Feb. 17, 1953 G. A. FINK 2,628,785

METHOD AND MEANS FOR COMMINUTING SOLID PARTICLES

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Fig.1

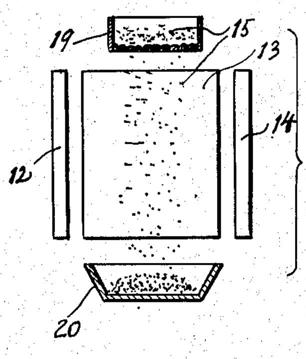


Fig. 2

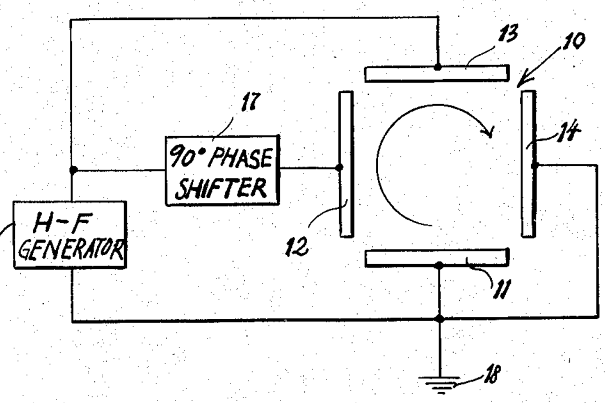
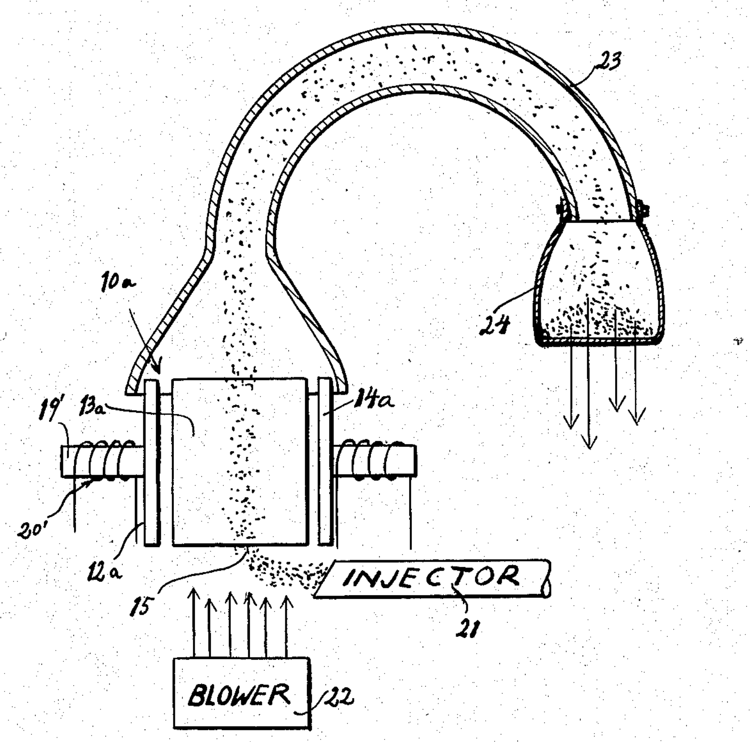


Fig. 3



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METHOD AND MEANS FOR COMMINUTING SOLID PARTICLES

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9 Claims. (Cl. 241—1)

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The present invention relates to a method of and means for comminuting particles of solid materials.

It is an object of the invention to provide a method of reducing the particle size of solid materials in a novel and expeditious manner.

It is another object of the invention to provide a method of and means for obtaining particles of a desired order of magnitude without resorting to repeated classifying (e. g. screening) processes.

When solid materials are comminuted in conventional devices such as ball mills, it will generally be found upon screening that a certain percentage of the particles have not been reduced to the desired size while others are considerably smaller than the norm. While the particles of the first group may be reprocessed and thereby ultimately brought to the proper dimensions, those of the second group cannot be enlarged and thus may be irretrievably lost for some purposes.

It is, accordingly, a further object of my invention to provide a method of and means for comminuting particles by subjecting them to forces which will be effective to reduce the size of the particle only where the latter exceeds a predetermined order of magnitude, but will be substantially ineffective for smaller particle sizes.

Still another object is to provide a method of and means for comminuting particles without incurring the risk of contamination such as will generally occur where, as in a ball mill, the particles come into violent contact with the surfaces of extraneous matter.

According to the present invention, I subject the particles to be comminuted to a force which will tend to rotate them at increasing speeds about their own centers of gravity, such rotation giving rise to centrifugal stresses within the particle which will be proportional to the square of the radius of gyration and, hence, roughly to the cross sectional area of the particle. The particles are preferably subjected to this force for a suitable length of time calculated so that all particles exceeding a given order of magnitude will attain the critical speed at which they are disintegrated.

In order to understand the operation of an arrangement according to my invention, it will be helpful to consider each particle as the short-circuited armature of an alternating-current motor, e. g. of the squirrel cage type, entrained by a rotating electromagnetic field. It can be shown that the torque applied to such armature will remain the same even if the axis of the armature

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no longer coincides with that of the field, that is, the armature will rotate irrespective of its location within the field provided the two axes are parallel or nearly so. The torque set up in the armature will tend to rotate the same at an angular velocity ω which ultimately approaches the value $2\pi f$, f being the frequency of the rotating field, this rotation giving rise to centrifugal forces proportional to the square of the effective diameter of the armature which, for a precalculable minimum radius, will overcome the cohesive forces of the material and break the armature in two.

Applying these principles to the particles under consideration, and assuming the shape of each particle to be that of a sphere of radius ρ, it can be shown that an alternating electromagnetic field of frequency f will induce currents in these particles resulting in a power loss

$$W=5.56\cdot 10^{-13}\cdot \epsilon f E^2 \alpha \text{ watts/cm.}^3$$

wherein E is the electric field strength and ϵ and α the dielectric constant and the power factor, respectively, of the material of which the particles are composed. The resulting torque M may be computed as $\rho^3 W/\omega$ or $8.85\cdot 10^{-7}\epsilon E^2\alpha\cdot\rho^3$ dyne-cm.

If the spherical particle has a density γ, then its moment of inertia will be given by the formula $I=8\pi/15\cdot\gamma\rho^5$ gram-cm.², whence the angular acceleration can be determined as

$$M/I=2.21\cdot 10^{-6}\cdot \epsilon^2\alpha/\gamma\rho^2$$

By assuming a constant acceleration we obtain a time of $2.84\cdot 10^6 f\rho^2\gamma/\epsilon E^2\alpha$ seconds as the time necessary to bring a particle up to the angular velocity $\omega=2\pi f$.

Actually, neither the torque nor the centrifugal stresses set up within the particle are susceptible to accurate calculation, owing to the irregular shape of the particle; the centrifugal force, however, will be of the order of magnitude of the stress existing in a thin ring or hoop whose diameter is equal to the diameter of a circle of an area equal to the maximum cross section of the particle in the plane of rotation which diameter we may again assume as 2ρ. This centrifugal force is given by the formula $F=4\pi 2\rho^2 f^2\gamma$ in which we may substitute r for ρ as the minimum radius at which disintegration should occur. The critical frequency can then be found by equating F to S, the latter being the tensile strength of the material.

In the accompanying drawing I have shown several arrangements for carrying the invention into practice. Fig. 1 is an elevation and Fig. 2

a schematic top view of a first arrangement according to the invention while Fig. 3 shows the invention in a modified form.

Referring first to Figs. 1 and 2, there are shown four electrodes 11, 12, 13 and 14 defining a chute 10 within which particles 15 may fall freely while being subjected to the influence of a rotating electric field. In order to produce the rotating field, electrodes 11 and 13 are connected directly across a high-frequency generator 16 which latter also energizes electrodes 12 and 14 over a 90° phase shifter 17. Electrodes 11 and 14 are grounded as indicated at 18, electrode 11 having been removed in Fig. 1 in order to show the interior of chute 10.

The particles 15 may enter the chute by way of a suitable screen 19 and may be collected at the bottom by a vessel 20. It will be appreciated that the chute 10 should be wide enough to insure a substantial uniform electric field across the path of the falling particles 15, the length of the chute being selected so that even the largest particles will find time to be sufficiently accelerated, as previously discussed, before reaching the bottom of the chute.

From the foregoing it will have been understood that the frequency of generator 16 determines the size of the particles ultimately obtained, higher frequencies resulting in smaller particles. High frequencies. on the other hand, tend to discriminate against large particles since the latter may not find time to accelerate to the final angular velocity $2\pi f$. To overcome this difficulty, I have illustrated in Fig. 3 an arrangement whereby particles may be exposed to a rotating field for an extended length of time without requiring a chute of impractical proportions. Fig. 3 also illustrates how the particles may be treated in a rotating magnetic rather than electric field. Chute 10*a* is here formed by four pole shoes of which only three, indicated at 12*a*, 13*a* and 14*a*, respectively, are shown, each pole shoe being an extension of a core 19′ of an electromagnetic coil 20′ connected to a suitable source of alternating current (not shown). Particles 15 are introduced into the chute from below, by means of an injector 21, being carried upwards by a stream of air produced by a blower 22. The particles are collected in a tube 23, of inverted U-shape, to the end of which a bag 24 is attached. The porosity of the bag should be such that air from the blower 22 may readily pass therethrough while the particles will be retained, this principle being generally applied in vacuum cleaners.

The arrangement of Fig. 3 has the additional advantage of counteracting the aforesaid discrimination against large-size particles, inasmuch as the smaller, lighter particles will pass more quickly through the chute 10*a* whereas the heavier ones will float for a longer period. If necessary, the air stream may be replaced by some inert gas in order to prevent oxidation of the particles during treatment, and similarly the process of Figs. 1 and 2 may be carried out in an inert atmosphere or in vacuum.

It will be understood that the formulae given above apply to the production of an electromagnetic field by electrostatic means, as illustrated in Figs. 1 and 2, but that similar formulae may be developed for the magnetic arrangement shown in Fig. 3. In the latter case, the permeability of the material of the particles will be a factor in lieu of the dielectric constant and the power factor thereof.

If the particles are composed, for example, of calcium carbonate (marble) which is a dielectric material sometimes used for insulating purposes, the frequency necessary for breaking up particles of a given diameter, say 10 microns, may be determined from the above formula for the centrifugal stress by inserting for S the value of 2000 p. s. i. or $1.38\cdot10^8$ dynes/cm.^{2}. This gives us a frequency of 2.26 megacycles per second which is easily obtainable. By inserting the values of 2.72 for γ, .04 for α, 13,000 for E and 8.3 for ϵ in the above formula for the time of acceleration, the latter will be established at .078 second, a very convenient value which corresponds to a free drop of roughly 3 cm. If the potential of 13,000 volts per cm. is too high, or if materials having a lower dielectric constant and/or power factor are used, the required length of the chute may be reduced by artificially increasing the power factor of the particles as by suitable coating, moistening or heating the same.

It will have become apparent from the foregoing that the loss factor of the particles to be disintegrated, i. e. the product of their dielectric constant ϵ and their power factor α, must be determined to enable proper selection of field strength, frequency and other parameters previously indicated. This loss factor can be established experimentally, on the basis of the above formula for the torque M, whence

$$\epsilon\alpha=\frac{M\cdot10^7}{8.85\cdot E^2\cdot\rho^3}$$

or, approximately, $5\cdot10^6\cdot M/E^2V$ wherein V is the volume of a spherical particle of radius ρ.

Inasmuch as this loss factor is thus independent of frequency, it can be determined with the aid of a rotating field of any convenient frequency, using the same principles as those on which the invention is based. Practical tests, which incidentally proved the correctness of the underlying theory, have been carried out on different materials, yielding the following results:

Material:	Loss factor
Aluminum oxide (coarse)	0.12
Aluminum oxide (fine)	0.26
Magnesium oxide	1.44
Ferric oxide (rouge)	1.20
Silicon carbide, 80 mesh	0.13
Slate (chips)	0.19
Soapstone (block)	0.11
Talc, powder (average particle size about 15 microns)	0.72

These tests were carried out as follows:

The materials to be tested, usually in powder form, were placed in a cup made of a material known to have an extremely low power factor, in the actual case polystyrene. The cup had a depth of 4.9 cm. and an inside diameter of 2.25 cm. The cup was suspended by a calibrated torsion wire approximately in the center of a plate assembly as shown in Fig. 2, to which alternating fields of about 2500 volts, shifted in phase by 90° as previously described, were applied. With a plate spacing of 5.25 cm. the field strength E, whose frequency was the commercial one of 60 cycles per second, was of the order of 500 volts/cm.

As was to be expected in view of the low power factor of polystyrene, no measurable torque was exerted by the field upon the empty cup, hence no corrections had to be applied to the torque measured when the material to be tested was placed inside the cup. The torque of the filled cup was determined with the aid of a mirror fastened to the lower end of the wire, by means of a telescope-and-scale reading device.

From the loss factor thus determined for the particular material at hand, and from the known initial and the desired ultimate particle size, the remaining variables such as, for example, chute length (given a particular field strength and frequency) may be readily computed.

Example

Marble particles ranging in diameter from 5 to 40 microns are to be comminuted in a field as above set forth, i. e. of 13,000 volts per cm. and 2.26 megacycles per second, until substantially all the larger particles have been reduced to a magnitude of less than 10 microns in diameter.

It has already been shown that a time T of 0.078 second will suffice to let the smallest particles to be broken up, i. e. those having the limiting diameter of 10 microns, attain a speed sufficient for their disintegration. With respect to the largest particles, i. e. those of 40 microns in diameter, it will be noted from the foregoing formula for the centrifugal force that they need only be accelerated to an angular velocity of about $\omega/4$ to attain the desired result. From the acceleration formula previously given it will further be apparent that this angular velocity will be attained by said large particles after a time of about 4T, or approximately 0.3 second; this represents a free drop of roughly 45 cm. The resulting fragments, having a mean diameter of 20 microns, must be further accelerated to an angular velocity of about $\omega/2$ which, again from the formula mentioned, may be computed as occurring within a time T or 0.78 second approximately. This step yields particles of about 10 microns in diameter which, having already an angular velocity of $\omega/2$, only need to be accelerated over a time T/2 to attain the velocity ω, the total procedure thus requiring a time of a little above 0.4 second corresponding to a drop of about 90 cm. It will thus be apparent that a chute length of less than 1 m. is required to disintegrate particles of the size mentioned to one-eighth of their original linear extent yet that at the same time all particles of lesser size will be broken up to not less than the same general order of magnitude. The foregoing example applies, apart from the fact that it is based on a number of approximations, only in a vacuum or at very reduced pressure, since otherwise a decrease in acceleration due to the effects of friction will have to be taken into account.

In passing it may be noted that whereas the disintegrating forces will have their maximum effect in a plane perpendicular to the field and will have no effect in a direction parallel thereto, the action of the centrifugal forces will tend to position each original particle or resulting fragment with its major dimension in such perpendicular plane, whereby disintegration will be substantially uniform in all dimensions.

It is understood that the specific values herein referred to have been given in an illustrative and not in a limiting sense, and that the invention may be embodied in arrangements other than those specifically described and illustrated without departing from its spirit or exceeding its scope as defined in the objects and in the appended claims.

I claim:

1. The method of comminuting solid particles which comprises the steps of producing a rotating electromagnetic field of high frequency, passing the particles to be comminuted through said field substantially in the direction of its axis of rotation, and so controlling the time of transit of said particles through said field that said particles, rotatively entrained by said field, attain an angular velocity sufficient to cause disintegration of substantially all particles exceeding a given order of magnitude.

2. The method of comminuting solid particles which comprises the steps of producing a rotating electromagnetic field of high frequency, said field having a substantially vertical axis of rotation, dropping the particles to be comminuted through said field, and so controlling the time of transit of said particles through said field that said particles, rotatively entrained by said field, attain an angular velocity sufficient to cause disintegration of substantially all particles exceeding a given order of magnitude.

3. The method according to claim 1, wherein the particles to be comminuted consist of dielectric material, comprising the further step of increasing the power factor of said particles prior to dropping them through said field.

4. The method of comminuting solid particles which comprises the steps of producing a rotating electromagnetic field at high frequency, said field having a substantially vertical axis of rotation, floating the particles to be comminuted through said field in an upward direction, and so controlling the time of transit of said particles through said field that said particles, rotatively entrained by said field, attain an angular velocity sufficient to cause disintegration of substantially all particles exceeding a given order of magnitude.

5. An arrangement for comminuting solid particles, comprising a source of high frequency alternating current, at least four electrode plates connected across said source with a progressive phase shift, thereby setting up a rotating electrostatic field of an angular velocity exceeding that at which particles of a given material exceeding a predetermined order of magnitude will be centrifugally disintegrated, said electrode plates forming a chute coaxial with the axis of rotation of said field, and feed means adapted to pass the particles to be comminuted through said chute in spaced relation to the walls thereof and at a rate allowing said particles to approach the angular velocity of said field.

6. The arrangement according to claim 5 wherein said chute is substantially vertically disposed, said feed means comprising a screen located at the top of said chute.

7. The arrangement according to claim 5, wherein said chute is substantially vertically disposed, said feed means comprising blower means adapted to produce an upward-traveling gas stream within said chute and injector means adapted to introduce said particles into said gas stream adjacent the bottom of said chute.

8. The method of comminuting solid particles of a given material which comprises the steps of producing an electromagnetic field rotating about a substantially vertical axis at an angular velocity exceeding that at which those of said particles which exceed a predetermined order of magnitude will be centrifugally disintegrated, introducing the particles to be comminuted into said field, creating an upwardly directed gas stream in said field, and floating said particles on said gas stream until said particles, rota-

tively entrained by said field, attain an angular velocity approaching that of said field.

9. The method of comminuting solid particles of a given material of density γ and tensile strength S which comprises the steps of producing an electrostatic field rotating at an angular velocity in excess of a value ω given by the formula

$$\omega=\sqrt{\frac{S}{r^2\gamma}}$$

wherein r is the diameter of the smallest particles to be comminuted, introducing the particles to be comminuted into said field, thereby causing said particles to be rotatively entrained by said field, retaining said particles in said field for a sufficient length of time to allow them to reach an angular velocity between ω and the velocity of said field, and removing the particles from the field after at least a major portion of

those exceeding said predetermined order of magnitude have been disintegrated.

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