

Dec. 27, 1966

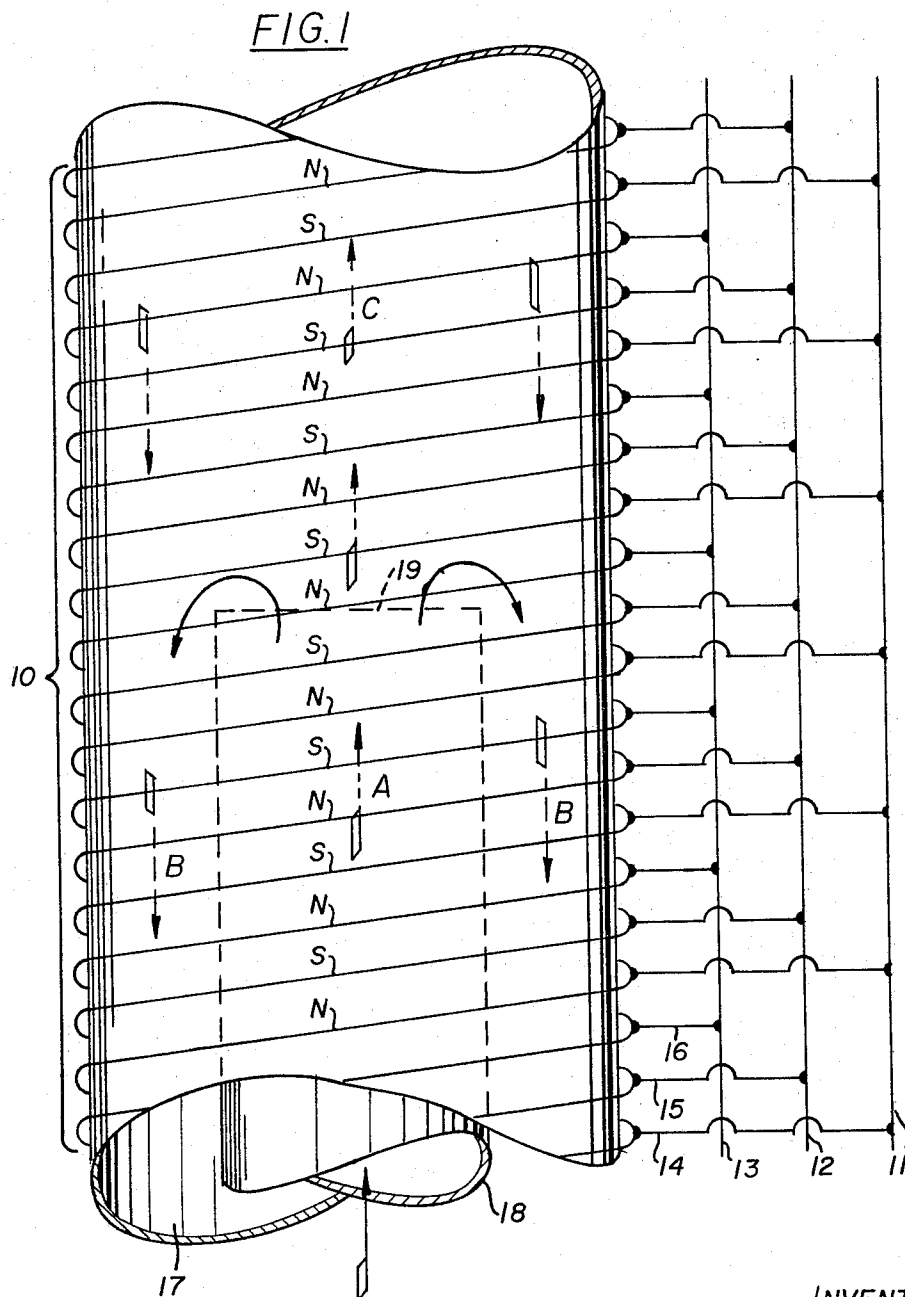
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3,294,237

MAGNETIC SEPARATOR

Filed May 31, 1963

5 Sheets-Sheet 1



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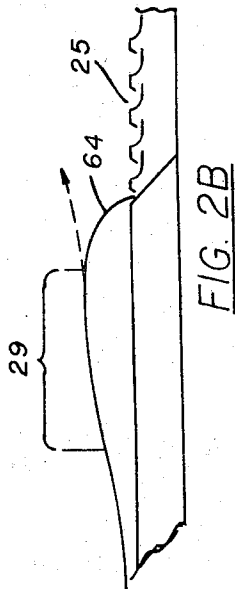
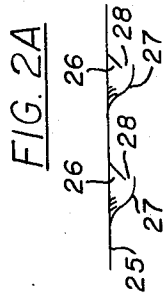
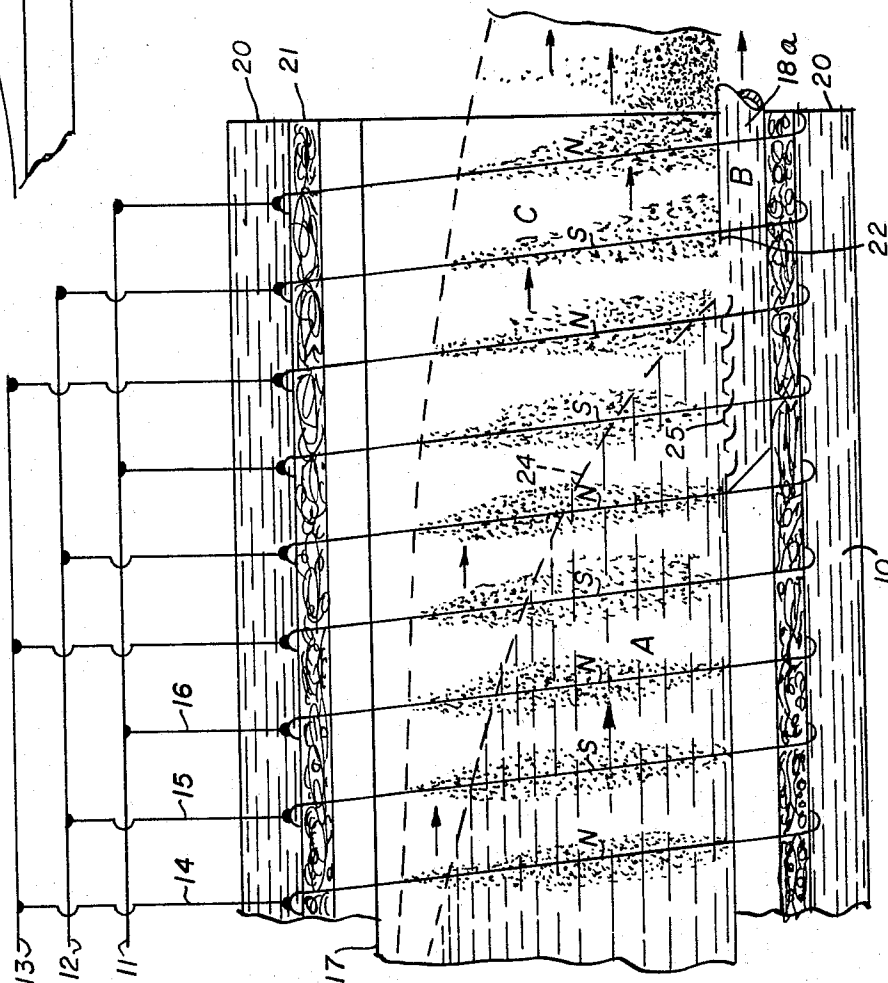


FIG. 2



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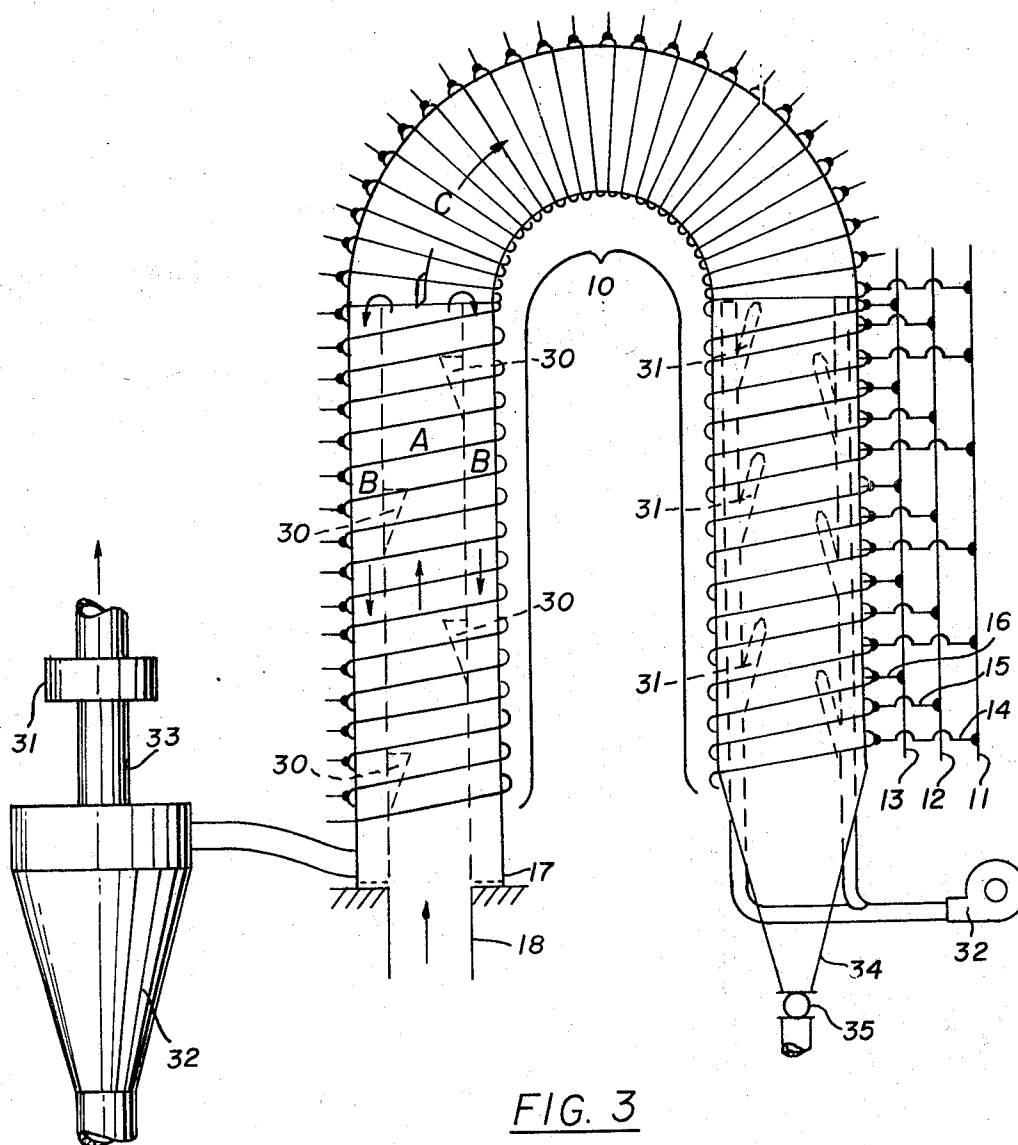


FIG. 3

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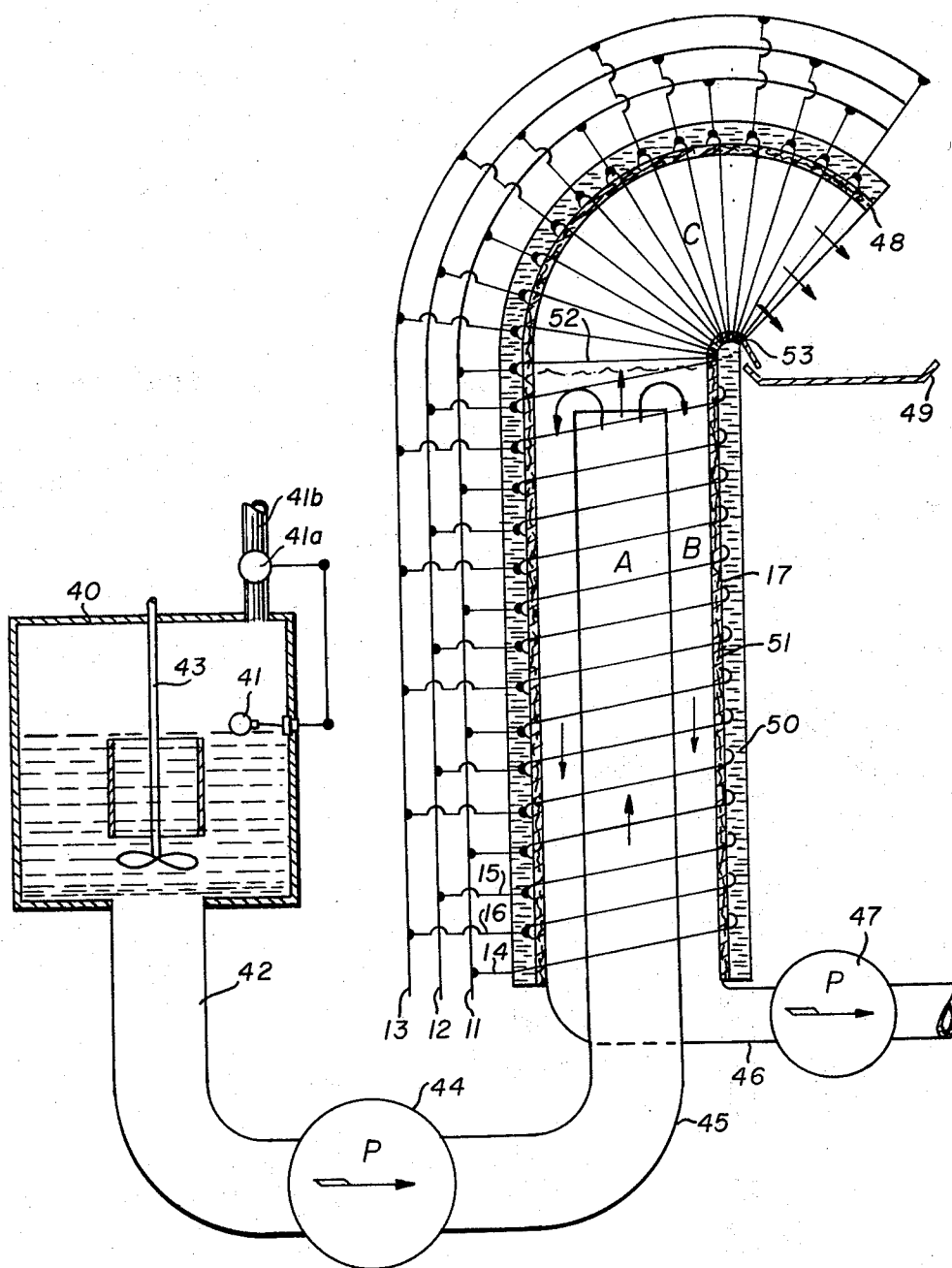


FIG. 4

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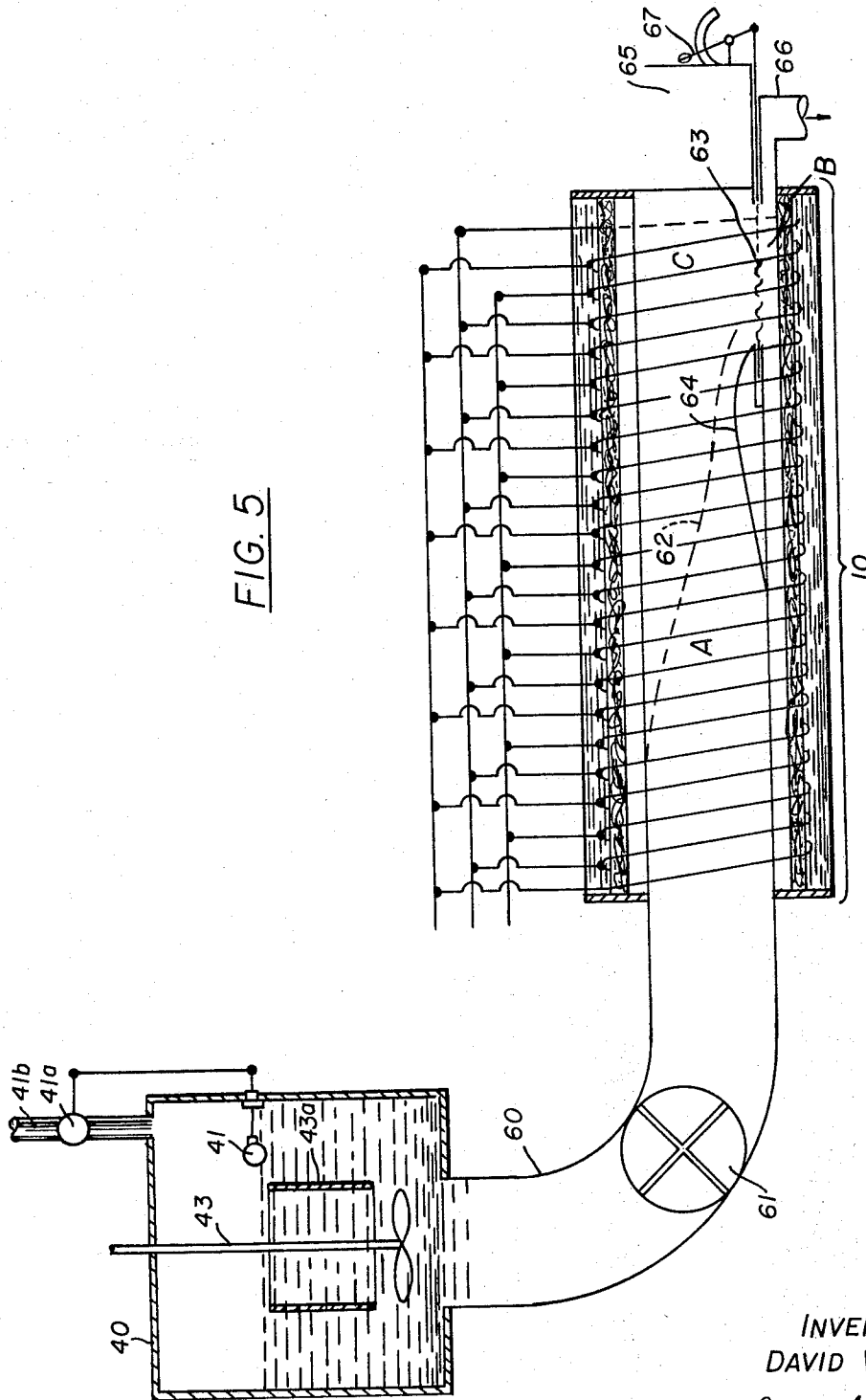
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MAGNETIC SEPARATORDavid Weston, 129 Adelaide St., W., Toronto,
Ontario, CanadaFiled May 31, 1963, Ser. No. 284,423
15 Claims. (Cl. 209—214)

This invention relates to a method and apparatus for the preparation of particles of material having a magnetic susceptibility above a given value from mixtures of such particles with particles having a lower magnetic susceptibility. The invention is particularly directed to the recovery of desired materials from comminuted ores, industrial minerals, industrial gases or the like.

As is well known in the electromagnetic art, all materials have magnetic properties which are a characteristic of the spin resonance in the outer shells of electrons in the atoms of the material. When the atoms are present in molecules, this characteristic is retained, and groups of molecules associate magnetically into domains, a domain being the smallest magnetic entity that is presently recognized in solid substances. When these domains in a material become oriented the material becomes a magnet. In some materials, the domains cannot be oriented, and such materials are referred to as non-magnetic. Other materials exhibit an unusual response to magnetic forces and are referred to as diamagnetic. By far the largest number of materials, the recovery of which are of interest to man, respond to the application of magnetic flux by tending in some degree or other to have their domains become oriented, that is to say, they tend to become magnets. The ease with which a material will become a magnet is a physical constant of the material and is called the magnetic susceptibility. Those materials with a high magnetic susceptibility become magnets when subjected to low flux densities and vice versa.

When a mixture of particles of materials of different magnetic susceptibility is subjected to a flux density sufficient to cause only the particles of a given material in the mixture to become magnets a means is afforded for separating those particles from the other particles in the mixture. This is the fundamental principle of all magnetic separators.

In my prior application Serial No. 77,895 now abandoned, I disclosed a magnetic separator in which the mixture of particles to be separated is suspended in a vehicle confined in a columnar pathway while being subject to the influence of an externally produced magnetic field characterized by magnetic gradients along the length of the pathway. By physically moving the means producing the magnetic field longitudinally with relation to the columnar pathway a separating action was accomplished enabling a magnetic concentrate and a magnetic tailing to be collected at remote ends of the said pathway. The described arrangement produces particularly good results in the case of materials having a magnetic susceptibility which is sufficient to effectively magnetize the particles which it is desired to concentrate by subjecting them to a flux density of up to about 25,000 gauss. When, however, it is necessary to employ higher flux densities the technology available in the magnetic art today tends to require a somewhat cumbersome and heavy means for excitation of the magnetic field and thus the problems inherent in providing for the physical movement of the magnets and excitation system make it desirable to provide a system for magnetic separation of such materials wherein provision need not be made for the physical displacement of the excitation system relative to the pathways along which separation is to be effected.

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According to the present invention, I provide such a system whereby the magnetic excitation system is stationary with relation to the pathways along with separation takes place and the design of the equipment is thus free of the mechanical conditions imposed by the increasingly ponderous nature of the excitation system which must be employed to produce flux densities substantially higher than 25,000 gauss.

According to one embodiment of the invention I provide a solenoid within the interior of which are disposed the pathways along which magnetic separation is to take place. Substantially centrally within the solenoid there is an interior pathway along which a suspension of particles upon which separation is to be effected is introduced axially with relation to the solenoid. The said inner pathway extends only part way along the interior of the solenoid and surrounding it is a generally annular space. The solenoid has successive windings tapped to the individual phases of a supply of alternating current which is adapted to develop a helical flow of current around said pathway whereby to produce in the interior of the solenoid and hence the pathway a magnetic flux density sufficient effectively to magnetize those particles of the feed material which it is desired should appear in the concentrate. In operation a suspension of the feed material in a fluid vehicle is introduced to the inner pathway at one end of the solenoid. As the suspension enters the interior of the solenoid, certain particles thereof become effectively magnetized while the vehicle and the remaining particles of feed are substantially unaffected by the magnetic field. The magnetic effect of connecting successive windings of the solenoid to successive phases of a multiple phase source is that there is created in the space within the solenoid a successive series of south and north magnetic poles which are disc-shaped and substantially at right angles to the axis of the solenoid. This series of north and south magnetic poles, by virtue of the alternation of the current supply, continually advances step-wise along the space within the solenoid at a linear velocity which is a function of the frequency of alternation of the current supply. As the suspension of feed material advances along the interior pathway those particles which become magnetized will move under the influence of the magnetic field rather than under the influence of the movement of the vehicle in which they were introduced while the non-magnetized particles of feed will continue to move substantially solely under the influence of the vehicle in which they are suspended. At the end of the inner pathway the vehicle and suspended non-magnetic particles are withdrawn usually in a reverse direction in the annular space between the inner pathway and the solenoid while the magnetized particles continue moving stepwise in their original direction along the solenoid under the continuing influence of the magnetic field. Preferably, additional vehicle is introduced further along the solenoid or from the remote end thereof which serves to clean the magnetic material with which it is there moving in counter-current and to assist in the transportation of the non-magnetic material in the annular space to a point of collection. The magnetic material may be collected at the remote end of the solenoid.

As will be apparent, the invention as described in general terms may be operated effectively using gaseous vehicles or liquid vehicles for the material which is to undergo separation and the selection of a particular vehicle will depend in any given case upon the conditions and the particular materials involved.

In general, and particularly when working with gaseous vehicles, it will be desirable to have the axis of the solenoid substantially vertical and to introduce the mixture

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to be separated either upwardly or downwardly into the interior of the solenoid.

A particular advantage of the foregoing arrangement is that it is feasible to provide within the one apparatus for not only the basic production of a magnetic concentrate and tailing but also for the provision of a substantial amount of cleaning of the concentrate and tailings during the transport of the concentrate to its point of collection and during transport of the tailing to its point of collection when the latter takes place in a reverse direction. As will be appreciated, the cross-sectional area of the interior pathway along which the suspension of particles upon which separation is to be effected is introduced and that of the exterior pathway along which the vehicle and suspended non-magnetic particles are withdrawn can be so selected that the cross-sectional area of the reverse pathway is relatively large in comparison to that of the interior pathway so that the velocity of the fluid vehicle, which in the interior pathway must be sufficient to transport the particulate material, may in the reverse pathway be substantially below such velocity. Accordingly, magnetized material which has been carried into the reverse pathway by the gaseous vehicle or material which is capable of being effectively magnetized but which, owing to its reluctance, may require a somewhat longer time period for effective magnetization than the general run of material which it is desired to concentrate, may upon becoming magnetized come under the influence of the magnetic field and travel with it in a direction opposite to that of the withdrawal of vehicle, eventually to join with the main concentrate at the point of collection thereof, notwithstanding the fact that a substantial amount of additional vehicle may be introduced along the pathway leading to the point of collection of the concentrate in counter-current direction to the transport of the magnetized material under the influence of the magnetic field, which newly introduced vehicle augments the volume of vehicle in the reverse pathway while carrying non-magnetic particles which have been freed from the concentrate into said reverse pathway and ultimately to the point of collection of tailing.

The process of the invention, particularly when liquid vehicles are employed for the transport of the feed material, may be carried out in a manner wherein the separating action is assisted by an increment of momentum imparted to the magnetized particles by the movement of the magnetic field. For instance, where the solenoid is horizontal, the inner pathway may extend almost to the end of the solenoid. The vehicle may be withdrawn from the lower end of the space within the solenoid near the downstream end thereof along an outer pathway running concurrently with the direction of flow in the inner pathway while the magnetic field under the influence of which the magnetized particles are moving may be so arranged as to impart to the effectively magnetized material a velocity higher than that of the liquid vehicle whereby the magnetized particles will be caused to leave the liquid vehicle through the surface thereof so that the latter are carried along the inner pathway beyond the point at which the vehicle is withdrawn, to a point of collection. The entrance to the outer pathway may in this case be provided with slicer means to enable accurate adjustment for the most economic point of cleanliness of the tailings versus grade of the concentrate.

The invention and its operation will be more clearly understood from a reading of the following detailed specification taken in conjunction with the accompanying drawings wherein

FIGURE 1 is a schematic illustration of a portion of a device according to the invention wherein the separating action takes place and which illustrates the principle on which the invention operates;

FIGURE 2 is a schematic illustration of a portion of a device according to the invention wherein the material to be separated is introduced in a liquid vehicle and use is

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made of an increment of momentum imparted to the magnetized material to assist the separation thereof from the vehicle and tailings;

FIGURE 2A is a fragmentary longitudinal vertical section illustrating a preferred form of perforation for providing communication between the separation pathways of FIGURE 2;

FIGURE 2B is a fragmentary longitudinal vertical section through the bottom of casing 17 illustrating a preferred configuration thereof;

FIGURE 3 is an illustration partly in schematic of an electromagnetic separator according to the invention in which the material to be separated is introduced in a gaseous vehicle;

FIGURE 4 is an illustration partly in schematic of a magnetic separator according to the invention wherein the material to be separated is introduced in a liquid vehicle;

FIGURE 5 is an illustration partly in schematic of an electromagnetic separator according to the invention wherein the material to be separated is introduced in a liquid vehicle and wherein the separating action takes place in a generally horizontal pathway.

Referring now more particularly to the drawings, FIGURE 1 illustrates generally the principle upon which the invention is based. Referring to FIGURE 1, numeral 10 indicates a solenoid successive windings of which are tapped to successive phases 11, 12 and 13 of a source of alternating current (not shown) by taps 14, 15 and 16 in the manner illustrated. As illustrated, there are three phases which represents a preferred arrangement particularly because of the ready availability of three phase current supply. However, it is perfectly feasible in place of the three phase arrangement illustrated to use any multiple phase which it may be convenient to supply, in which case the taps to the windings of the solenoid 10 will be made in a comparable manner in sequence. Additionally, it is to be appreciated that although in the drawing there is a tap on each and every winding of the solenoid 10 in practice, the taps may be made at intervals of a number of windings. As will be appreciated by those familiar with the electrical art, the solenoid 10 may have a number of layers of windings in which case each tap may connect to the windings in each layer at the particular tap interval which has been selected.

Within the solenoid 10 is the cylindrical casing 17 which is suitably composed of some non-magnetic material such as fiber-glass, plastic or the like. The casing 17 need not necessarily be circular in section nor is it essential that it entirely fill all of the space within the solenoid 10 as illustrated. It is preferred, however, to have the casing 17 circular and to utilize as much as possible of the space within the solenoid 10 in order to provide for the maximum economic efficiency.

Within the casing 17 is an inner casing 18 which is made of non-magnetic material which suitably may be of the same type as that from which the casing 17 is made. As will be observed, the casing 18 terminates at 19 in an open end within the space within the solenoid 10 and the casing 17.

In operation with the current supply turned on, the space within the solenoid 10 contains a magnetic flux as a result of the current flowing through its windings.

The flux density will be substantially uniform on any cross section of the solenoid 10 and at any given instant the cross sections of the solenoid 10 correspond to the windings connected to the taps 14, 15 and 16 will constitute magnetic poles which are in effect planar in configuration and disc shaped. These poles will be arranged alternately north and south as illustrated. Because the current supply is alternating current at each alternation the series of north and south poles illustrated will move stepwise so that in the interior of the solenoid 10 there is produced a series of north and south poles moving upwardly in stepwise fashion at a rate of speed deter-

mined by the frequency of the alternating current supply and the distance between taps.

In practice, the design of solenoid 10 and the power supply is such as to produce in the space within the solenoid a flux density which is sufficient effectively to magnetize the particular material which it is desired to separate and to collect. For instance, if the material which is to be concentrated is hematite, a flux density in the neighbourhood of twenty to twenty-five thousand gauss might effectively be employed. Other materials of lower magnetic susceptibility than hematite will require a higher flux density, and it is within the contemplation of the invention to produce such higher flux densities up to the region of forty-five thousand gauss and higher depending upon the particular material to be separated.

With the current supply turned on, a gaseous suspension of a mixture of solid particles which is to be separated is introduced through casing 18. As a gaseous vehicle, air is in general satisfactory although in certain instances it may be desirable to use other gases such as nitrogen. The velocity of the air will be sufficient to maintain the solid material in suspension and may conveniently be of the order of two to five thousand feet per minute. As the suspended material enters the space within solenoid 10 while still within casing 18, those particles of the mixture which have the highest magnetic susceptibility will tend to become magnetized, and when this occurs, they will be attracted to the poles and their movement upwardly in casing 18 will tend to become governed by the movement upwardly of the series of north and south poles which is produced by the alternating current, so that within casing 18 there will be moving along the pathway A defined thereby the gaseous medium and suspended non-magnetized particles together with the magnetized particles which have come under the influence of the upward movement of the north and south poles. As the material and suspending vehicle issue forth from the end 19 of the casing 18, the gaseous vehicle is made to change its direction of movement and is sent downwardly through pathway B between the casings 18 and 17 by suitable air motivation means (not shown) carrying with it the bulk of the suspended non-magnetized particles. Meanwhile, the magnetized particles continue to move upwardly in pathway C and are eventually collected in suitable collection means (not shown). Preferably, additional vehicle is introduced in the upper portion of the solenoid 10 by suitable air supply means (not shown) whereby the fresh vehicle is in countercurrent with magnetized particles and tends to entrain and carry away into pathway B the non-magnetized particles which may have been carried along or entrained with the magnetized particles moving under the influence of the magnetic field.

Various refinements of design are necessary in order to achieve flux densities of the magnitude contemplated within the solenoid 10 and to dissipate the heat produced. Such refinements of design are well known in the electromagnetic art and include conventional means for dissipating the heat produced in the solenoid. For achieving flux densities of up to the neighbourhood of 10,000 gauss using conventional windings, use may be made of disc shaped sections of solenoid having interspaced discs of high heat conducting material such as copper or aluminum which extend outwardly from the solenoid and may be air cooled. For flux densities in the 15 to 20,000 gauss range, use may be made of cooling coils or discs imbedded in the windings of the solenoid through which a conventional coolant may be circulated. For achieving flux densities of between twenty and thirty thousand gauss, the windings themselves of the solenoid may be formed from copper or the like tubing through which there may be circulated a refrigerated brine solution. However, as one approaches the upper end of this range of flux densities, increased electrical efficiency may be achieved through the use of special alloys whose coefficient of electrical resistance exhibit a pronounced drop

within ranges of temperatures which may be achieved with refrigerated brine. Such materials are well known in the art and include, for instance, high purity copper containing less than one ten thousandth of 1% impurity. The achievement of flux densities higher than about thirty thousand gauss renders desirable the employment of temperatures for the excitation system of down to about 80° Kelvin. Such temperatures may readily be achieved through the use of tubular conductors through which a coolant such as liquid nitrogen or helium is passed. As the flux density is increased, special alloys having particularly low electrical resistance at low temperatures such as certain niobium tin alloys become desirable in order to make more reasonable the demands upon the cooling system which vary as is well known with the power requirements of the system. At these high intensities of field, the electrical resistance of the excitation system becomes a governing factor because as will be appreciated, the heat produced in overcoming electrical resistance is produced within the conductors of the system and works against the refrigeration system which cannot produce a temperature materially lower than that of the liquefaction temperature of the coolant medium. It therefore becomes increasingly important to utilize a design for the excitation system which involves as little electrical resistance as possible as the flux density of the magnetic field increases. For very high flux densities up to about 75,000 gauss, it may be found desirable to operate at temperatures as low as about 10° Kelvin, utilizing liquid helium as the coolant and employing alloys for the coils of the solenoid which are composed of material whose resistance approaches zero at such temperatures. In such cases, techniques common in the cryogenic art will be necessary to maintain an efficient operating temperature for the excitation system.

It will be obvious to those skilled in the art that where the flux densities to be employed according to the invention are such as to require the maintenance of temperatures substantially below room temperature, provision must be made for adequate insulation of the solenoid. Where the vehicle used for transport of the feed material is liquid (e.g. brine), insulation of the separation pathways within the space inside the solenoid is not needed down to temperatures of about 21° below zero centigrade if the vehicle itself is refrigerated to a temperature comparable with that of the excitation system. Similarly, where a gaseous vehicle is employed, insulation of the separation pathways from the solenoid may not be necessary where the excitation system is not maintained below about 21° below zero centigrade excepting under operating conditions where high temperature and humidity of the ambient air introduce condensation problems and problems of heat removal. However, when operating the excitation system below about 21° below zero centigrade, it will be most important to provide for adequate thermal insulation of the separation pathways within the solenoid from the excitation system.

FIGURE 2 is a schematic illustration which illustrates the separating action of the embodiments of the invention wherein the solenoid is horizontal and the material to be separated is introduced in a liquid vehicle. Referring to FIGURE 2, the solenoid 10 having taps 14, 15 and 16 connected to the three phases 11, 12 and 13 of a three-phase alternating current supply (not shown) in the same fashion as has already been explained in connection with FIGURE 1 has its coils immersed in a sub-zero cooling system 20 through which there may be circulated a liquid coolant such as helium or hydrogen in order to maintain a coil temperature of between about -20° F. and about 10° K. depending upon the particular flux density which the apparatus has been designed to produce. The coils themselves may be of pure copper or of special alloys such as niobium tin, again depending upon the flux density which is to be achieved. Within the solenoid 10 is a layer of thermal insulation 21. Inside the layer of thermal

insulation 21 is the casing 17 which defines the pathway along which material to be separated is to be passed. At the lower side of the casing 17 and radially outward thereof is a second casing 18a which communicates with the interior of the casing 17 and defines a pathway for the removal of tailing. Preferably, the position of the opening, which provides communication between the interior of the casing 17 and the interior of the casing 18a, is adjustable as will be hereinafter explained.

In operation, the material to be treated is introduced into the casing 17 as a slurry in a liquid vehicle which may be water or brine at a rate which is such that at the inlet (left hand) end of the solenoid 10, the casing 17 is completely filled with slurry. Liquid is continually being withdrawn through the casing 18a by a pumping means (not shown) at substantially the same rate as the slurry is being introduced to the casing 17. This results in the formation of a liquid surface 24 of generally parabolic shape extending from the upper side of the casing 17 to the end 22 of the entrance to casing 18a.

The excitation of the solenoid 10 is such as to produce a flux density sufficient effectively to magnetize the particles which it is desired in the concentrate and tap interval and frequency of alternation of the current supply is such as to produce a rate of progression of magnetic waves along the solenoid which is substantially higher than the velocity of flow of the slurry. The effectively magnetized particles come under the influence of the magnetic field and are attracted to the planes of the poles produced thereby in the same manner as has been explained in connection with FIGURE 1. This material begins to move at a higher velocity than that of the liquid vehicle, and as the slurry moves along pathway A, the increase in velocity will cause the material to leave the surface 24 and be carried under the influence of the magnetic field into pathway C. The additional velocity imparted to the magnetized material tends to carry it in a generally parabolic path beyond the point 22 and to a point of collection (not shown) at the end of pathway C. The vehicle and particles of slurry which have not become magnetized are uninfluenced by the magnetic field and continue to move in the vehicle into pathway B within casing 18a to a point of tailings collection (not shown).

Since the magnetized particles are not supported by the magnetic field against the pull of gravity, the parabolas along which some of these particles are moving will tend to carry them into pathway B. In order to obtain the optimum cut-off point as between concentrate and tailing, the position of the end 22 of the opening is adjustable to permit adjustment of the "cut"; preferably the opening may be covered by a punched plate which is provided with perforations over an area 25. A preferred design of perforation is shown in section in FIGURE 2A. As will be observed, the perforations are each provided with a ramp 26 and a drainage lip 27 which underlies the ramp 26. Slurry landing on the portion 25 will impinge almost directly on the ramps 26 losing most of its forward velocity. Magnetic particles contained in such slurry will be picked up and carried along by the magnetic field while liquid vehicle and non-magnetic particles will tend to be drawn out along drainage lip 27 owing to the reduced pressure created at point 28 by the flow of slurry in pathway B. In order to take full advantage of the velocity imparted to the magnetized particles by the magnetic field, the lower side of casing 17 may be modified as illustrated in section in FIGURE 2B, so as to impart a hydrofoil profile thereto which over the portion 29 will impart a substantial upward increment of velocity to the vehicle and the particles therein. This component of upward velocity will be imparted both to the magnetic and non-magnetic particles contained in the vehicle adjacent the portion 29 of the hydrofoil but owing to the higher velocity of the magnetic particles will impart to the latter a flatter trajectory and tend to permit fewer of

the magnetic particles to enter the pathway B. If desired, the communication between pathway B and pathway A may be entirely through an area of perforations preferably of the type illustrated in FIGURE 2A.

The description of FIGURES 1 and 2 explains the principle upon which separation is effected in accordance with the invention. FIGURES 3, 4 and 5 which are now described illustrate how these principles may be employed in separating devices according to the invention.

FIGURE 3 shows a preferred form of electromagnetic separator according to the invention in which the vehicle employed for the introduction of the material to be separated is gaseous, the most commonly employed vehicle being air. As will be observed, the solenoid 10 is here formed in the shape of an inverted "U" as is the casing 17 which is surrounded by it. The material to be separated enters vertically upwardly through casing 18 suspended in an airstream. A suitable feed may, for instance, be the discharge from an air-swept dry comminution mill. The velocity of the airstream may be of the order of from about two thousand to four thousand feet per minute. The solenoid 10 is connected to the three phases 11, 12 and 13 by taps 14, 15 and 16 in the same manner as has already been explained in connection with FIGURE 1. The flux density of the field is such as to be calculated to effectively magnetize the particles of material which it is desired to have in the concentrate and the tap interval and the frequency is such as to be calculated to produce a linear velocity for the magnetic wave produced within the solenoid 10 which is substantially the same as the velocity of the air in which the material to be separated is introduced within casing 18, i.e. a velocity of the order of two thousand to four thousand feet per minute. As the material carried by the air in casing 18 comes under the influence of the solenoid 10, the particles susceptible to magnetization at the flux density produced within solenoid 10 commence to become magnetized and move under the influence of the magnetic field. Preferably, baffles 30 are placed within casing 18 in order to minimize occlusion of non-magnetic materials in the concentrations of magnetized material which form along the planes of the poles of the magnetic field. As the material and vehicle come to the end of pathway A, most of the magnetic susceptible material will have become magnetized and will be moving substantially solely under the influence of the travelling magnetic field, and will, therefore, continue to be carried along pathway C over the top of the inverted "U". The vehicle and non-magnetic particles is withdrawn downwardly along pathway B by fan 31, the non-magnetic solids being collected in cyclone 32, and the gaseous vehicle departing through conduit 33 from which it may be recirculated for purposes of resuspending more material to be separated for introduction into casing 18 or, if the source of material to be separated is an air-swept mill to the inlet side of such mill. As the vehicle and non-magnetic material is being withdrawn through pathway B, it may still contain the most difficult to magnetize particles of the material that it is desired to concentrate. Where such particles become magnetized during passage downwardly in pathway B, they will tend to be drawn upwardly under the influence of the magnetic field concurrent to the vehicle. As will be appreciated, the cross-sectional area of pathway B is substantially greater than that of pathway A, and accordingly the velocity of the gas flow therein will be substantially lower than that in pathway A, thus making it feasible to withdraw magnetized particles upward in a direction countercurrent to the flow of gas. As will be observed, pathway C extends over the crest of the inverted "U" and downwardly into the other leg of the inverted "U". During its downward passage, the magnetized material is subjected to a cleaning action by means of a plurality of jets of air produced by nozzles 31 which are supplied by the fan 32. Non-magnetic cleanings are carried back over the crest of the "U" and joined the original vehicle and tailings descending

in pathway B. The concentrate drops into the hopper 34 and is extracted through air lock 35 from whence it may pass to a subsequent treatment stage.

In the apparatus illustrated in FIGURE 4, the material to be treated is introduced in a liquid vehicle which may be water or brine. The slurry tank 40 equipped with float valve 41 for maintaining a constant level of slurry therein is supplied with liquid and solid feed in any conventional manner under control of the said float valve 41 which controls valve 41a in feedline 41b. The slurry is kept suspended by agitator 43 which is preferably associated with shroud 43a. Pump 44 pumps the slurry from slurry tank 40 into conduit 45 which is made of non-magnetic material and extends upwardly within the non-magnetic casing 17 which is surrounded by a solenoid 10 which is connected by taps 14, 15 and 16 to the phases 11, 12 and 13 of a three phase current supply in the same manner as illustrated in FIGURE 1. The lower end of the casing 17 communicates with conduit 46 through which slurry pump 47 controllably withdraws the vehicle and suspended tailings. The pumping rate of pumps 45 and 47 is controlled in conventional manner to maintain a constant level of slurry within casing 17. The top of casing 17 is elbowed so that the open end 48 thereof faces in a generally downward direction towards concentrate collecting pan 49. The coils of solenoid 10 are enclosed within an insulated cooling system 50 through which a refrigerated liquid is circulated to maintain the coils solenoid at a desired low temperature. The type of refrigerating system will depend upon the flux density at which the apparatus is designed to operate and may be for instance brine at temperatures of down to about 21° below zero C. or liquid helium or nitrogen where the operating temperature is to be below about 21° C. Details of the refrigeration system are not shown as such systems are conventional. Between the coils of solenoid 10 and the casing 17, there is a layer of insulation 51 which is adapted to protect the liquid vehicle from temperatures which would cause freezing within pathways A and B. In operation, the slurry is fed into conduit 45 which leads it upwardly within the space of solenoid 10 along pathway A. As the slurry rises along pathway A, the particles of solids which become effectively magnetized at the flux density employed will become magnetized and will tend to move under the influence of the magnetic field in the manner which has already been explained. These particles will on leaving pathway A continue to move under the influence of the magnetic field through the surface 52 of the slurry and into pathway C where they are discharged through the end 48 of casing 17 and collected in the concentrate collection pan 49. The liquid vehicle and magnetized material moves radially outward into pathway B on leaving the upper end of the conduit 45 and flows downwardly under the influence of pump 47. On passing downwardly through pathway B, any particles of magnetic material which may have been carried over in a vehicle either because of failure to become effectively magnetized through pathway A or by occlusion will tend to be picked up by the magnetic field and moved counter-currently upwardly in pathway B to join the concentrate in pathway C.

In operation, the flow rate of the slurry up pathway A will be adjusted to correspond with the rate of progression of the series of north and south poles along pathway A produced by the alternating current supply, the actual rates depending upon the material undergoing treatment. Generally speaking, the speeds involved will be sufficiently low that the vehicle and non-magnetic material will not tend by virtue of their momentum to rise higher than the surface 52 of the slurry so that there will be no tendency for vehicle and non-magnetic material to be carried over the lip 53 at the bottom of the elbow at the end of casing 17.

In the embodiment illustrated in FIGURE 5, in which the feed material is again introduced in a liquid vehicle,

the supply means for feed material is the same as that employed in connection with FIGURE 4. However, in this case supply of feed through conduit 60 is controlled by the valve 61 as the slurry is fed downwardly by gravity. The rate of speed of feed of the slurry is such that the conduit 60 is full at the point at which it enters the pathway A in the space within the solenoid 10, but soon after entering pathway A the surface of the slurry will break away from the upper surface of the conduit 60 in a generally sloping surface 62. In the bottom of the conduit 60 in advance of the perforated plate 63 which affords communication between pathways A and B there is a hydrofoil section 64 which acts as a sort of weir over which the slurry must pass on its way to the section of perforated plate 63. In operation, the hydrofoil 64 serves to give an upward increment of momentum to the magnetized material in the slurry giving such material a trajectory which will tend to carry it beyond the perforated section 63 and into pathway C and thence into the concentrate collector pan 65. The vehicle and non-magnetic tailings flow outwardly by gravity through conduit 66. The perforated section 63 is preferably constructed in the manner illustrated in FIGURE 2A to minimize the amount of magnetic concentrate which will pass downwardly into pathway B. The position of the perforated section, and the end of the opening 22 may be adjusted by lever 67.

The frequency of the alternating current and the spacing of the taps in the embodiment illustrated in FIGURE 5 will be such as to produce a progression of north and south poles along pathways A and C which is substantially greater than the linear velocity of the pulp which is being introduced so that the magnetized material will acquire an increment of momentum which will tend to shoot it through pathway C with a considerable velocity. This effect may be increased by progressively increasing the tap interval along the length of the solenoid 10 whereby the rate of travel of the progression of north and south poles will progressively increase along the length of the solenoid 10.

It will be appreciated that in connection with the embodiment illustrated in FIGURE 5, it is not necessary that the solenoid 10 be horizontal as illustrated. The solenoid and the pathways therein contained may tilt upwardly or downwardly at a substantial angle from the horizontal. Where the solenoid tilts upwardly, it will be appreciated that it will be necessary to have the communication between conduit 66 and pathway A below the level of the liquid surface 62 and to include pumping means within pathway B.

What I claim as my invention is:

1. A process for separating particles of a solid material having at least a predetermined magnetic susceptibility from a mixture of said particles with other solid particles having a lower magnetic susceptibility, said process comprising: helically developing a flow of multi-phase alternating current around a tubular space whereby to form and maintain within said tubular space a magnetic field characterized by a plurality of planar north and south poles alternately disposed transversely to the longitudinal axis and substantially across the whole cross section of said tubular space, said magnetic field having a sufficient flux density effectively to magnetize said particles of solid material having at least said predetermined magnetic susceptibility: forming a suspension of said mixture in a fluid vehicle: introducing said suspension and advancing the same along a first pathway within said tubular space and extending lengthwise thereof, advancing said poles stepwise along said tubular space whereby the particles of material within said suspension which are effectively magnetized are advanced along said first pathway under the influence of the stepwise advancement of said poles: discharging said suspension from said first pathway into said tubular space: withdrawing along a second

pathway within said tubular space said fluid vehicle and suspended solid material which is not effectively magnetized and subsequently collecting such material; and continuing to advance said effectively magnetized particles within said tubular space under the influence of the stepwise movement of said poles to a point of collection and collecting the same.

2. A process for separating particles of a solid material having at least a predetermined magnetic susceptibility from a mixture of said particles with other solid particles having a lower magnetic susceptibility, said process comprising: helically developing a flow of multi-phase alternating current around a tubular space whereby to form and maintain within said tubular space a magnetic field characterized by a plurality of planar north and south poles alternately disposed transversely to the longitudinal axis and substantially across the whole cross section of said tubular space, said magnetic field having a sufficient flux density effectively to magnetize said particles of solid material having at least said predetermined magnetic susceptibility; forming a suspension of said mixture in a fluid vehicle; introducing said suspension and advancing the same along a first pathway within said tubular space and extending lengthwise thereof, advancing said poles stepwise along said tubular space whereby the particles of material within said suspension which are effectively magnetized are advanced along said first pathway under the influence of the stepwise advancement of said poles; discharging said suspension from said first pathway into said tubular space; withdrawing in a reverse direction along a second pathway within said tubular space said fluid vehicle and suspended solid material which is not effectively magnetized and subsequently collecting such material; and continuing to advance said effectively magnetized particles within said tubular space under the influence of the stepwise movement of said poles to a point of collection and collecting the same.

3. A method of separating particles consisting essentially of material having a magnetic susceptibility above a given value from a mixture of particles of said material with particles of material having a lower magnetic susceptibility, said method comprising: suspending said mixture in a stream of gaseous vehicle which is moving at sufficient velocity to transport said mixture; directing said stream and suspended mixture in a substantially vertical direction while confining said stream within an inner pathway; helically developing a flow of multi-phase alternating current around said pathway whereby to form and maintain within said pathway a magnetic field characterized by a plurality of planar north and south poles alternately disposed transversely to the longitudinal axis and substantially across the whole cross section of said pathway, said magnetic field having a sufficient flux density effectively to magnetize said particles of solid material having at least said predetermined magnetic susceptibility; synchronously moving all of said poles stepwise along said pathway concurrently with said stream whereby the effectively magnetized particles move under the influence of the stepwise movement of said poles, but the particles of lower magnetic susceptibility are substantially uninfluenced by said magnetic flux; providing an outer pathway substantially coaxial with and surrounding said inner pathway and continuing beyond the same, said outer pathway being subject to the said magnetic flux across substantially its whole cross section; directing said gaseous vehicle into said outer pathway in a reverse direction, whereby the particles of lower magnetic susceptibility are carried thereby in said reverse direction in said outer pathway, while the effectively magnetic particles continue to move in the original direction under the influence of the stepwise movement of said poles; and collecting separately the particles carried by said gaseous vehicle and the particles moving under the influence of said magnetic flux.

4. A method of separating particles consisting essen-

tially of material having a magnetic susceptibility above a given value from a mixture of particles of said material with particles of material having a lower magnetic susceptibility, said method comprising: suspending said mixture in a stream of liquid vehicle; directing said stream and suspended mixture in a substantially vertical direction while confining said stream within an inner pathway; helically developing a flow of multi-phase alternating current around said pathway whereby to form and maintain within said pathway a magnetic field characterized by a plurality of planar north and south poles alternating disposed transversely to the longitudinal axis and substantially across the whole cross section of said pathway, said magnetic field having a sufficient flux density effectively to magnetize said particles of solid material having at least said predetermined magnetic susceptibility; synchronously moving all of said poles stepwise along said pathway concurrently with said stream whereby the effectively magnetized particles move under influence of the stepwise movement of said poles, but particles of lower magnetic susceptibility are substantially uninfluenced by said magnetic flux; providing an outer pathway substantially coaxial with and surrounding said inner pathway and continuing beyond the same, said outer pathway being subject to the said magnetic flux across substantially its whole cross section; directing said liquid vehicle into said outer pathway in a reverse direction, whereby the particles of lower magnetic susceptibility are carried thereby in said reverse direction in said outer pathway, while the effectively magnetic particles continue to move in the original direction under the influence of the stepwise movement of said poles; and collecting separately the particles carried by said liquid vehicle and the particles moving under the influence of said magnetic flux.

5. A process for separating particles of solids material having at least a predetermined magnetic susceptibility from a mixture of said particles with other solid particles having a lower magnetic susceptibility, said process comprising: helically developing a flow of multi-phase alternating current around a tubular space whereby to form and maintain within said tubular space a magnetic field characterized by a plurality of planar north and south poles alternately disposed transversely to the longitudinal axis and substantially across the whole cross section of said tubular space, said magnetic field having a sufficient flux density effectively to magnetize said particles of solid material having at least said predetermined magnetic susceptibility; forming a suspension of said mixture in a fluid vehicle; introducing said suspension and advancing the same along a first pathway within said tubular space and extending lengthwise thereof, advancing said poles stepwise along said tubular space whereby the particles of material within said suspension which are effectively magnetized are advanced along said first pathway under the influence of the stepwise advancement of said poles; discharging said suspension from said first pathway into said tubular space; withdrawing along a second pathway in the lower side of and within said tubular space said fluid vehicle and suspended solid material which is not effectively magnetized and subsequently collecting such material; and continuing to advance said effectively magnetized particles within said tubular space under the influence of the stepwise movement of said poles across substantially the whole cross section of said tubular space to a point of collection and collecting the same.

6. The process defined in claim 5 wherein said tubular space is substantially horizontal.

7. A process for separating particles of a solid material having at least a predetermined magnetic susceptibility from a mixture of said particles with other solid particles having a lower magnetic susceptibility, said process comprising: helically developing a flow of multi-phase alternating current around a tubular space whereby to form and maintain within said tubular space a mag-

netic field characterized by a plurality of planar north and south poles alternately disposed transversely to the longitudinal axis and substantially across the whole cross section of said tubular space, said magnetic field having a sufficient flux of density effectively to magnetize said particles of solid material having at least said predetermined magnetic susceptibility: forming a suspension of said mixture in a fluid vehicle: introducing said suspension and advancing the same along a first pathway within said tubular space and extending lengthwise thereof, advancing said poles stepwise along said tubular space whereby the particles of material within said suspension which are effectively magnetized are advanced along said first pathway under the influence of the step wise advancement of said poles: discharging said suspension from said first pathway into said tubular space: withdrawing in a reverse direction along a second pathway within said tubular space said fluid vehicle and suspended solid material which is not effectively magnetized and subsequently collecting such material: and continuing to advance said effectively magnetized particles within said tubular space under the influence of the stepwise movement of said poles through a cleaning zone, introducing additional vehicle within said cleaning zone in a direction countercurrent to the movement of said effectively magnetized particles and advancing said effectively magnetized particles to a point of collection and collecting the same.

8. Apparatus for the production of concentrates from particulate mixtures of materials having different magnetic susceptibilities, said apparatus comprising: a tubular space having a conductor wound helically around and adjacent the surface thereof in the form of a solenoid, said tubular space defining a confined pathway through which material to be separated is passed, said confined pathway being composed of non-magnetic material, said solenoid being adapted, when appropriately energized to produce flux densities in the space within its coils of a magnitude sufficient effectively to magnetize the material in said particulate mixtures which it is desired to concentrate; excitation means for said solenoid adapted to energize the latter to produce said sufficient flux densities, said excitation means comprising a multiphase alternating current power supply, a series of taps connecting coils of said solenoid to each of the phases of said power supply, said taps being arranged in regular sequence along the length of the solenoid, the taps of a series connected to one phase being followed by the tap of a series connected to a later phase, and the taps of the series connected to the latest of said phases being followed by the taps of the series connected to the earliest of phases, whereby on supply of power to said solenoid a series of planar north and south poles are formed across sections of said solenoid corresponding to the positions of said taps, said series of north and south poles advancing along said solenoid from tap to tap at a rate determined by the frequency of the power supply; said tubular space extending axially into the space within the coils of said solenoid, and defining within said space a separation pathway for material; means for supplying and advancing along said separation pathway, a particulate material upon which separation is to be effected suspended in a fluid vehicle; a second tubular casing means composed of non-magnetic material within the coils of said solenoid separate from but communicating with the end of said separation pathway and defining a second pathway; means associated with said second pathway for withdrawing tailing and vehicle therealong; and means for collecting concentrate from the end of the space within the coils of said solenoid.

9. Apparatus for the production of concentrates from particulate mixtures of materials having different magnetic susceptibilities, said apparatus comprising: a tubular space having a conductor wound helically around and adjacent the surface thereof in the form of a solenoid,

said tubular space defining a confined pathway through which material to be separated is passed, said confined pathway being composed of non-magnetic material, said solenoid being adapted, when appropriately energized to produce flux densities in the space within its coils of a magnitude sufficient effectively to magnetize the material in said particulate mixtures which it is desired to concentrate; excitation means for said solenoid adapted to energize the latter to produce said sufficient flux densities, said excitation means comprising a multiphase alternating current power supply, a series of taps connecting coils of said solenoid to each of the phases of said power supply, said taps being arranged in regular sequence along the length of the solenoid, the taps of a series connected to one phase being followed by the tap of a series connected to a later phase, and the taps of the series connected to the latest of said phases being followed by the taps of the series connected to the earliest of phases, whereby on supply of power to said solenoid a series of planar north and south poles are formed across sections of said solenoid corresponding to the positions of said taps, said series of north and south poles advancing along said solenoid from tap to tap at a rate determined by the frequency of the power supply; said tubular space extending axially into the space within the coils of said solenoid, and defining within said space a separation pathway for material; means for supplying and advancing along said separation pathway, a particulate material upon which separation is to be effected suspended in a fluid vehicle; a second tubular casing means composed of non-magnetic material within the coils of said solenoid separate from but communicating with the end of said separation pathway and defining a second pathway; means associated with said second pathway for withdrawing tailing and vehicle therealong in a reverse direction; and means for collecting concentrate from the end of the space within the coils of said solenoid.

10. Apparatus as defined in claim 9 wherein said second tubular casing is of larger diameter than and concentric with said first tubular casing whereby to form between the walls of said first and second tubular casings a pathway within said solenoid for the withdrawal of vehicle and tailings in a reverse direction.

11. Apparatus as defined in claim 10 comprising means for the introduction of fresh vehicle within said second tubular casing beyond the end of said first tubular casing for countercurrent cleaning of concentrate.

12. Apparatus as defined in claim 10 wherein the windings of said solenoid are formed from tubes of a metallic substance selected from the group consisting of pure copper and niobium-tin alloys of low electrical resistance at low temperatures and in which means are provided for circulating a low temperature refrigerant through the tubes forming said coils.

13. Apparatus for the production of concentrates from particulate mixtures of materials having different magnetic susceptibilities, said apparatus comprising: a tubular space having a conductor wound helically around and adjacent the surface thereof in the form of a solenoid, said tubular space defining a confined pathway through which material to be separated is passed, said confined pathway being composed of non-magnetic material, said solenoid being adapted, when appropriately energized to produce flux densities in the space within its coils of a magnitude sufficient effectively to magnetize the material in said particulate mixtures which it is desired to concentrate; excitation means for said solenoid adapted to energize the latter to produce said sufficient flux densities, said excitation means comprising a multiphase alternating current power supply, a series of taps connecting coils of said solenoid to each of the phases of said power supply, said taps being arranged in regular sequence along the length of the solenoid, the taps of a series connected to one phase being followed by the tap of a series con-

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ected to a later phase, and the taps of the series connected to the latest of said phases being followed by the taps of the series connected to the earliest of phases, whereby on supply of power to said solenoid a series of planar north and south poles are formed across sections of said solenoid corresponding to the positions of said taps, said series of north and south poles advancing along said solenoid from tap to tap at a rate determined by the frequency of the power supply; said tubular space extending axially into the space within the coils of said solenoid, and defining within said space a separation pathway for material; means for supplying and advancing along said separation pathway, a particulate material upon which separation is to be effected suspended in a liquid vehicle; a second tubular casing means composed of non-magnetic material within the coils of said solenoid separate from but communicating with said separation pathway and defining a second pathway; means associated with said second pathway for withdrawing tailing and vehicle therealong concurrently with the material in said first pathway; means for collecting concentrate from the end of the first pathway; and means for collecting tailings from the end of said second pathway.

14. Apparatus as defined in claim 13 wherein said solenoid is disposed substantially horizontally and said second pathway is disposed at the lower side of said first pathway.

15. Apparatus for the production of concentrates from particulate mixtures of materials having different magnetic susceptibilities, said apparatus comprising: a tubular space having a conductor wound helically around and adjacent the surface thereof in the form of a solenoid, said tubular space defining a confined pathway through which material to be separated is passed, said confined pathway being composed of nonmagnetic material, said solenoid being adapted, when appropriately energized to produce flux densities in the space within its coils of a magnitude of at least 20,000 gauss that will effectively magnetize the material in said particulate mixtures which it is desired to concentrate; excitation means for said solenoid adapted to energize the latter to produce said sufficient flux densities, said excitation means comprising a multiphase alternating current power supply, a series of taps connecting coils of said solenoid to each of the

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phases of said power supply, said taps being arranged in regular sequence along the length of the solenoid, the taps of a series connected to one phase being followed by the tap of a series connected to a later phase, and the taps of the series connected to the latest of said phases being followed by the taps of the series connected to the earliest of phases, whereby on supply of power to said solenoid a series of planar north and south poles are formed across sections of said solenoid corresponding to the positions of said taps, said series of north and south poles advancing along said solenoid from tap to tap at a rate determined by the frequency of the power supply, the spacing between said taps being greater at the downstream end of said solenoid than at the upstream end thereof; said tubular space extending axially into the space within the coils of said solenoid, and defining within said space a separation pathway for material; means for supplying and advancing along said separation pathway, a particulate material upon which separation is to be effected suspended in a liquid vehicle; a second tubular casing means composed of non-magnetic material within the coils of said solenoid separate from but communicating with said separation pathway and defining a second pathway; means associated with said second pathway for withdrawing tailing and vehicle therealong concurrently with the material in said first pathway; means for collecting concentrate from the end of the first pathway; and means for collecting tailings from the end of said second pathway.

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