

[54] **APPARATUS FOR PELLETIZING
POWDEROUS MATERIALS BY
VIBRATIONAL FORCES**

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264/69; 198/220 A, 220 BA, 220 DB, 220 DC

[56]

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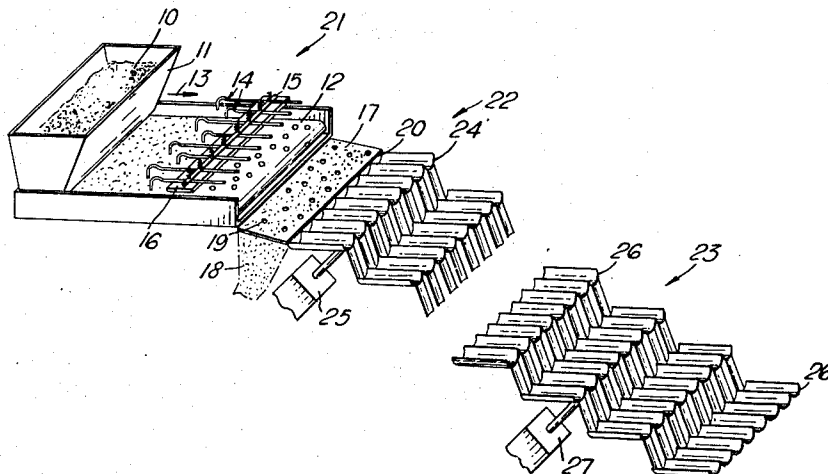
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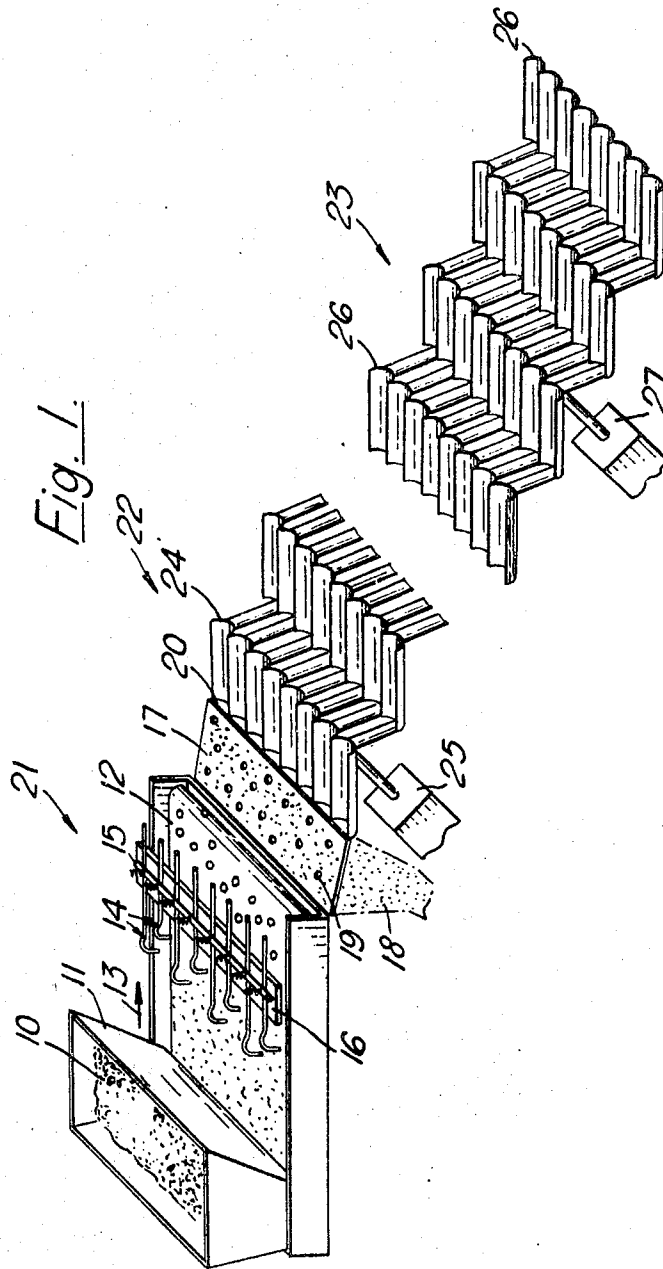
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ABSTRACT

An apparatus for pelletizing powderous materials, such as iron ore and alumina, the apparatus including rows of vibrating trough-like members, each row being spaced below the preceding row so that primary pellets fed into the apparatus pass from the top row to the bottom row of trough-like members and are formed into hard pellets.

11 Claims, 7 Drawing Figures





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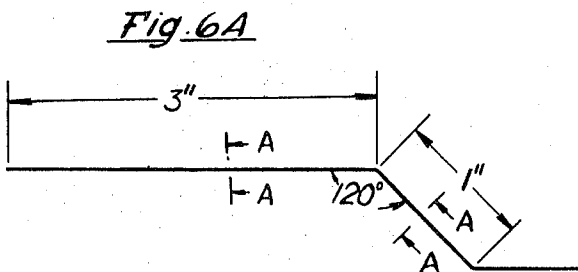
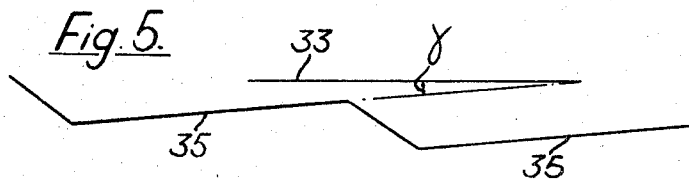
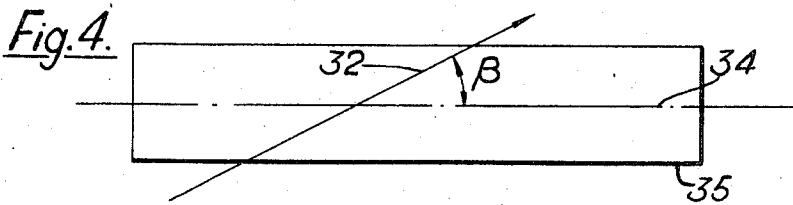
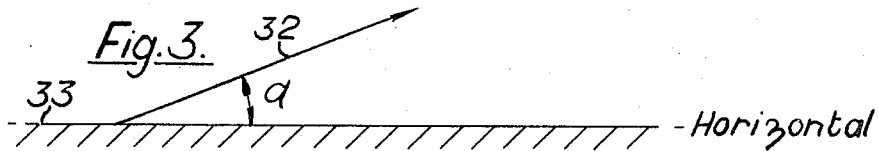
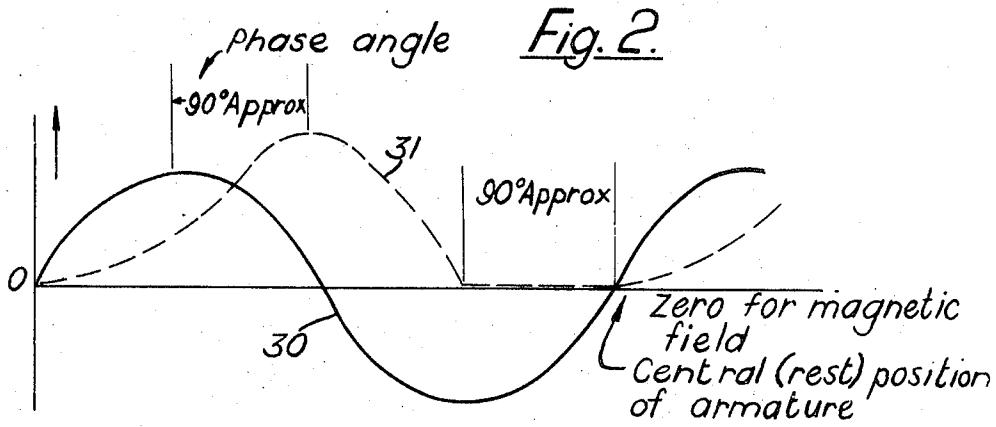


Fig. 6B
SECTION A-A.



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APPARATUS FOR PELLETIZING POWDEROUS MATERIALS BY VIBRATIONAL FORCES

This invention relates to apparatus and a method for pelletizing material from powder form by vibrating forces.

Apparatus has previously been proposed for pelletizing powderous material and one such apparatus has included a vibrating feeder trough containing powder to which is then added a liquid binder. Subsequent vibration results in the formation of primary pellets or lumps of varying sizes which are then subjected to a particular vibrating motion so that they recirculate in the feeder trough in a predetermined manner and accumulate more powder and, to some extent, acquire a hard exterior due to the hammering action as a result of the vibratory motion. In another proposed apparatus, a rolling action has been proposed for balling fine grained material into a conglomerate, ball-like mass suitable for sintering. However, such previously proposed apparatus has often been relatively expensive to manufacture and not capable of sufficient control to ensure that the final hard pellets were of substantially uniform shape and size, as is desirable in many operations.

From one aspect of the present invention, it is an object to provide apparatus for pelletizing powderous materials wherein greater control may be achieved of the final size and shape of the pellets produced by means of the apparatus.

According to this aspect there is provided apparatus for pelletizing powderous materials including means for feeding primary pellets formed from said powderous material and a binder to vibratile means comprising a plurality spaced-apart members each at a different level and forming a path for movement of said primary pellets therealong, and vibrator means capable of causing said members to vibrate in a predetermined manner to cause said primary pellets to move down said path, the vibration, in operation, forming said primary pellets into hard pellets.

From another aspect of the present invention there is provided a method of pelletizing powderous materials wherein greater control may be achieved of the final size and shape of the pellets produced by means of the method.

According to this aspect of the invention there is provided a method of pelletizing powderous materials including the steps of forming primary pellets from powderous material and a binder, feeding said primary pellets to vibratile means comprising a plurality of spaced-apart members each at a different level and forming a path for movement of said primary pellets therealong, vibrating said members in a predetermined manner to move said primary pellets down said path, the vibration forming said primary pellets into hard pellets.

An embodiment of the present invention will now be described by way of example with reference to the accompanying drawings in which:

FIG. 1 is a diagrammatic perspective view of apparatus for pelletizing powderous materials according to the present invention;

FIG. 2 is a graphical representation of the relative phase-angle of the force on the vibrator armature and the motion thereof during vibration of the troughlike members of FIG. 1;

FIG. 3 is a vectorial representation of the angle α between the horizontal and the angle representing the direction of vibration;

FIG. 4 is a vectorial representation of the angle β between the vertical plane through the vibration vector and the horizontal projection of the centerline of a troughlike member;

FIG. 5 is a diagrammatic representation of the angle of elevation γ made with the horizontal by the longitudinal, nearly horizontal, portion of each troughlike member; and

FIGS. 6A and 6B are a diagrammatic representation of the contour of the troughlike members.

Referring to FIG. 1, there is diagrammatically illustrated a perspective view of apparatus for pelletizing powderous materials according to the present invention. A liquid binder is initially added to the powderous material so as to form crude lumps, i.e., primary pellets, of appropriate size and moisture content and these primary pellets are subsequently subjected

to a continuous vibratory motion as they proceed along a predetermined path through the apparatus.

The powder 10 is fed by way of a hopper 11 onto the upper surface of a vibrating conveyor means 12. The powder needs to flow readily and, of course, may have to be dried or otherwise treated to achieve this condition. It is fed as a shallow bed of moderately aerated (i.e., not compacted) powder on the vibrating conveyor 12, although it will be appreciated that a belt conveyor may be substituted therefor if desired. As the bed of powder moved along the vibrating conveyor in the direction of arrow 13, a metered quantity of a binding liquid, for example water, is injected onto the top surface of the bed of powder. Capillary action causes water to enter the powder bed so as to form a shapeless mass, and this can be regarded as the embryo pellet, i.e., primary pellet. The water is injected onto the powder by way of a plurality of nozzles 14 connected by flexible tubing to a reservoir (not shown) of the water binding liquid and the reservoir is so located as to give the correct hydrostatic head at the nozzle opening for proper operating of the apparatus. Flow of water to the nozzles is controlled and could be stopped by means of a spring-loaded bar 15 capable of pressing each of the flexible tubes against a base plate 16 so as to cut off the flow of liquid. Control of the motion of the spring-loaded bar or arm 15 is achieved by means of a motor-driven cam arrangement (not shown) capable of lifting the spring-loaded bar 15 at predetermined intervals so as to permit the flow of liquid through the flexible tubing, out of the nozzles thereof and onto the surface of the bed of powder.

It will be appreciated that the shape and size of the primary pellet will depend on certain parameters. Parameters of significance include:

- the quantity of liquid permitted to flow through the nozzles 14 from the reservoir of liquid;
- the time duration of the injection of the water binding liquid through the nozzles;
- the velocity of impact of the slug of water on the bed of powder and
- the angle between the axis of the injection nozzles 14 and the surface of the bed powder on the vibrating conveyor 12.

Vibration of the vibrating conveyor 12 causes the powder thereon, including the formed primary pellets, to be vibrated onto a vibrating screen 17 formed from tubular wires having a predetermined diameter and spaced apart by a predetermined distance. The tubular wires are caused to be heated by an internal electric heating wire (not shown) so as to heat the screen to a predetermined temperature. Because of the construction of the screen as a grizzly screen, the powder which has not formed into primary pellets passes through the wire screen 17 and this surplus powder 18 is removed for further processing. However, the primary pellets 19 which have been formed are not able to pass through the wire mesh screen and therefore are vibrated by the apparatus across the screen 17 until they drop over the edge 20 thereof. The apparatus, up to this point including the vibrating conveyor 12 and the wire screen 17, may be regarded as the first stage 21 of the apparatus according to the present invention, there being two further stages 22 and 23 each comprising a plurality of troughlike members, such as 24, each having a semicircular cross section.

Stage 22 consists of 10 rows of semicircular troughlike members 24, each row comprising 8 troughlike members. The width of each semicircular trough will, of course, depend on the size of the pellet being processed but in one construction, the width was eleven sixteenths inch and each troughlike member 24 was arranged with its leading edge in the direction of movement of a pellet, i.e., arrow 13, above the trailing edge of the same troughlike member so that each troughlike member 24 sloped backwards at approximately 1° to the horizontal. Thus the training edge of each trough was below the leading edge of the preceding troughlike member 24 and thus, during operation, each primary pellet pellet under gravity from one troughlike member in the series to the next troughlike member 24 in the series in the direction of motion

of the primary pellets, arrow 13, the trailing edge of each troughlike member 24 being stepped seven-eighths inch below the leading edge of the preceding troughlike member, each troughlike member 24 being 3 inches in length. Heating means (not shown) is also provided for the troughlike members of stage 22 so as to heat the troughlike members to a temperature of about 500° F.

Vibrating apparatus 25 is also provided to produce vibration of the troughlike members at a frequency of 60 cycles per second with an amplitude of 0.040 inch. The angle of vibration was arranged to be 43° with the horizontal while the plane of vibration was at an angle of 30° with the longitudinal axis of the troughlike members 24.

In stage 22 each primary pellet was caused to rotate in two directions during its passage along each troughlike member 24. The primary pellet was caused to rotate forwards about a horizontal axis which was itself normal to the longitudinal axis of the troughlike members 24 and also sideways in each respective troughlike member about an axis which was parallel to the longitudinal axis of the respective troughlike member 24. In the constructed apparatus, each primary pellet took 10 seconds to pass through the second stage 22 while two primary pellets were processed by the second stage every 1 second. The pellets had a diameter of from one-half to five-eighths inch and after passing through stage 22 the primary pellets fell, under gravity, into the first troughlike member 26 of the third stage 23 (FIG. 1). Stage 22 is concerned with the forming of the primary pellet into a spherically shaped pellet and the number of troughlike members provided therein, side by side, is determined by the desired production rate. In the constructed apparatus, stage 23 was provided to harden and strengthen the pellet. This stage follows immediately on stage 22 and is actually integral therewith although it need not be. The general construction of stage 23 is the same as stage 22 except that 9 rows of troughlike members 26, i.e., steps, are provided. The surface temperature of each troughlike member was arranged to be around 350° F., although in some applications 133° C. was found to be best. The troughlike members 26 of the third stage 23 were caused to vibrate by vibrating means 27 so as to impart a particular motion to each pellet passing therethrough. The motion of the pellet was arranged to be slightly different to the motion during passage through the second stage 22 and each pellet was caused to rotate backwards rapidly and also sideways at the same velocity as in the second stage. Each pellet took approximately 8 seconds to pass the third stage 23 and when the original powder was ground hematite, see below, the final pellet from stage 23 had a diameter which was between one-half and five-eighths inch, a mass between 5.5 and 6 grams, and a final moisture content of 7 to 8 percent when dried at 350° F. The resultant pellets withstood 10 drops under gravity, each drop being 18 inches. No binder other than ordinary tap water was used.

As mentioned above, apparatus according to the present invention was used to form pellets from powdery hematite. A bed of ground hematite (90 percent minus 375 mesh) was conveyed through the first stage 21 at a rate of 1 to 1½ inches per second in a bed which was 1¼ inches deep and 7 inches wide. The ground hematite was conveyed by a vibrating conveyor which vibrated at 60 cycles per second with an amplitude between 0.005 and 0.020 inches. The slope of the bed was arranged, in this instance, to be, 0° and the row of nozzles was arranged with the nozzles one inch apart and one-half inch above the powdery bed of hematite, the diameter of each nozzle being 0.07 inches. Each nozzle was connected by flexible tubing to a reservoir of binding liquid, water, so as to give a hydrostatic head of 22 inches at the nozzle opening. As stated above, the flow was allowed to occur for 0.2 seconds under the control of a motor-driven cam which lifted bar 15 every second to permit liquid to flow through the nozzles. The quantity of liquid, i.e., water, that was injected each time was between 0.55 and 0.6 cc. The nozzles were arranged at an angle of 90° to the horizontal, i.e., vertical. They were posi-

tioned 3 inches from the place at which the powder 10 emerged from the hopper 11 onto the conveyor 12 and the primary pellet was conveyed 9 inches before it and the residual dry powder passed over the vibrating screen 17 of tubular wire having a diameter 0.130 inches. The spacing between the tubular wires of the screen 17 was arranged to be one-half inch and the wires were electrically heated by an internal electric heating wire so as to be at a temperature of approximately 800° F. As will be appreciated, the surplus powder 18 passed through the screen 17 while the primary pellets, having a mass of 6 grams, did not pass through the screen 17 but continued to fall, under gravity, over the edge 20 onto the first row of troughlike members 24 in the second stage 22. After passing through the second stage 22, the pellets then continued through the third stage 23.

It will be appreciated that the position of the nozzles 14 connected to the flexible tubing may be adjusted in position up or down the bed of powdery material, i.e., parallel to arrow 13 (FIG. 1), during operation of the illustrated apparatus. It will also be appreciated that, while the troughlike members have been described and illustrated as of semicircular cross section, they may have any convenient shape, for example, some or all of the troughlike members may be V-shaped or U-shaped. In some cases it would appear that even troughlike members of square or rectangular cross section could be utilized in apparatus according to the present invention. Furthermore, the troughlike members may be covered in some operations. The second and third stages 22 and 23, i.e., first and second stages having troughlike members, have been described as integral and vibrating together. It will be appreciated that the vibratile means may, alternatively, comprise two separate such stages with the troughlike members thereof vibrating at a different frequency and with different characteristics.

In apparatus constructed according to the present invention, a detailed investigation was made as to certain characteristics of the apparatus. Particular interest was initially centered around the harmonic content of the mechanical vibration of the troughlike members in FIG. 1. To investigate this, a displacement transducer (Daytronic Model DF 160-C) was attached to the troughlike members and connected electrically to a Sanborn 311A transducer controller. The output of the latter was connected to (a) an oscilloscope and (b) a spectral analyzer (a Bjuel and Kjaer Type 2107). The operation of the Syntron vibrators used was determined by the number of springs in their spring system and it was found that the waveform obtained on the oscilloscope appeared to be sinusoidal with all values of spring stiffness used. This visual observation is not, of course, a good test of harmonic purity, but it showed that there was no marked "square wave" or abrupt decelerative or accelerative portions of the wave. The spectral analysis was not particularly enlightening either. Before stating what was found, it should be explained that the vibrators used, consisting of a vibrating armature of iron and rigidly connected to the troughlike members, was caused to move back and forth under the influence of the magnetic force from an electromagnet and the spring system. The electromagnet was supplied with half-wave rectified current so that periodic unidirectional impulses were fed to the armature. The stiffness of the springs could be varied by adding or subtracting leaves, and the process is normally referred to as "tuning." In the normal course of events, for a machine designed for conveying, tuning was carried out so that material on the trough stages was conveyed with a minimum of both energy consumption and of material breakage, and yet at the maximum rate possible. In the constructed apparatus, the purpose of the tuning was to form the pellets into the right shape with minimum energy and in the shortest time.

To return to the measurements, it was found that when the vibrator spring was weak (19 spring leaves), all the energy was at 60 cycles per second when the amplitude was greater than ±0.02 inches. With smaller amplitudes a small amount of 120 c./s. component was detected.

When the spring was stiff (using 22 spring leaves) the ratio of the amplitude of the 60 c./s. waves to that of the 120 c./s. waves was 4.5 to 1. These were the only components found. It would seem that although the harmonic content of the vibration must be the only thing that can affect the process apart from amplitude, it seems to be a somewhat insensitive criterion. In any case, it appeared to be a rather difficult thing to synthesise artificially. Accordingly some other measurements were made and these seem to provide a more reliable means of scale—up and design—at least when similar vibrators and troughs are used. These measurements will now be described.

(1) The Relative Phase-angle Between the Force on the Vibration Armature and the Motion of the Vibrator Armature

It was assumed that the magnetic field in the airgap between the face of the electromagnet core and the armature was a measure of the magnitude and phase of the force acting on the armature. Even if it is not, the magnetic wave can still be used as a design criterion for the particular model of the vibrator used (a syntron F-152-2). Accordingly a Gaussmeter (Bell model 110) was used to measure the magnetic wave, and the outputs from this and the transducer controller were compared by an AD-YU type 406H phase meter. FIG. 2 shows diagrammatically the shape of the displacement wave 30 and the magnetic field strength wave 31. It will be seen that the displacement wave is, as already stated, approximately sinusoidal but the magnetic wave 31 is distorted from the half-wave rectified sine wave that would be expected.

In the description below, the phase-angle referred to is the angle measured and indicated by the AD-YU phase-meter but the exact meaning of phase angle when one of the waves is badly distorted is open to doubt. However, it was found to be a useful design criterion in the constructed apparatus, for this phase angle depended markedly on the spring stiffness. That is to say the portion of the movement cycle over which the force is applied depends on the spring stiffness, and most importantly, the "goodness" of pellet-making seemed to depend on this phase-angle. It was found that the best phase angle ("best" in the sense of making pellets having a maximum strength, minimum breakage, in minimum time and with minimum energy) was 90° and this is shown in FIG. 2. It is an approximation because the magnetic wave was impure. Thus, the maximum force is applied when the trough, comprising the troughlike members, is moving at its maximum speed in the same direction as the force is applied. This appears to be a desirable critical design criterion (others are described below) in that this optimum angle was first found on a single troughlike member; when the larger multi-member trough had its vibrators tuned so that the phase-angle was again 90° it was found that the pellets it made were of the same good quality and were made in about the same residence time.

If the stiffness of the spring was increased the phase-angle was increased, more power was needed from the vibrator and the pellets were found to spin rapidly with very little forward motion to destroy themselves. If the spring stiffness was decreased, or if the weight of the trough was increased, the phase-angle was decreased (by up to 90°) and there was then a tendency to get "resonance" with large amplitudes. When the springs have this low stiffness (but without being so soft that resonance occurs) the pellets were conveyed forward very rapidly without spinning, and tended to destroy themselves.

(2) Other design criteria which appeared to influence the efficacy of the process, and which are of varying degrees of criticality are discussed below. They are:

2.1 Trough Temperature

The trough, stages 22 and 23, needed to be heated to prevent the pellet from sticking. Too low a temperature was ineffectual; too high a temperature caused steam to form at the surface of the pellet, thus cushioning the vibration and making the ball not only lose mechanical contact with the trough but also causing too great a loss of moisture, i.e., the ball became too dry to deform to the desired shape. The optimum temperature for stage 23 was found to be 130° C., $\pm$ about 5° C.

2.2 Material Being Balled, i.e., formed into pellets

The material being pelletized and its particle size distribution affected the ease or even the possibility of balling but the designer does not appear to have very much freedom here. The size-distribution will be determined partly by the need for sufficient size reduction to free the valuable mineral from worthless gangue, and partly by the fact that this size distribution affects the strength of a ball irrespective of the mode of pelletizing.

In the present series of tests four classes of material were used:

2.2.1 - Hematite (representing material difficult to ball).

This was a specular hematite from Labrador, Canada, containing 40 percent iron ground 90%—325 mesh but with the finest material blown out.

2.2.2 - Magnetite (75%—325 mesh) and non-swelling clays.

These represent materials reasonably easy to ball. The magnetite was a cobber concentrate of a taconite ore from Northwestern Ontario containing 50 percent soluble iron.

2.2.3 - Alumina dust (ex "multiclones") of Aluminum Company of Canada, Arvida, Province of Quebec, representing material easy to pelletize.

2.3 the angle α between the vector 32 (FIG. 3) representing the direction of vibration and the horizontal 33. The angle of 20° was found to be a very useful angle and the useful range extended up to 60°.

2.4 The angle β between the vertical plane containing the vibration vector 32 and the horizontal projection 34 of the centerline of a troughlike member 35 (FIG. 4—projection being onto a horizontal plane). The minimum usable angle was 15° and the useful range extended up to 60°.

2.5 The angle of elevation γ between the horizontal 33 and the long, nearly horizontal, portion of each troughlike member 35 (FIG. 5). For different materials the "best" value of γ was found to be:

For hematite: 6°

For magnetite: 3°

For alumina: 3°

2.6 The contour of the troughlike members was found to be of significance. Typical dimensions and contour are illustrated in FIG. 6.

2.7 The amplitude of vibration, from midpoint to peak, was found to be equal to 0.035 inches, (measured by a "V-sticker," supplied by Syntron, and mounted so as to measure the vibrations along the vibration vector).

2.8 The initial amount of liquid in the primary pellet, i.e., its moisture content, depended on the solid being balled. For example, with the hematite powdery material, it seemed that it must be not less than 12½ percent and not more than 13½ percent (wt/wt).

2.9 The phase angle between the magnetic wave and the displacement wave for maximum efficiency appeared to be approximately 90°, as shown in FIG. 2.

2.10 The weight of mechanical parts being vibrated is apparently significant. It was kept in the range specified by the manufacturer of the vibrator. When tuned, it was found that the weight must not be altered by more than ± 5 percent. The weight of the conveyed material seemed to have little effect.

3. After pelletizing, the final pellets were tested at different points in the subsequent processing procedure to determine their properties.

3.1 The testing procedure was:

3.1.1—For wet (green) pellets

Pellets were dropped from a height of 18 inches onto a hard surface. The number of these drops that the pellets could stand before 50 percent of the mass was broken sufficiently to be sieved out was taken as a strength criterion. In the series of tests the pellet was rated "good" if the number of drops was at least 10; and "excellent" if in 10 drops no breakage occurred and if in addition, the ball, i.e., pellet, was spherical.

3.1.2—Dried Pellets

Dried iron ore pellets were not tested. Dried alumina pellets were tested in compression between flat plates in a Chicago Testing Company's 1,000-lb. ring deflection press or, alternatively, by pressing on a 10-kg. Mettler balance.

3.1.3—Fired Pellets

A few measurements of compression strength were done on fired pellets.

3.2 The results of the testing of the quality of the balls, i.e., pellets, was as follows:

With the compacting trough variables adjusted to the optimum values described above, it was possible to make balls of the following kinds. All balls were 5/8 inch dia. $\pm 1/32$ inch.

3.2.1—Iron Ore

Hematite (no binder) "good" to "excellent" in green strength.

Magnetite (no binder) "excellent" in green strength.

Additions of bentonite tended to make the balls "rubbery" and to break up when being formed.

3.2.2—Alumina

The binder was water or dilute sodium hydroxide solution of concentrations ranging from 0.25 to 2.5 normal. The balls were formed extremely readily; the green balls withstood from 3 to 7 (18-inch) drops, those made with sodium hydroxide being stronger. Dried pellets showed crushing strengths ranging from about zero (for those for which water was the binder) to 2.1 lbs. (Much stronger dry-strengths could be attained after an autoclave treatment.)

3.3—Structure of the Balls

The cross-sectional fracture of the balls showed a very uniform structure, there being no layering or agglomerations of lumps.

A measurement on a fired hematite pellet of the pore-size distribution by mercury porosimeter showed that this distribution was a very narrow one, centered at 6 microns, with a majority of the pore volume lying in the range 3 to 8 microns.

This uniformity of structure is an attractive feature of the pellets; it would be expected to give reduced risks of spalling and cracking, and high and uniform rates of reduction. Indeed any chemical reaction in which pellets so produced are involved should be consistently uniform and rapid, and this process may well be applicable to making pellets from catalysts. In the above description considerable detailed experimental results have been given in connection with the conversion of the primary pellet issuing off screen 17 (FIG. 1) onto the first set of troughlike members in the second stage 22 into a pellet emerging from the third stage 23 and subsequently being fired. It will be appreciated that the first stage 21 illustrated in FIG. 1 is by way of example only and that there may well be other ways of making the primary pellets, i.e., the embryo pellets. It is apparent that each primary pellet, to give an extreme example, may be made individually. Stage 21 may process dry or wet powders depending on the method of forming the pellets but it would seem that the pellets entering stage 22 (FIG. 1) for compacting should preferably be of a wet composition.

The principle in the constructed apparatus according to the present invention was that a mixture of powder and binding liquid (for example water) was made into a crude lump of appropriate size and moisture content and was then subjected to a continuous vibration of small amplitude and relatively high frequency.

The purpose of the vibration was, as will be appreciated, to convey the embryo pellet along the various stages of the apparatus, to make (in conjunction with the design of the apparatus) the pellet spherical, and to distribute the moisture uniformly throughout the pellet at the same time as the powder grains were rearranged so as to form a compact, strong pellet. As described above, the process included three stages each stage being a separate piece of apparatus which may be joined to its adjacent stage, or alternatively, may be physically separate therefrom. Each pellet, as described, is in-

dividually made and the size of the finished pellet would appear to be determined by the size of the initial lump, primary pellet 19 (FIG. 1). It, therefore, follows that if the primary pellets are of uniform size then the final pellets issuing from stage 23 will also be of uniform size.

As described, the pellet progresses in sequence from the first stage in which the required amount of powder and moisture are mixed into the shapeless primary pellet and the procedure adopted in this stage will, of course, depend upon whether the supply of powder is dry or wet. If the initial powdery material is dry, then either the powder may be mixed with a suitable binder liquid in conventional apparatus (e.g., a blunger or pug mill) and then handled in the second stage 22, or it may be treated in the first stage 21 of the apparatus illustrated in FIG. 1.

If the powdery material is initially wet and of the correct binder composition, then it could be extruded and chopped into short lengths. The extrusion operation could, of course, be done by forcing the liquid through a die either by means of a piston, or in a vibratory conveyor. In the second stage 22, the shaping process is accomplished in which the crude primary pellet is given a spherical shape, while in the third stage 23 the strengthening procedure is accomplished whereby the pellet is made stronger and the surface thereof is made harder. No matter in which way the pellets are made, the powder from which they are formed would appear to have to have a size distribution that has been found by experiment to result in the formation of strong pellets and this condition would appear to be applicable to the described apparatus. It will be appreciated that the primary pellets need not necessarily be spherical but may be any desired shape.

It will be appreciated that in the described embodiment the characteristics referred to will be selected possibly by experiment in accordance with the task to be performed. It will be straightforward to provide apparatus according to the present invention with an adjustable slope, amplitude of vibration, and temperature, for example, if this should be desirable. Furthermore, the quantity of liquid binder and its place of introduction may be varied if desired.

The existing methods of forming green pellets or granules are in bulk, in a pan, disc or drum granulator, or individually by pressing or extrusion. In the latter individual methods, the size, shape and strength of the pellets may be controlled but both the capital and maintenance costs are high on an annual ton basis. In the bulk methods, there are disadvantages in that control, etcetera, is not as good as could be desired. In the described embodiment of the present invention, each pellet is individually formed; there is no substantial undersize (apart from a small percentage of breakages) and no substantial oversize (unless the machine is overloaded to the extent of pellets sticking together). Hence, no screens are required except for screen 17 (FIG. 1) for separating the fine powder from embryo pellet at the exit of stage 21.

Furthermore the described apparatus is mechanically simple; no moving parts are used except for the vibrators, which are purely electromagnetic and simple and robust, and the light-duty cam mechanism used to allow water to be injected in stage 21. Maintenance and wear appear to be very small due to this and the fact that individual pellets pass along the trough, in a single layer, i.e., there is practically no weight on the surface of the troughlike members. Since the construction is light and there is an absence of a small burden on the apparatus the foundations need not be deep or massive. No heavy-duty bearings or gears are required. The high frequencies used means that practically no vibrations are transmitted outside the apparatus.

As will be clear, the apparatus is simple to fabricate. As many pressed steel troughs as required can be fabricated into one unit. Scale-up problems should be small. The output is directly proportional to the linear width of the trough and the length is constant for any given material and pellet size. To make the apparatus compact, troughs may be arranged in layers, each, say 10 feet wide. The unutilized powder from one

layer can then fall onto the layer below. The power requirements are small and the produced pellets were strong. It is likely that the required addition of binding material (e.g., bentonite) will be small or even nil.

Automatic control of the described apparatus is possible. In the second stage 22 (FIG. 1) since the water is redistributed from a situation where there is a moist center and a relatively dry outer shell to one where the distribution is uniform, there is a difference in appearance of the pellet. This may be detected by optical means and used to adjust the position and amount of the water injection in the first stage 21, so that the appropriate process is complete before the end of the second stage 22, i.e., the first stage comprising troughlike members.

I claim:

1. Apparatus for pelletizing powdorous material, including:
 - a. means for heating primary pellets formed from said powdorous material and a binder and feeding them to vibratile means comprising a plurality of spaced-apart members each at a different level and forming a path for movement of said primary pellets therealong; and
 - b. vibrator means capable of causing said members to vibrate at approximately 20° to the horizontal, the plane of vibration being at an angle of approximately 30° with the longitudinal axis of each spaced-apart member, to cause said primary pellets to move down said path and to form them into hard pellets.
2. Apparatus for pelletizing powdorous materials including:
 - a. means for heating primary pellets formed from said powdorous material and a binder and a feeding them to vibratile means comprising a plurality of troughlike members forming a path for movement of said primary pellets therealong; and
 - b. vibrator means capable of causing said troughlike members to vibrate at approximately 20° to the horizontal, the plane of vibration being at an angle of approximately 30° with the longitudinal axis of each troughlike member to cause said primary pellets to move down said path; said path being sloped downwardly and the trailing edge of each troughlike member in said path being located at a lower level than the leading edge of the immediately preceding troughlike member; and the vibration in operation forming said primary pellets into hard pellets.
3. Apparatus according to claim 2 wherein said vibrator means is electromagnetic and the force acting on the armature thereof makes an apparent relative phase-angle with its

direction of motion of substantially 90°.

4. Apparatus according to claim 2 including a first stage including:
 - a. a first plurality of said troughlike members;
 - b. a second stage comprising a second plurality of said troughlike members;
 - c. first vibrator means for causing vibration of said first stage; and
 - d. second vibrator means for causing vibration of said second stage.
5. Apparatus according to claim 4 wherein the vibration of each troughlike member is at 20° to the horizontal and the plane of vibration is at an angle of 30° with the longitudinal axis of each troughlike member.
6. Apparatus according to claim 2 wherein each troughlike member is caused to vibrate at 60 cycles per second, the vibration of each troughlike member is at 20° to the horizontal and the plane of vibration is at an angle of 30 with the longitudinal axis of each troughlike member.
7. Apparatus according to claim 3 wherein each troughlike member is caused to vibrate at 60 cycles per second, the vibration of each troughlike member is at 20° to the horizontal and the plane of vibration is at an angle of 30° with the longitudinal axis of each troughlike member.
8. Apparatus according to claim 4 wherein each troughlike member is caused to vibrate at 60 cycles per second, the vibration of each troughlike member is at 20° to the horizontal and the plane of vibration is at an angle of 30° with the longitudinal axis of each troughlike member.
9. Apparatus according to claim 2 wherein each troughlike member is of semicircular cross section.
10. Apparatus according to claim 2 wherein said means for feeding primary pellets includes a vibratory conveyor for a bed of said powdorous material, a plurality of nozzles positioned above said vibratory conveyor for supplying a liquid binder therethrough to form said primary pellets, and screen means to separate said primary pellets from surplus powdorous material.
11. Apparatus according to claim 3 wherein said means for feeding primary pellets includes a vibratory conveyor for a bed of said powdorous material, a plurality of nozzles positioned above said vibratory conveyor for supplying a liquid binder therethrough to form said primary pellets, and screen means to separate said primary pellets from surplus powdorous material.

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