more uniform ion current distribution on the surface of the drum and an increased ion current density. In the embodiment shown in Fig. 3, an extended curved ground plate produces a similar effect.

The ionizing zone C' is followed by a particle-separating zone D', the two zones merging into one another and together occupying about the entire half-circle, more or less, through which the drum surface has a downward component of motion. This zone D' includes a plurality of 63 mil copper wires 34 spaced about three degrees apart circumferentially. The wires 34 form an insulating series of electrodes, each having a relatively large diameter so that a high gradient can be produced without the generation of any significant amount of ions. This means that the electrodes are of the non-discharging type and produce a substantially non-ionized field. The wires are spaced in an arc concentric with the surface of the drum and about ¾ inch from it, the wires being conductively connected together and insulated from ground in any suitable manner, and connected to a positive terminal of a unidirectional voltage supply whose other terminal is grounded. The polarity of the non-discharging electrodes 34 is the same as that of the ionizing electrodes or wires 28, and in conjunction with the drum 24 create a substantially non-ionized electrostatic field in the particle-separating zone D'.

In the operation of the apparatus thus far described, ore particles of appropriate size are fed through the discharge opening of the storage hopper 2 onto the feeding drum 12. The speed of the treating drum 24 is primarily determined by the size and electrical characteristics of the particles, and is preferably adjusted to as high a value as is consistent with the desired quality of ore-beneficiation. The rate of feed of ore particles to the drum 24 can be controlled by the position of the edge 10 and the speed of the feeding drum 12.

The particles fed on the drum 24 have different resistivities, but all of the particles will be charged in the ionizing or charging zone C' since they are continuously bombarded with ions, or the equivalent, during the time they pass through the zone. The particles being charged with respect to ground tend to adhere to the grounded drum. However, when the bombardment of the particles ceases and even during the bombardment, the charge on the particles is gradually being conducted to the drum 24, the rate of leakage being a function of the resistivity of the individual particles and the voltage gradient of the electrostatic field through which they pass. The electrostatic forces causing the particles to adhere to the drum decrease with leakage of charge from the particles, these forces being primarily the attractive force between a charged particle and the drum, and the repellant force between a charged particle and the electrodes 34 which have a polarity of the same sign as the original charge on the particle. A point is soon reached when particles of low resisitivity leave the drum 24 through the action of centrifugal or gravitational forces, or both, and particles on the drum which become charged by conduction with a charge of a polarity opposite that of the original charge are acted upon by electrostatic forces which encourage the separating action of these particles. The separated particles can be collected in any suitable receptacles or other collecting means, any desired number of insulating partitions or baffles such as 35', 36' and 37' terminating near the drum or the electrodes, serving to confine the particles within the spaces defined by them, and acting as dividing partitions for segregating the particles falling in the bins R, S, T and U.

However, high resistivity particles do not lose their charges as rapidly as particles of relatively lower resistivity and the charges they retain create electrostatic forces causing them to adhere, more or less, to the drum as they rotate therewith. The relatively most conducting particles discharge most rapidly by conduction to the drum and leave the drum first, while those having relatively higher resistivity will not be sufficiently discharged until farther points along the arc of rotation are reached. As the particles separate from the drum they can be collected in the separate bins, it being understood that as many bins can be provided as desired, and that the partitions may be spaced apart differently.

For the highest degree of separation, the insulating particles or gangue should be carried around on the drum beyond the separating zone D', and in order to remove such particles a third particle-pull-off zone E' is provided which includes insulated non-discharging electrodes 40 of the same construction and arrangement as those in zone D', but connected to a voltage supply so as to be at a polarity opposite to that of the electrodes 34 and the charge retained by the high-resistivity particles. In the specific embodiment being described, the zone E' extends from about 195° to 261°, although this zone may be extended farther to as much as almost 360°, in such case being the last treating zone of the device. The zone E', accordingly, has a non-ionized electrostatic field which tends to counteract the effect of the charge on the particles on the drum and to establish on the particles remaining on the drum an attracting force toward the electrodes 40 so that they will be pulled off the drum.

The features thus far described constitute a portion of the invention of the aforesaid joint application.

In the treatment of some ores, very fine particles of very high resistivity have been found still to stick to the drum after passing through zone E', so that I have found it desirable to provide, either in addition to zone E' or as a substitute for the zone E', a neutralizing or charge counteracting zone F' which includes discharging ionizing electrodes in the form of relatively fine wires similar in construction and arrangement to those of zone C', and connected to a potential which will establish an attenuated ionized field for neutralizing or counteracting the charge on these particles so that they will fly off the drum or may be easily brushed off.

In accordance with the embodiment shown in Fig. 1, this neutralizing zone F' augments the particle pull-off zone E', and includes six tungsten wires of 4½ mil size, providing ionizing electrodes 51 to 56, inclusive, spaced 4½° apart and and about one inch from the treating drum. A plurality of spaced 63 mil copper wire non-discharging electrodes 57–64, inclusive, is arranged in back of these ionizing electrodes, being in an arc spaced one inch from them. Following the ionizing electrodes in the same circle is a plurality of spaced non-discharging electrodes 65 of

63 mil copper wire. The ionizing electrodes of the zone F' are connected to be at gradually lower alternating current potentials in the direction of rotation of the drum, while the back-up electrodes are connected to further decrease the intensity of the ionized field in that direction so that the particles still on the drum in passing through this zone pass through an alternating ionized field of gradually decreasing strength for gradually neutralizing the charge on the particles to the point where they fly off the treating drum. For obtaining the desired potentials on the electrodes of the zone F', a potentiometer **66**, connected across an alternating-current voltage supply **67** and having nine taps separated by resistances of 5 megohms each can be utilized. The tap **68** is preferably grounded and is connected to the non-discharging electrode **57** while successive taps **69** through **75** are connected to the non-discharging electrodes **58** through **64**, respectively, the tap **75** also being connected to all of the non-discharging electrodes **65** which are, therefore, at the same potential.

The ionizing electrodes **51** and **52** are at the highest potential with respect to ground and connect to the tap **76**, the ionizing electrodes **53** and **54** being connected to the tap **74**, and the ionizing electrodes **55** and **56** to the tap **73**.

In the operation of the neutralizing system shown in Fig. 1, the ionizing electrode **51** is at the relatively highest potential and the associated non-discharging electrodes in back of it at the relatively lowest potential so that the ionized alternating field toward the grounded treating drum is relatively strongest. However, in the direction of the rotation of the drum the potentials of the ionizing electrodes gradually decrease, while the potentials of the associated back-up electrodes approach those of the ionizing electrodes so that their aiding effect on the field is gradually changed to a shielding effect, weakening the intensity of the field. This produces a gradually weaker ionized field in the zone F' in the direction of rotation of the drum.

In the embodiment shown in Fig. 3, the zone F'' is similar to the zone F' in its function, but in this embodiment the particle-pull of zone E' has been omitted, the zone F'' extending from the termination of the zone D' through the lower right-hand quadrant of the path of movement of the drum and into a good part of the upper right-hand quadrant. This ionizing zone F'' comprises a plurality of ionizing wires **90**, similar to the other ionizing wires, which are backed up by a plurality of non-discharging electrodes **92** for influencing the ionization over the surface of the drum. A similar arrangement of electrodes for a similar zone but of much smaller extent is shown in the aforesaid joint application.

The ionizing electrodes of the neutralizing zones of both embodiments are preferably energized by an alternating-current voltage source having a frequency high enough to cause, in effect, several reversals of the charge on the particle during the time the particle is in the neutralizing ionized zone, but should be low enough to prevent neutralization of the opposite ion streams before they reach the particles. This frequency, of course, has a relation to the speed of rotation of the drum. Thus, for example, if the drum should be rotating at 360 R. P. M. or 6 revolutions per second, a particle will take $^1/_{18}$ of a second to travel through 120°. If a 60 cycle source is utilized to energize the ionizing electrodes **90** of Fig. 3, a particle will be acted upon by an alternating ionized field alternating through a fraction over three cycles. Generally it is more desirable to subject the particles to a greater number of cycles and a source having a frequency of about 500 cycles is satisfactory. With the attenuated field shown in Fig. 1, the possible maximum charge which the particle might have at the trailing end of the zone is low because of the field attenuation, but in both embodiments I believe that the particles leave the drum because the electrical forces tending to cause them to adhere to the drum are decreased, the forces becoming sufficiently low at some time during the movement of the particle through the neutralizing zone or perhaps toward the end of the zone.

In the embodiment shown in Fig. 3, the back-up electrodes **92** are grounded, but all or part of the electrodes of zone F'' may be so energized as to provide an attentuated alternating ionized field.

The embodiment of Fig. 3 has certain advantages over the embodiment generally shown in Fig. 1 since one set of electrodes is eliminated, for, as described in the aforesaid joint application, the ionizing electrodes in the zone C' and the non-discharging electrodes in the zone D' are potentialized positively with respect to the drum, whereas the non-discharging electrodes of the zone E' are potentialized negatively. This requires that the electrodes of the zone E' be insulated from both the drum and the other electrodes, and that another source of voltage, or the equivalent, be employed. A further advantage of the embodiment shown in Fig. 3 resides in the much longer arc subtended by the neutralizing zone which permits a lower frequency alternating-current voltage source to be used, especially if the drum is rotated at a relatively low speed. Moreover, it has been found that the electrodes of the zone E' may accumulate dust deposits requiring means such as rappers or vibrators to jar the accumulations off.

There are many ways in which a neutralizing field with an attenuated ionization intensity can be obtained and utilized in the zone F', or even in the zone F'', if desired, and Figs. 4 through 9 are schematically representative of such different embodiments. In these figures the reference character **100** represents the portion of the surface of a drum, such as drum **24**, which is in the neutralizing zone, and the reference character **101** an alternating-current source.

In Fig. 4 the ionizing wires **102** are all connected to be at the same potential but are spaced in the direction of the movement of the drum, which is represented by the arrow, increasingly greater distances from the drum so that a particle moving through this field is subjected to an alternating ionized field of gradually weaker ionization intensity.

In the embodiment of Fig. 5, the same effect is produced with ionizing wires arranged substantially equidistant from the drum surface **100** but having gradually increasing diameters in the direction of movement of the drum surface; the attenuated field resulting from the fact that for a given voltage, intensity of ionization is decreased with increased diameter of ionizing wires.

It is also possible to use the same diameter-size ionizing wires spaced the same distance from the drum but energized with different potentials which may be obtained either by a potentiometer arrangement, such as shown in Figs. 1 and 7, or by the equivalent means, shown in Fig. 6, in which resistances of different values are inserted in the circuit to each ionizing wire, the largest resistor 103 being connected to the trailing ionizing wire 104, and resistors 105–112, of gradually decreasing resistances, being connected respectively to the wires successively preceding the wire 104. In the embodiment shown in Fig. 6, the source 101 is applied to bus bar 113, and the voltage difference between the grounded drum 100 and each of the wires 104 will be the voltage of the source less the voltage drop through the respective resistances due to the flow of ionizing current. The resistor 112 will have the lowest drop while the resistor 103 will have the largest drop, the intermediate resistors having intermediate voltage drops, depending on their resistance values. With the arrangement shown, an attentuated ionized field is produced of greatest strength at the ionizing wire connected to the resistor 112, and weakest strength at the wire 104 connected to the resistor 103. Instead of graduated resistors, graduated reactors can be substituted or used in conjunction with resistors.

In Fig. 7, the ionizing wires are of the same diameter-size, equidistant from the drum surface 100, and energized by being connected to taps of a potentiometer 114 in such manner that an ionized field of relatively highest intensity is produced by the leading wire 115, and of gradually weaker intensity by each successive wire in the direction of drum movement.

The effect of an attenuated field may also be obtained by varying the size, the shape or the distance of the field-modifying or screen electrodes behind the ionizing wires, and in Figs. 8 and 9 two forms are shown which are somewhat different than that shown in Fig. 1.

In these embodiments the influence of other electrodes placed near the ionizing wires is utilized to affect the ionization from the ionizing wires by controlling the voltage gradient at the wires, which gradient is affected by the size, shape, distance and potential of the influencing electrodes in the region near the wires. In the circuit shown in Fig. 8, the influence of the nearby non-discharging electrodes is used to decrease the ionization from the ionizing wires from a maximum at the first ionizing wire 120 to a minimum at the last ionizing wire 122. All the ionizing wires are operated at the same potential, which is the potential of the last non-discharging electrode 124 connected to the end 126 of the high-voltage winding 101′ of the transformer 128 across which is connected the potentiometer 130 whose center is connected to the center of the winding 101′, this center point being grounded. The non-discharging electrodes 131–138, inclusive, are connected to progressive taps on the potentiometer. In operation the potentials of the non-discharging electrodes 131–134 are opposite in phase to that of the ionizing wires and tend to distribute and increase the density of ionization of the associated ionizing wires with gradually weaker effects, while the electrodes 136–138 and 124 produce a gradually increasing shielding effect on the ionizing wires. The general operation of this circuit is similar to that of the neutralizing zone of Fig. 1.

In Fig. 9, spacing of the non-discharging ionization-modifying electrodes is utilized to attentuate the ionized field produced by the ionizing wires which are all connected to be at the same potential and equi-distant from the drum. The field-modifying electrodes 140 are grounded and spaced gradually increasing distances from the ionizing wires in the direction of rotation of the drum so that their effect is gradually decreased. Being at the same potential as the drum, their effect is to augment and distribute the ionizing field due to the ionizing wires, the effect being gradually weaker in the direction of drum movement. The upper set of field-modifying electrodes 142 is connected to be at the same potential as the ionizing wires, and, consequently, they shield and thereby weaken the ionized field produced by the upper ionizing wires, the weakening effect on the field being increased due to the smaller distance between these electrodes and the ionizing wires in the direction of rotation of the drum.

In general, the potentials used for energizing the electrodes of the ore-concentrator may be substantially the same as those disclosed in the aforesaid joint application and may be, for example, from 12 to 15 k. v. positive on the electrodes 28, from 9 to 12 k. v. positive on the electrodes 34, and an alternating-current voltage having a frequency of 500 cycles and a 10 k. v. root-mean-square value for the sources 67 and 101. These values represent specific values used for carrying out certain ore beneficiations, and are not necessarily limiting values.

The embodiments of Figs. 4 through 9 show the drum surface in developed form as a straight line, and the extent of the zones shown may be varied, depending on how tenaciously the fine particles of a particular ore may be expected to cling to the drum after passing through the prior ore-treating zones, and also depending on the arrangement and number of zones utilized. Thus, if a particle-pull-off zone is used, which is preferably disposed in the lower right-hand quadrant of the drum, the number of and the arc subtended by the ionizing electrodes of the neutralizing zones will be smaller than an embodiment in which the particle pull-off zone has been omitted. In the latter case it is desirable to extend or dispose the neutralizing zone in the lower quadrant of the path of rotation of the drum and immediately following the electrodes of the zone D′. This disposition is preferred so that both gravity and the centrifugal forces help to cause the particles whose charges are being neutralized to fly off the drum.

The feature of my invention directed to neutralizing or counteracting the charge on the fine particles adhering to the drum after being treated in the prior zones is not necessarily limited to ore beneficiation, but can be utilized for overcoming electrostatic charges produced on movable sheets such as newspaper, or on other forms of movable elements such as cards passing through card-sorting machines, belts, or the like. In such cases, of course, the reference character 100 may represent an insulated moving element which is charged or which has insulating charged particles on it, the charges in both instances being effectively neutralized and counteracted by the attenuated ionized alternating fields.

While I have described my invention in forms which I believe to represent preferred embodiments thereof, it is obvious that the nature of the invention is such that many alternative arrangements are possible and equivalent structures utilized.

I claim as my invention:

1. The method of beneficiating a finely-divided ore having a mixture of metal-bearing particles and gangue particles of relatively high resistivity,

which comprises feeding a thin layer of the mixture of particles on the upper part of a conducting endless surface moving in a curved path about a substantially horizontal axis, substantially immediately thereafter subjecting the particles moving with said surface to a generally unidirectional electrostatic field having an initial extended ionized portion of an extent sufficient to charge the particles, and a subsequent non-ionized portion of an extent greater than that sufficient to permit metal-bearing particles to appreciably decrease their charge by conduction to said surface, and then subjecting the particles still moving with said surface to an ionized field tending to reduce the charge on these particles.

2. The method of beneficiating a finely-divided ore having a mixture of metal-bearing particles and gangue particles of relatively higher resistivity, which comprises feeding a thin layer of the mixture of particles on the upper part of a conducting endless surface rotating about a substantially horizontal axis, thereafter subjecting the particles moving with and on said surface to an extended ionized electrostatic field for a time sufficient to bombard the particles with charged matter to charge the particles, immediately thereafter subjecting the charged particles to an extended non-ionized electrostatic field which reacts with charged particles to repel them toward said surface, and in the meantime rotating said surface at a speed which will cause metal-bearing particles having charges which leak off rapidly by conduction to said surface to move away from said surface, and subjecting the particles still remaining on said surface to an ionized field tending to reduce the charge still remaining on these particles so that these particles also move away from said surface at places spaced from the places where the last said metal-bearing particles move away from said surface.

3. The method of beneficiating a finely-divided ore having a mixture of metal-bearing particles and gangue particles of relatively higher resistivity, which comprises feeding a thin layer of the mixture of particles on the upper part of a curved conducting endless surface rotating about a substantially horizontal axis, thereafter subjecting the particles moving with said surface to an extended ionized electrostatic field for a time sufficient to bombard the particles with charged matter to charge the particles, immediately thereafter subjecting the charged particles to an extended non-ionized electrostatic field which reacts with charged particles to repel them toward said surface, and in the meantime rotating said surface through a path in which gravity may act on said particles for causing metal-bearing particles having charges which leak off rapidly by conduction to said surface to leave said surface, and then subjecting particles still remaining on said surface before they return to the feeding point and while gravity acts on them, to an alternating ionized field attenuated in the direction of movement of the particles, for rendering the particles substantially charge-free so that these particles also leave said surface at places spaced from the places where the last said metal-bearing particles leave said surface.

4. The method of beneficiating a finely divided ore having a mixture of metal-bearing particles and gangue particles of relatively higher resistivity, which comprises feeding a thin layer of the mixture of particles on the upper part of a curved conducting endless surface rotating about a substantially horizontal axis, thereafter subjecting the particles moving with said surface to an extended ionized electrostatic field for a time sufficient to bombard the particles with charged matter to charge the particles, immediately thereafter subjecting the charged particles to an extended non-ionized electrostatic field which reacts with charged particles to repel them toward said surface, and in the meantime rotating said surface through a path in which gravity may act on said particles and at a speed for causing metal-bearing particles having charges which leak off rapidly by conduction to said surface to leave said surface, and then subjecting particles still remaining on said surface before they return to the feeding point and while rotated at said speed, to an ionized field tending to reduce the charge on these particles so that these particles also leave said surface at places spaced from the places where the last said metal-bearing particles leave said surface.

5. The method of beneficiating a finely divided ore having a mixture of metal-bearing particles and gangue particles of relatively higher resistivity, which comprises charging a thin layer of the mixture of particles, causing the layer of particles to move along a conducting surface moving in a curved path, subjecting the particles immediately after charging and while substantially following the path of movement of said surface, to a non-ionized electrostatic field which is substantially uniform for an appreciable extent along the path of movement of said surface, and then subjecting the particles on the surface to an ionized electrostatic field of decreasing strength along the path of movement of said surface.

6. The method of treating a mixture of particles including particles of relatively low resistivity and particles of relatively high resistivity, which comprises continually feeding a thin layer of the mixture on the upper part of a conducting surface of an endless conveyor rotatable about a substantially horizontal axis, rotating said conveyor with the particles on its surface, passing the particles fed to said conveyor through an extended ionized electrostatic field for charging the particles, then passing the particles through an extended non-ionized field tending to repel to said surface those particles which retain an appreciable portion of their charge, the said conveyor being rotated at such speed that relatively low resistivity particles which do not retain charges are caused to leave said drum while relatively high resistivity particles adhere to said surface because of the action of the non-ionized field, then passing particles which remain on said surface through a non-ionized electrostatic field tending to pull way from said surface the particles remaining on said surface, and through an ionized electrostatic field tending to reduce the charges on the particles still on said surface.

7. A device for separating particles of relatively low resistivity from particles of relatively high resistivity, comprising a cylindrical drum having a conducting surface; means for rotating said drum; means for depositing a thin layer of particles on said drum; and substantially concentrically about said drum from the last said means in the order named: a plurality of spaced ionizing electrodes, a plurality of non-discharging electrodes in grid form, and a plurality of spaced ionizing electrodes; means for potentializing the

first said ionizing electrodes and said non-discharging electrodes for establishing electrostatic fields between said ionizing electrodes and said conducting surface, and between said non-discharging electrodes and said conducting surface, and means for potentializing the second said ionizing electrodes for establishing an ionized electrostatic field of gradually weaker intensity in the direction of rotation of said drum, the last said field being between the last said ionizing electrodes and said conducting surface.

8. A device of the class described for separating particles of relatively low resistivity from particles of relatively high resistivity, comprising a cylindrical drum, means for rotating said drum, means for depositing a thin layer of particles on the upper part of said drum, means for establishing a unidirectional ionized electrostatic field to said drum, said field being of substantially uniform density circumferentially for an appreciable angular extent, means for establishing a non-ionized unidirectional electrostatic field to said drum, merging into said ionized field and of the same general direction, said non-ionized field being of substantially uniform density circumferentially for an appreciable angular extent, and means following the last said means for establishing an ionized field to said drum of varying intensity of ionization.

9. A device of the class described for separating particles of relatively low resistivity from particles of relatively high resistivity, comprising a cylindrical drum, means for rotating said drum, means for depositing a thin layer of particles on the upper part of said drum, means for establishing a unidirectional ionized electrostatic field to said drum for charging said particles, means for establishing a non-ionized unidirectional electrostatic field merging into said ionized field and of the same general direction, the both said field establishing means comprising electrodes in grid form spread along the direction of movement of said drum, and subsequent means for establishing an ionized field for reducing the charges on particles remaining on said drum.

10. A device for separating particles of relatively low resistivity from particles of relatively high resistivity, comprising an endless conveyor rotatable in a closed path about a substantially horizontal axis, means for rotating said conveyor, means for depositing a thin layer of particles on the upper part of said conveyor, means comprising ionizing electrodes arranged in grid-form in the general direction of the movement of said particles for charging the particles deposited in said conveyor, subsequent means comprising electrodes arranged in extended grid-form for producing a subsequent electrostatic field, following said ionized field, for reacting with charged particles to produce a force tending to repel them to said conveyor, and means subsequent to the last said means and comprising electrodes arranged in extended grid-form for producing an ionized electric field having the effect of decreasing the charges on particles on the conveyor entering the last said field.

11. A device for separating particles of relatively low resistivity from particles of relatively high resistivity, comprising a cylindrical drum; means for rotating said drum; means for depositing a thin layer of particles on said drum; and substantially concentrically about said drum from the last said means in the order named: means including a plurality of spaced ionizing electrodes for charging said particles, means including a plurality of non-discharging electrodes for producing an electrostatic field reacting with charged particles to tend to repel them toward the drum, and electric field means for reacting with the charges on particles still on the drum when they reach the last said electric field means for increasing their tendency to separate from the drum, the last said means including provisions for establishing an attenuated ionized electric field having the effect of gradually decreasing the charges on particles on the drum passing through the last said field.

12. A device for separating particles of relatively low resistivity from particles of relatively high resistivity, comprising an endless conveyor rotatable in a closed path about a substantially horizontal axis, means for rotating said conveyor, means for depositing a thin layer of particles on the upper part of said conveyor, means comprising ionizing electrodes arranged in grid form in the general direction of the movement of said particles, for charging the particles deposited in said conveyor, subsequent means comprising electrodes arranged in extended grid-form for producing a subsequent electrostatic field, following said ionized field, for reacting with charged particles to produce a force tending to repel them to said conveyor, means subsequent to the last said means and comprising electrodes arranged in extended grid-form for producing an electrostatic field, following the last said subsequent electrostatic field, for reacting with charged particles to produce a force tending to pull them away from said conveyor, and means subsequent to the last said means and comprising electrodes arranged in extended grid-form for producing an ionized electric field having the effect of decreasing the charges on particles on the conveyor entering the last said field, particles leaving said conveyor being capable of passing through the spaces of said grid-forms.

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