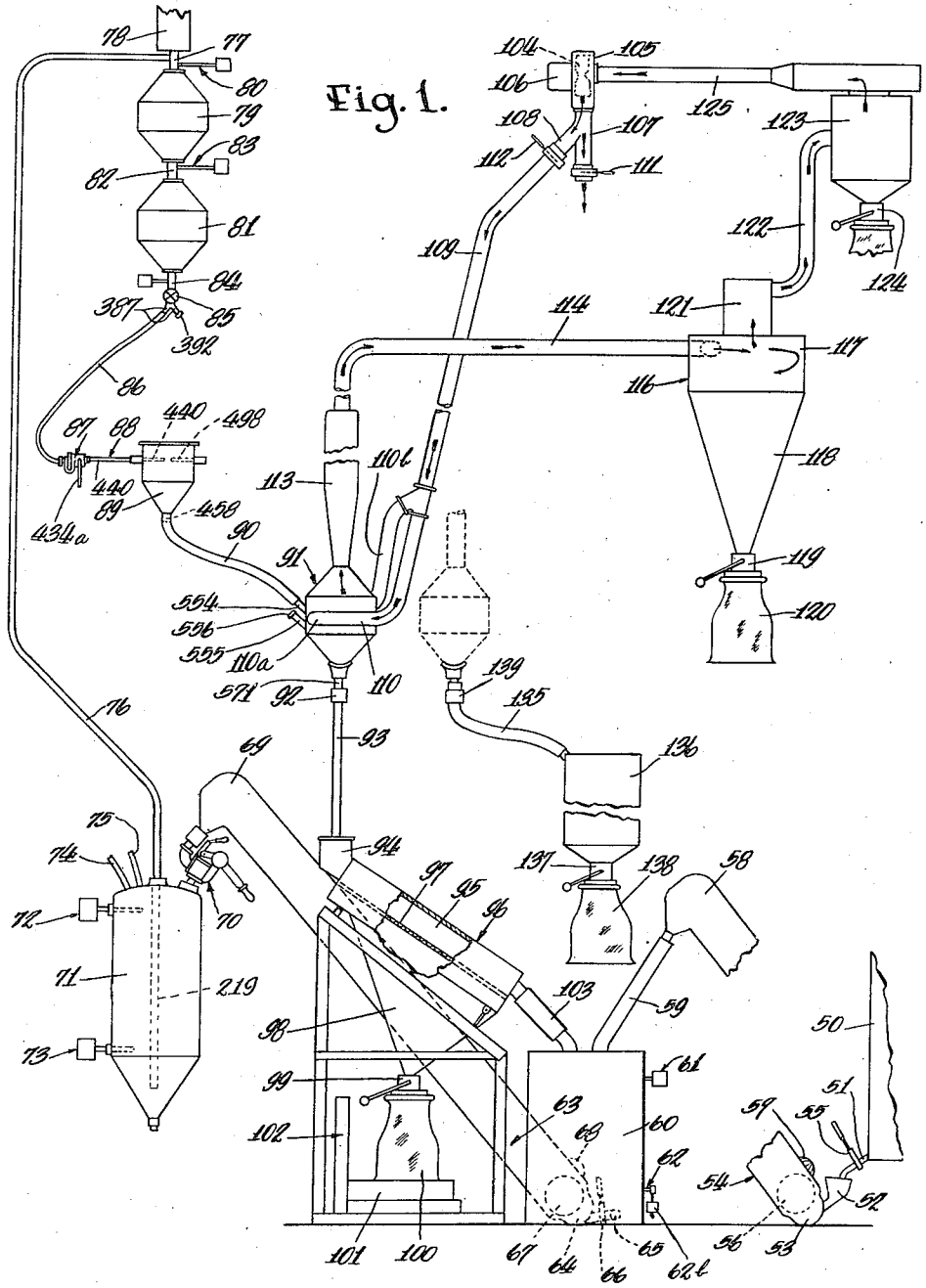
Jan. 1, 1946. E. L. WIEGAND 2,392,019

PROCESSING OF MATERIALS

Original Filed Dec. 7, 1939 2 Sheets-Sheet 1

Fig. 1.



Edwin L. Wiegand
INVENTOR
BY Freeman, Sweet, and Albright
ATTORNEYS

Jan. 1, 1946. E. L. WIEGAND 2,392,019

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Original Filed Dec. 7, 1939 2 Sheets-Sheet 2

Fig. 2

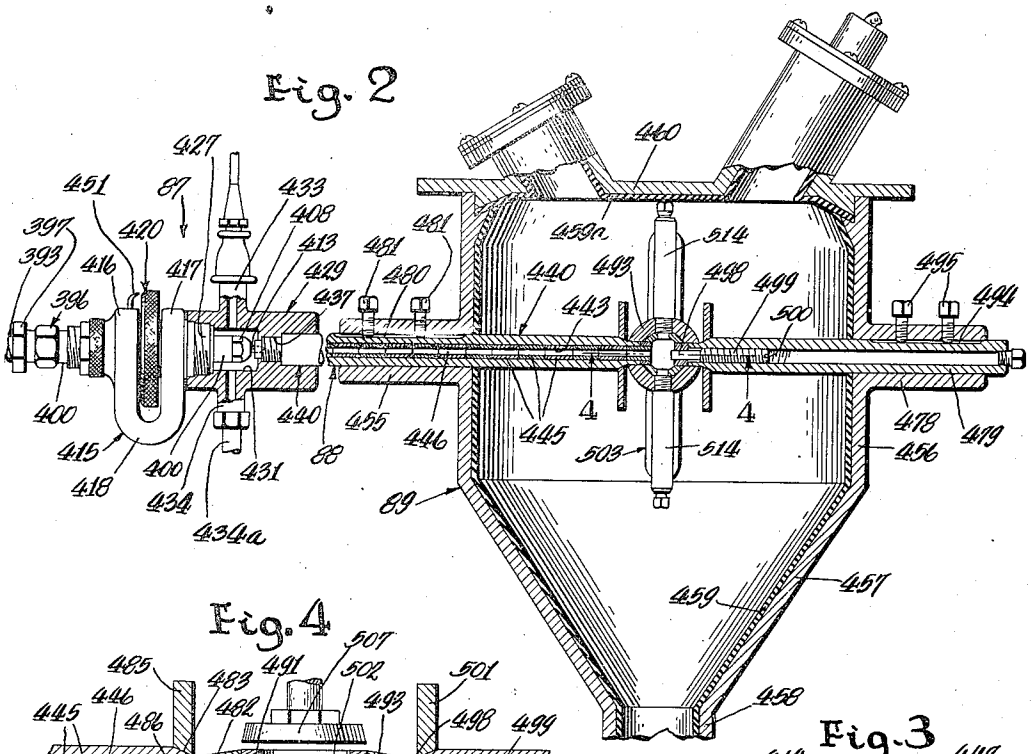


Fig. 4

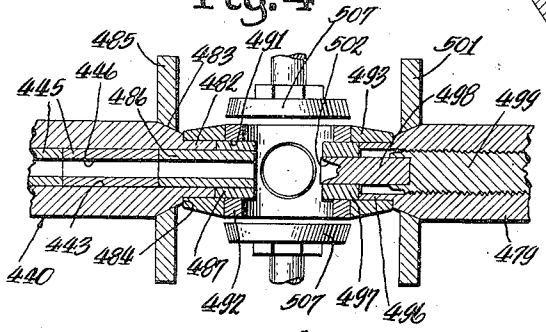


Fig. 3

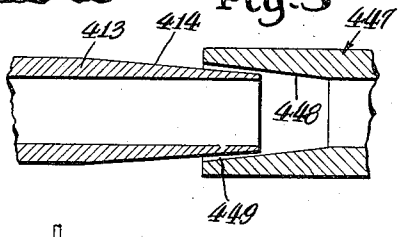


Fig. 5

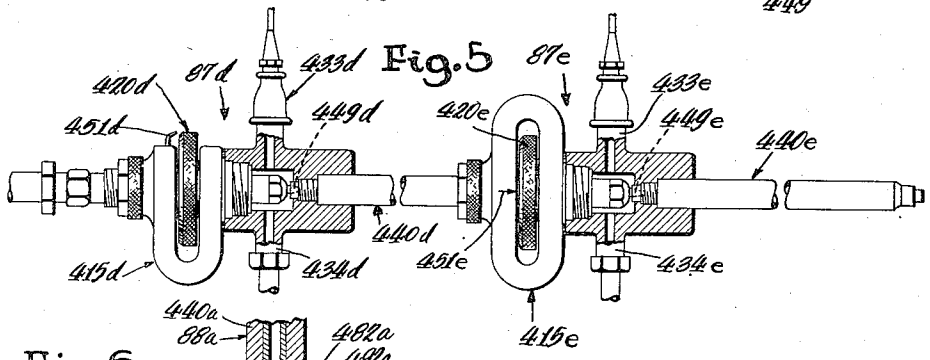
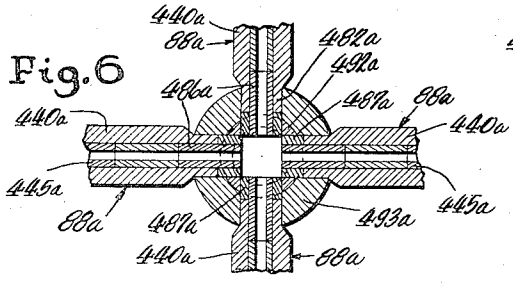


Fig. 6



Edwin L. Wiegand
INENTOR

By Freeman, Sweet & Albrecht
ATTORNEYS

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UNITED STATES PATENT OFFICE

2,392,019

PROCESSING OF MATERIALS

Edwin L. Wiegand, Pittsburgh, Pa., assignor to Orefraction Incorporated, Pittsburgh, Pa., a corporation of Pennsylvania

Original application December 7, 1939, Serial No. 308,002, now Patent No. 2,375,057, dated May 1, 1945. Divided and this application October 25, 1940, Serial No. 362,767

1 Claim. (Cl. 241—5)

My invention relates to the processing of materials, and more particularly, the grinding of materials, the separation of co-mingled material particles, and the purification of materials. With respect to the grinding of materials, the invention involves the projection of a stream of fluid and material particles moving at high velocity against an anvil or against a counter-stream of particles. The principal objects of the invention are the improvement of methods and apparatuses for carrying out such processing of materials, and the provision of new and improved materials. This application is a division of my application Serial Number 308,002, filed December 7, 1939, now Patent 2,375,057 of May 1, 1945.

In the drawings accompanying this specification and forming a part of this application, there are shown, for purposes of illustration, several embodiments of apparatus embodying the invention, and in these drawings:

Figure 1 is a more or less diagrammatic view of the relation between material conveying means, grinding means, and separating means, as these means may be utilized in one embodiment of my invention,

Figure 2 is a broken view, partly in elevation and partly in section, of the grinder case and one single-stage material-projecting gun,

Figure 3 is an enlarged fragmentary sectional view showing certain parts, adapted to provide an air jet, of a gun such as shown in Figure 2,

Figure 4 is an enlarged horizontal fragmentary sectional view corresponding generally to the line 4—4 of Figure 2,

Figure 5 is a broken sectional view with parts in elevation showing a two-stage gun, and,

Figure 6 is a fragmentary sectional view showing another gun arrangement.

The term "material" is used herein to include any substance of a divided nature, as distinguished from relatively large blocks of substances. The term "grinding" is used herein in its broader aspects as meaning reduction in size, in any way, of the material being treated, and in its more specific aspects, such "grinding" as occurs when material is subjected to impact. Examples of material which may be ground by an apparatus embodying my invention are such materials as zircon, rutile, quartz, feldspar, fluorspar, marble, glass, enameling frit, hard metals, artificial or other abrasives, industrial diamonds, and many others either of similar or different characteristics. My invention is particularly adapted to reduce hard, tough, and abrasive materials, including ores having these characteristics. Also it is particularly adapted to grind material to ultra-fine sizes, such as for example —200 mesh to micron sizes. Preferably the material to be ground should not be larger than 16 to 18 mesh size, although it is possible to accommodate larger sizes. In general the size to be commenced with may be any desirable size which cannot be better or more economically crushed otherwise, but the size of the material to be ground is related to gun size, and therefore also to the capacity of the apparatus. However, the capacity of apparatus embodying my invention is very great in relation to the gun bore area, as will fully appear hereinafter.

Referring to the schematic arrangement shown in Figure 1, the embodiment of the invention there illustrated comprises a container 50 adapted to contain material to be ground, and hereafter referred to as the new-materials container. The new-materials container 50 may be formed with an outlet spout 51 discharging into a funnel 52 carried by the receiving end 53 of an elevating device 54, such as the bucket elevator here shown. A suitable slide valve 55 is interposed in the outlet spout 51 to regulate the flow of material from the new-materials container 50 to the receiving end 53 of the elevator 54. The elevator 54 may be driven by means of an electric motor 56, and may also have a signal device, such as the electric light 57, to indicate when the elevator 54 is operating. The discharge end 58 of the elevator 54 discharges into a conduit 59 leading to a blending and metering hopper 60, having high and low limit controls 61 and 62, so as to control operation of the motor 56 of the elevator 54, the connections being such that the motor 56 of the elevator 54 is automatically started when the level of the material falls enough to actuate the low level device 62, and the motor 56 is automatically stopped when the material rises enough to actuate the high level device 61. The details of the blending hopper 60 and the controls therefor are described in my aforesaid application and, as far as the subject matter of the present application is concerned, these details need not be set forth herein.

Positioned alongside of the receptacle 60 is a second elevator 63, having its inlet end 64 receiving material from the lower end of the hopper 60, as by means of a conduit 65, a suitable slide valve 66 being so interposed as to control the amount of material flowing from the hopper 60. The elevator 63 is driven by an electric motor 67, and may have a signaling device, such as the electric light 68, to indicate when the motor 67 is running. The discharge end 69 of the elevator 63 leads to the inlet of a solids valve 70 the outlet of which communicates with the interior of a charge metering and hoist tank 71. The hoist tank 71 has high and low level devices 72 and 73 respectively, so related to other parts (as described in my aforesaid application) as to permit the motor 67 to operate when the material is below the low level device 73, and to interrupt

the dust separator 123 is connected by a conduit 125 to the inlet of the fan chamber 105.

Assuming that the motor 106 is operating, and that the valve 111 is at least partially open, and that ground material, along with air used in grinding it, is being delivered through the conduit 90 to the first separating device 91, the material which under the air conditions prevailing in the separating system is not heavy enough to gravitate at once from the separating device 91, will be picked up by the stream of air in the column 113. Some of this material will continue to be carried by that stream to the top of the column 113 and through the conduit 114 to the upper end of the second separating device 116, and will be caused to swirl in this upper end because of the tangential connection of the conduit 114. The heavier materials in the second separating device 116 will gravitate downwardly through the conical portion 118, and will be delivered to the bag 120 through the bagging device 119. The lighter material will be carried upwardly by the air stream through the housing 121 and the conduit 122, to the dust collector 123, where the dust will be separated from the air, the dust particles being discharged from the bottom of the dust separator 123 and to the bagging device 124, and the air passing to the conduit 125 and back to the inlet of the blower chamber 105. Some of the material which enters the separating column 113 from the separating device 91 does not continue with the upwardly moving stream of air into the conduit 114, but gravitates back through the stream into the separating device 91 and finally reaches the lower or discharge end of the separating device 91, and thus the separating action of the system is improved.

Depending upon the setting of the slide valves 111 and 112, either an under-pressure or an over-pressure condition (with respect to atmospheric pressure) can be made to exist in the first separating device 91. Usually the valve 112 is partially or completely closed, and the valve 111 partially or completely open, so that an under-pressure or partial vacuum exists within the first separating device 91 and in the column 113, whereby material readily passes from the grinder case 89 to the first separating device 91, and no back pressure is created in the conduit 90 leading from the grinder case 89. Also, usually the valves 111 and 112 are adjusted to effect substantially zero (atmospheric) pressure in the grinder case 89, thereby to avoid back pressure in the grinder case 89 that might interfere with the operation of the grinder gun. However, it will be apparent that the pressure conditions in the grinder case and in the separating system can be regulated by adjustment of the slide valves 111 and 112 to obtain any desired pressure conditions. Furthermore, the velocity of the upwardly moving stream of air in the separating column 113 may be adjusted to a most suitable velocity so that the separating function of the column 113 will be optimum.

Since a certain "head" of material is maintained within the tube 571 by the valve 92, air communication between the conduits 93 and the interior of the first separating device 91 is prevented. Thus the pressure condition within the device 91, either greater or less than atmospheric pressure, as may be desired, will not be changed, since the check valve 92, either open or closed, substantially prevents flow of air through the tube 571.

The first separating device 91 may be moved from the position shown in full lines in Figure 1 to the position shown in dotted lines, wherein its lower end no longer communicates with the conduit 93, but instead communicates with a conduit 135 leading to a tank 136, hereinafter referred to as a by-pass tank. The lower end of the tank 136 carries a bagging device 137, to which a bag 138 may be attached, and a check valve 139 is interposed in the conduit 135, the check valve 139 being provided for the same purpose as the check valve 92. In this position of the device 91 the ground material, excepting only a controllable amount and size of very fine material, instead of going to the screen chamber 95, passes directly to the by-pass tank 136. The conduit 113 in this position may still be connected to the conduit 114. The by-pass tank connection is particularly useful when it is desired to make an unscreened ground aggregate, with only a minimum of extreme fines removed.

The valve 85 is closed when initially charging the apparatus, and may also be closed for interrupting the process temporarily without relieved pressure on the lower feed tank 81, or at the end of a run prior to a subsequent initial charging or beginning of operations. In other words, it is closed before initially charging, or at the end of a day's run, or for temporary interruption, and it is opened when beginning operations, as at the beginning of a day, or after an interruption as for inspection or adjustment of other equipment.

While the material in the lower feed tank 81 is being ground, the hoist tank 71 will have again been filled, with either new material or with a mixture of new and partly ground material from overage from the screen 96, and this charge will have been hoisted, and all is in readiness to "dump" the same into the tank 81 when a low lever responsive device (not shown) in the lower tank 81 indicates sufficient evacuation to receive the next charge from the upper feed tank 79.

From the foregoing description of the apparatus and the operation thereof, it will be apparent that operation of the apparatus and process are enabled to be continuous, but interruptable when desired.

As shown in Figure 1, the first separating device has an inlet pipe 554 to which the conduit 90 is suitably connected, but also has another inlet pipe 555 directly below the inlet pipe 554, the inlet pipe 555 being in this instance closed by a cap 556. If desired, the inlet 555 may lead to another grinder case, the separating device 91 in such instance serving both grinder cases, or the pipe 555 may be used as an inspection opening.

The outlet conduit 84, in which the valve 85 is interposed, terminates in a plurality of nipples 387 to one of which the conduit 86 is securely clamped and another of which is here shown as closed by a cap 392, but which may be used to feed another gun projecting material against an anvil in another grinder case, or to feed another gun taking the place of the anvil 498 or otherwise disposed to project a stream of material impinging the stream from the gun 88, as will appear hereinafter.

The conduit 86 comprises a heavy-duty flexible tube 393, within which is disposed a heavy-duty rubber hose, having its one end securely fastened over one nipple 387, and its other end extending into a union joint 396 (Figure 2). The end of the flexible tube 393, seen in Figure 2, is provided with a coupling device 397 screw-threadedly en-

gaging one end of the union joint, to hold the flexible tube 393 assembled with the union joint. The other end of the union joint 396 screw-threadedly receives one end of an elongated tubular body 400, which forms part of the breech 87 of the gun 88.

The bore of the tubular body 400 is lined with a material capable of withstanding the abrasive wear produced by the material passing therethrough. In the present embodiment this lining is of tungsten carbide, and in the form of a series of short abutting bushings, only a special one, 413, being visible, this special bushing being a jet nozzle (see also Figure 3). A nut 408 having an opening through which the jet nozzle 413 projects, is threaded on a reduced extension of the body 400 and constructed and arranged to hold the jet nozzle in place. Herein the jet nozzle 413 also is formed of tungsten carbide. The outer surface 414 adjacent the extremity of the nozzle is preferably so formed as to be defined by a cone of straight line generatrix, a generatrix line thereof making an angle of six degrees with the longitudinal axis of the nozzle.

The body 400 passes through a longitudinal opening in a generally U-shaped member 415, the legs 416 and 417 of the member 415 being spaced apart and rigidly connected by an integral bight 418. The tubular body 400 is formed with external screw-threads (not shown) at the space between the legs 416 and 417, and a micrometer hand-wheel 420 is threaded onto these threads, and has portions slidably bearing against the facing surfaces of the legs 416 and 417, so that rotation of the micrometer wheel 420 will effect longitudinal movement of the body 400 with respect to the member 415.

The leg 417 of the member 415 is formed with a reduced axially extending threaded part 427 which is threaded into an aperture formed in a body 429. The threaded aperture in the body 429 is reduced as shown at 431, producing a chamber encircling the end of the tubular body 400. The body 429 is formed with lateral extensions 433 and 434, each extension being provided with a bore communicating with the chamber formed by the opening 431.

The bore in the extension 433 communicates with a pressure gauge (not shown), while the bore in the extension 434 is connected to a conduit 434a leading to a source of air under pressure (not shown). If desired air may be delivered to the bore of the lateral extension 434 under a pressure either higher or lower than that under which the air is delivered to the lower tank 81, thereby to permit adjustment to secure the optimum qualitative-quantitative output.

The opening in the body 429 is further reduced as shown at 437 and threaded, and then enlarged, to receive the correspondingly shaped end of the gun barrel 440.

The bore 443 of the barrel 440 is preferably lined with a hard liner, herein a series of abutting similar tungsten carbide tubes 445, providing a barrel bore 446 of constant diameter. Some of the bushings 445 may be of a slightly different length, so that by using the right combination of bushings, the exact length of the barrel 440 may be lined. A bushing 447 (see Figure 3) positioned at the breech end of the barrel 440 is formed with a bore of the same diameter as the bushings 445 but terminating in a conically flared portion, as shown at 448 (see Figure 3), to cooperate with the tapered end 414 of the jet nozzle 413. In the embodiment illustrated, the bore of the jet nozzle 413 is of the same diameter as the bore of the bushing 447, but under certain circumstances it may be desirable to have the bore of the jet nozzle 413 slightly smaller than the bore of the bushing 447. The surface 448 is defined by a straight line generatrix cone a generatrix line thereof preferably making an angle of 7° with the longitudinal axis of the bushing 447, and the surface 448 is adapted to cooperate with the tapered end 414 of the jet nozzle 413 to provide an annular air jet 449 the stream lines of which make a mean angle of about 6½° with the axis of the nozzle 413.

It will be appreciated that the axis of the air jet 449 may be very finely adjusted by means of the micrometer wheel 420. A pointer or finger 451, carried by the leg 416, cooperates with markings on the micrometer wheel so that its position may be read.

Booster air, at any desired pressure, may be permitted to pass through the conduit 434a, to the chamber 431, and from there through the air jet 449 in an annular conical stream surrounding the material passing through the bore of the jet nozzle 413, such additional air acting to increase the velocity of the material moving through the bushings in the body 400 and the bushings 445 in the gun barrel. The pressure within the chamber 431 may be read on the pressure gauge connected to the extension 433.

The end of the barrel 440 opposite to that secured to the body 429, extends through a boss 455 formed on the grinder case 89. The grinder case comprises a cylindrical portion 456 and an integral downwardly tapering lower portion 457 terminating in a reduced cylindrical portion 458, the entire interior of the grinder case being preferably lined with rubber 459 to prevent the flying material within the grinder case from abrading the adjacent walls. To the reduced portion 458 is attached one end of the conduit 90 (see Figure 1) preferably rubber lined.

As indicative of the small size of the apparatus, it may be stated that in the illustrated embodiment of the appartus the cylindrical portion 456 is about 12 inches in diameter and has an axial length of about 8 inches.

The upper open end of the cylindrical portion 456 is closed by a cover 460, the interior surface of which is also lined with rubber 459a. Other details of the grinder case 89 are described in my aforesaid application and need not be described here.

The gun barrel 440 is provided with an elongated longitudinal groove 480 at that portion where it passes through the boss 455, for the reception of the ends of bolts 481 which hold the gun barrel 440 against both axial and rotative movement. The end of the gun barrel 440 within the grinder case 89 has a reduced extremity 482 (see also Figure 4) and a conical portion 483 spaced inwardly from the extremity, a shoulder 484 being provided between the reduced extremity 482 and the conical portion 483. A shield plate 485, herein of tungsten carbide, is secured to the barrel 440 at the conical portion 483, in any suitable manner, to restrict movement of the flying particles of ground material. The tungsten carbide bushings 445 extend to the muzzle end of the barrel 440, and an end bushing 486 extends beyond the extremity, and has its end surrounded by a tungsten carbide collar 487 snugly fitting the extending portion of the bushing 486. The collar 487 snugly fits within an aperture 491 formed in a ring 492 herein formed

of tungsten carbide. An annular housing 493 surrounds and carries the ring 492. The reduced extension 482 of the gun barrel 440 fits within an aperture formed in the annular housing 493.

Diametrically disposed with respect to the boss 455, and extending outwardly from the cylindrical portion 456 of the grinder case 89, is a boss 478, through which extends a tubular body 479, disposed in axial alinement with the gun barrel 440 and formed with an elongated longitudinal groove 494 adapted to receive the ends of bolts 495 to hold the tubular body against both axial and rotative movement. The tubular body 479 has a reduced extremity 496 fitting within an aperture in the annular housing 493, the ring 492 also being apertured at this point to receive a tungsten carbide collar 497. An anvil 498 is slidably disposed in the collar 497. Herein the anvil 498 also is formed of tungsten carbide. The anvil 498 need be of a diameter only about one and one-half to two times the diameter of the opening in the tungsten carbide bushings lining the gun barrel 440. One end of the anvil 498 is directed toward the gun barrel opening, and is spaced a slight distance from the muzzle of the gun barrel, one-half inch to one inch having been found satisfactory under usual circumstances. The other end of the anvil 498 is firmly gripped by an adjusting screw 499 interengaging with screw-threads formed on the interior of the body 479 and having a diametrical slot 500 in its outwardly directed end so that a screw-driver may be inserted in the opening of the tubular body 479 and engage the slot 500 to effect adjustment of the anvil 498 toward or away from the muzzle of the gun barrel 440. The end of the tubular body 479 adjacent the annnular housing 493 is also preferably provided with a shield plate 501 to restrict movement of the flying particles of ground material and herein formed of tungsten carbide.

Excellent results have been had with an anvil of the "pencil" type, the diameter of the anvil not greatly exceeding the diameter of the bore of the bushing 486, in the present instance the bore of the bushing 486 (as well as that of the bushings 445) being about .180 of an inch in diameter and the anvil being about ⅜ of an inch in diameter. The end of the anvil, in the present embodiment, is positioned about three-quarters of an inch from the muzzle of the gun barrel, although this distance may be varied, as will be obvious, by adjustment of the screw 499, and in any event preferably the anvil is close enough to the gun muzzle so that no material divergence of the particles occurs before they strike the anvil.

It has been found in practice that an anvil with a perfectly flat surface directed toward the particles expelled by the gun barrel, quite rapidly has formed therein a crater 502 of conoidal form having a small central projection, as best seen in Figure 4. It will be noted that the rim of the crater 502 is defined by the cross-sectional outline of the anvil 498. Once this crater is formed, the wear on the anvil is extremely slight, because the material is ground by impact of particles against particles in the crater. In practice, upwards of a hundred tons of material have been ground without showing any appreciable wear on the anvil. Furthermore, any wear on the anvil is even, that is, the crater 502 remains of substantially uniform shape as wear takes place, and this wear accordingly results in substantially uniform and very slow reduction in length of the anvil portion 498. Such is not the case if the cross-sectional area of the anvil is considerably larger than that of the bore of the gun muzzle. In that case the crater is of composite form usually comprising a central conoidal portion and an annular portion surrounding and more or less concentric with the conoidal portion. Such a composite crater wears more rapidly, and as it wears, the form of the crater varies, and the wear does not result in uniform reduction in length of the anvil.

The annular housing 493 and ring 492 are additionally supported by a frame 503 comprising members 514 screwed into diametrically opposite openings in the annular housing 493, the frame being suitably supported by the case 89. This construction is described in my aforesaid application and requires no further description herein.

Confining disks 507, herein formed of tungsten carbide, are adjustably supported in any suitable way, as from the frame 503, so that they may be moved toward or away from the respective open ends of the ring 492, thus providing more or less vent for air and the material being ground in the space within the ring 492. The confining disks 507 prevent the ground material from flying about the interior of the grinder case 89, any kinetic energy remaining after the material has been ground by impact in the crater 502 being largely absorbed by the confining disks 507, so that the ground material may pass through the openings between the disks 507 and the ring 492 and to the bottom of the grinder case 89, or will strike the disks 485 and 501 before so dropping.

With the exception of parts herein of tungsten carbide, all of the parts within the grinder case 89 which are in any way exposed to the material being ground, preferably are coated with rubber applied in any suitable way.

In some cases, for reasons which will more fully appear, it is desirable to project the material and subject it to impact by means of an embodiment such as shown in Figure 6, in which the gun arrangement shown comprises a ring 492*a* and an annular housing 493*a*, similar to the ring 492 and annular housing 493 hereinbefore described. As before, the ring 492*a* and the annular housing 493*a* are formed with apertures disposed approximately 90° apart, but in this case none of the apertures is formed with threads, but each of the apertures receives a gun 88*a*, similar to the gun 88 hereinbefore described, each gun 88*a* cooperating with a gun breech (not shown) similar to the breech 87 already described. Each gun comprises a barrel 440*a*, the interior of which is lined with bushings 445*a* herein of tungsten carbide, and each barrel 440*a* is formed with a reduced end 482*a* fitting within a respective opening formed in the annular housing 493*a*, the innermost bushing 486*a* extending outwardly of the gun barrel 440*a* and being surrounded by a tungsten carbide collar 487*a*.

In the construction shown in Figure 6, each gun projects material at high velocity toward the center of the ring 492*a*, the material thus projected, instead of striking on an anvil as before described, now strikes a counter-stream of material from an oppositely disposed gun, and also strikes a lateral stream of material from a transversely disposed gun. However, two oppositely disposed guns may be omitted, thus providing only one pair of oppositely disposed guns, each projecting a stream of material against a counter-stream projected by the opposite gun. Other embodiments involving impinging streams of material are described in my aforesaid application and need not be described herein.

Figure 5 shows what I term a two-stage gun,

and this example will be sufficient for the present application to illustrate plural or multi-stage guns of any number or stages. By the provision of a plurality of stages I mean the provision of more than one booster jet, such as 449, Figure 3, suitably placed to increase the velocity of the stream of material in the gun barrel means, and for other purposes. The purposes and results of this method of propelling the material through the gun barrel will appear hereinafter.

Referring to Figure 5, the gun construction therein shown provides two successive accelerating jets. The construction comprises a breech 87*d*, similar to the breech 87 hereinbefore described, having a generally U-shaped member 415*d*. A micrometer wheel 420*d* is provided, as before, for the purpose of adjusting the jet opening 449*d*, the jet opening receiving a supply of booster air through an opening in a lateral extension 434*d*. An oppositely disposed lateral extension 433*d* has an opening leading to a pressure gauge (not shown). The jet 449*d* discharges into a gun barrel 440*d*. The bore of the jet nozzle of the jet 449*d* (corresponding to the jet nozzle bushing 413) is preferably slightly smaller than the bore of the gun 440*d*, although it may be equal to but preferably not greater than the bore of the bushings corresponding to the bushings 445 and 447 (Figures 2 and 3).

The gun barrel 440*d*, instead of extending to the grinder case, extends to another gun breech 87*e*, in which in this instance the member 415*e* is generally O-shaped. The breech 87*e* includes an air jet 449*e* provided by a jet nozzle bushing and a cooperating bushing analogous to the jet nozzle bushing 413 and cooperating bushing 447 of Figure 3. A micrometer wheel 420*e* provides for adjustment of the air jet 449*e*. A lateral extension 434*e* has a bore providing for a supply of additional booster air to the air jet 449*e*. An oppositely disposed lateral extension 433*e* has a bore communicating with a pressure gauge (not shown). A gun barrel 440*e* extends from the breech 87*e* and leads to the grinder case, similar to the grinder case 89, the gun barrel 440*e* being similar in construction to the gun barrel 440 hereinbefore described. The jet nozzle of the jet 449*e* (corresponding to the bushing 413) is preferably of a design no smaller than the preceding bushings, while the subsequent bushings corresponding in function to the bushings 445 and 447 of Figures 2 and 3, preferably are the same bore size as that of the preceding jet nozzle, or may be slightly larger, such as 5 to 15% larger than the preceding diameter, depending on the absolute size of the gun bore concerned, although they may be the same as that of the preceding jet nozzle.

Readings of the micrometer wheels 420*d* and 420*e* may be taken with reference to pointers 451*d* and 451*e* respectively. The booster air admitted through the bores in the extensions 434*d* and 434*e* may be under the same pressure, as for instance 500 pounds per square inch. However, the pressures may be unequal, the pressure of the air through the opening of the extension 434*e* being, for example, greater than the pressure of the air in the extension 434*d*. The breech 87*e* is made of O-shape to provide for pressures of the order of 1000 pounds per square inch.

In general, with respect to plural stage guns of the type illustrated in Figure 5, the jet nozzle bushings in the stages subsequent to the first stage are preferably of a design no smaller than the preceding bushings, and the subsequent bushings corresponding in functioning to the bushings 445 and 447 of Figures 1 and 3 are the same bore size as that of the preceding jet, or may be slightly larger, such as 5 to 15 percent larger than the preceding diameter, depending on the absolute size of the gun bore concerned, although they may be the same as that of the preceding jet.

Considering now the methods by which the material is ground, I have used with excellent results a gun having a bore of .180 of an inch provided with a single accelerating jet, and having a length from the accelerating jet to the muzzle of the gun of approximately 54 inches. It will be noted that in this instance the area of the bore is approximately .025 of a square inch, and since the length is 54 inches, the ratio of inch length to square inch area of bore is approximately 2100. However, also I have used with excellent results a gun having the same bore area and a barrel length of 44 inches, the ratio of inch length to square inch bore area being in this instance approximately 1700. A further example is a gun of the same bore area but having a length of 10 inches, in which instance the aforesaid ratio is approximately 390. These examples are given as illustrative, and it is to be understood that my invention is not limited to these particular dimensions or ratios, and in fact at least part of my purposes may be accomplished when the aforesaid ratio is as low as approximately 200.

In considering the action of a single stage gun, that is, a gun having a single accelerating jet, constructed in accordance with my invention, the mixed stream of material and air which enters the bore of the bushing 447 (Figure 3) may be conceived theoretically as a core which is surrounded by the internal surface of an annular stream provided by the jet 449. This annular stream at the moment it issues from the jet aperture is moving at a much greater velocity than the core, and acts to impart its velocity to the immediately adjacent outer surface elements of the core, and these in turn act to impart their velocity to the elements of the core radially inward of the core. Obviously the center of the core will not acquire the velocity of the annular stream instantaneously, or for an appreciable period or distance, and the acceleration of the core is rendered more difficult because the solid material in the core accelerates less rapidly than the air. Under these conditions, it is evident that acceleration of the core must take place, at least initially, largely by application of force at the outer surface of the core. However, if the diameter of the core is increased, the area and content of the core increases as the square of the radius, whereas the circumference increases only as the first power of the radius. Thus for a gun having a bore twice as large as another, the theoretical surface at which accelerating force is initially applied is approximately twice as large, whereas the core which is being accelerated has an area and a mass approximately four times as large. As far as the foregoing considerations are concerned, obviously it is highly desirable that the core be relatively small, or in other words, that the bore of the gun be relatively small, particularly if the gun is a single stage gun. However, the jet must have a substantial kinetic energy, would presumably can be secured at given pressure adjustment to a suitable jet area, or at a given jet area by adjustment to a suitable pressure of the booster air, or by some combination of the two. It seems

that increase of the jet area would involve greater penetration of the annular jet into the core, but however that may be, I have found that within limits which will be referred to, an increase of jet area is beneficial, and seems to involve a more positive impelling action of the jet on the core than is involved in considering the jet as impelling the core merely by the theoretical inner annular surface of the jet along the theoretical outer surface of the core. Nevertheless, I have found that there is an optimum relation between the area of the jet and the area of the gun bore.

In a gun of more than one stage the bore of the gun may be made larger than for a gun of a lesser number of stages, but I have not found the use of relatively larger bores necessary, because with a plurality of stages the velocity of the material, the fineness of the product, the production, and the efficiency, may be still further increased even with a gun bore no larger than that of a single stage gun. Obviously this is exceedingly important, for example in respect of the weight and expense of the equipment, particularly the cost of the parts made of tungsten carbide or other suitable wear-resisting material. However, before discussing plural stage guns further, there may be considered results I have obtained on the single stage guns.

For example, I have obtained the following results using a gun having a bore diameter of .180 of an inch and a length of 54 inches from the jet **449** to the muzzle of the gun barrel **440**, the stream being directed against an anvil such as the anvil **498**. The positive pressure behind the stream, as furnished by the air under pressure in the feed tank **81**, was approximately 500 to 550 pounds per square inch, and air was fed to the jet **449**, through the connection **434**, also at a pressure of approximately 500 to 550 pounds per square inch. The solid material fed from the feed tank **81** was zircon ($ZrSiO_4$) of −60 mesh comprising substantially no particles of −200 mesh. The jet **449** was so adjusted that the cross-sectional area thereof at its outlet into the gun barrel was approximately 40 percent of the cross-sectional area of the gun barrel bore **446**. These conditions resulted in a feed of solid material through the gun of approximately 1092 pounds per hour. The quantity of free air compressed and used per ton of solids feed, was approximately 12,250 cubic feet. The ratio of the volume of solid material to the volume of the mixture of compressed air and solid material comprising the stream projected from the gun muzzle, was 2.15 percent. The material was passed through the gun once, with the results shown in the following table, Number I, in which for each minus mesh size produced there is given in column A the number of pounds thereof produced per hour, and in column B the cubic feet of free air which was compressed and used per ton produced:

Table Number I

Mesh	A	B
−200	514	14,700
−270	443	17,050
−300	372	19,700
−325	348	21,700
−400	295	25,600

In connection with these results it may be observed that zircon is not only very hard and abrasive but also very tough, and these characteristics render its impact resistance high and make it difficult to grind. Furthermore, it is well known that it is extremely difficult to further grind or pulverize materials which are already relatively fine, due to the fact that the impact energy decreases while the resistance to fracturing remains approximately constant. By way of example, it is more difficult to break down by impact to half its volume a material particle in the range of 200 mesh and finer than it is in the coarser ranges.

It seems that in a single stage gun the optimum ratio between the cross-sectional area of the accelerating jet, and the cross-sectional area of the gun bore, is approximately 40 to approximately 50 percent. In general, the net result of putting more than a certain limited amount of energy into the gun at one point, is that entrainment of solids is seriously reduced, that is, the feed of solids is decelerated, and the consumption of air per ton of feed is too greatly increased to be economical. In fact, with too high an energy input at a single point of the gun, the solids feed may even be choked off.

However, I have found that this difficulty may be overcome by using successive jets, at points spaced longitudinal of the gun, each jet having a desired cross-sectional area and being supplied at a desired pressure, so that the stream is permitted to increase in velocity before a second accelerating jet acts on the stream to further increase its velocity, and so on. With such a gun the solids feed to the gun is not choked off nor materially reduced, even with high gas pressures, and can be regulated to a desired richness of solids-gas mixture merely by regulating the pressure on the multiple jets and the pressure on the feed tank **81**. Moreover, it is possible to get results quite out of proportion to increase in pressure, and in fact, the use of high pressure is made possible, and the advantages thereof are realized, without resulting in choking off or seriously reducing the solids feed. With such a gun the maximum gas pressure and velocity appear to be limited only by construction problems. Furthermore, great gun barrel length is made possible without introducing offsetting disadvantages, thereby overcoming excess "slip" of the solids in the gas stream.

I have further found that in a plural stage gun, even if the sum of the cross-sectional areas of the successive jets be no more or not substantially more than the cross-sectional area of the optimum size jet for a single stage gun, and even if the bore of the plural stage gun be no different than that of a single stage gun, yet the results produced are far superior. Furthermore, I have found that in a plural stage gun the ratio of the sum of the cross-sectional areas of the jets to the cross-sectional area of the gun bore may be increased much beyond the optimum ratio for a single stage gun, in fact the ratio may approach and even exceed 100 percent, without substantial impediment of the solids feed. The respective jet pressures need not be the same as the positive pressure on the stream at the breach of the gun, but may be either higher or lower, depending upon the jet opening which happens to work best at a particular point, the important thing being (*a*) the total energy supplied at that point, and (*b*) remaining within limits of the maximum desirable jet opening area for a single stage which in turn depends on the velocity and particle energy state existing at that point.

The gist of a principle underlying my invention is the applying of energy in controlled stages de-

pendent upon various limitations, particularly the particle energy state existing at a particular point in the gun barrel, and that again is the result of the velocity, size, shape, and specific gravity, of the material particle, existing at that particular point. If it is endeavored to boost too much, either by way of jet area or by way of pressure, the result may be instead to decelerate and interfere.

An example of the functioning of a two stage gun is afforded by results obtained on a gun of the type shown in Figure 5 which had a bore diameter of .180 of an inch and in which the gun barrel portion **440***e* had a length from the jet **449***e* to the muzzle of the portion **440***e* of approximately 34 inches. The length of the gun portion **440***d* from the jet **449***d* to the jet **449***e* was approximately 20 inches. The stream from the muzzle of the gun was directed against an anvil such as the anvil **498**. In one of the runs the jets had a combined area of approximately 56 percent of the gun bore, the jet **449***d* being set so that its area was approximately 16% of the area of the gun bore, and the jet **449***e* being set so that its area was approximately 40% of the area of the gun bore. The air supplied to the gun from the tank **81**, and the air supplied to the jets **449***d* and **449***e*, was at a pressure of approximately 500 to 540 pounds per square inch. The solid material fed to the gun was the same kind of material as in the case of the single stage gun hereinbefore referred to, and there resulted a feed of approximately 1865 pounds per hour. The quantity of free air compressed and used per ton of solids feed was approximately 7517 cubic feet. The ratio of the volume of solid material to the compressed air and solids mixture volume, was approximately 3.54%. The material was passed through the gun once, with the results shown in the following table, Number II, in which the columns have the same meaning as in Table Number I:

Table Number II

Mesh	A	B
−200	947	14,760
−270	756	18,510
−306	638	21,940
−325	619	22,600
−400	535	26,200

Further data is given in my aforesaid application, but the foregoing is sufficient for an understanding of the subject matter of the present application. As the number of stages is increased, in general the hourly production rate is materially increased, even though the gun is neither longer nor of greater bore.

Perhaps the greatest difficulties in grinding hard materials have been rapid wear and damage to the grinding means, and the introduction into the product of added material from grinding means. Such added material from the grinding means is hereinafter referred to as additions. The introduction of additions into the product is undesirable in most instances. An example is zircon, ground by a prior art method, which had a bluish gray color, a relatively low electrical resistivity, and a lowered fusing point, due to metallic iron inclusion. These defects render the zircon unsuitable for use for example as a refractory electrical insulating material particularly at elevated temperatures. It is sometimes attempted to remove the additions or other impurities by treatment with chemicals, but this necessitates subsequent removal of the chemicals, and also, is not necessarily successful, and in fact, may leave not only the previous impurities but also some of the chemicals used in the treatment, besides being cumbersome and expensive. With my method and apparatus substantially no additions are introduced into the product, and most existing impurities are removed, as will be pointed out hereinafter, so that the product requires no subsequent treatment.

While zircon, which has a hardness of about 7 to 7½ (Mohs' scale), has been hereinbefore used as an example of the grinding of hard materials, it is of course to be understood that materials of substantially any hardness may be ground to great fineness without contamination. This is due in part to the fact that the gun is so constructed and arranged that it may be and is lined with tungsten carbide or other suitable wear-resisting material, in all portions where material wear might occur, and is due in part to the provision and continuance by the accelerating jet or jets of a protecting sheath of air between the surface of the gun bore and the material-carrying stream. However, the construction and arrangement of the anvil, and mode of cooperation of the anvil and the projected stream of material, whereby there is substantially no wear of the anvil, also is a material factor in preventing contamination.

My invention is particularly useful in the grinding of the harder materials, of hardness 4 or more (Mohs' scale), and will readily and efficiently grind such materials for example to −200 mesh with less than 1/50% additions, to −325 mesh with less than 1/40% additions, and to −400 mesh with less than 1/25% additions. In fact, my apparatus will grind readily and efficiently with substantially no additions whatever. For example, with apparatus embodying my invention I have ground 100 tons of zircon (about 12 cubic feet to the ton) with loss from the grinding apparatus of 1/50 of one cubic inch, which represents additions carried into the material from the grinding apparatus of approximately one part in one hundred million, and even of this minute amount, part is removed with impurities previously present in the material. In fact, not only are there substantially no additions that would contaminate the product, but the material may be so ground that the greatest fraction of the ground product contains less impurities than the raw material, or substantially no impurities.

Zircon, other silicates, rutile, monazite sand, silica, and other materials found in a natural state, have lain for ages subjected to all kinds of impurities, and thereby have acquired anything from a surface stain to a mantle of impurities, or the impurities have more or less penetrated the grains or particles, or the surface has broken down. Analogous conditions may also be true in the case of substances produced artificially. In either event, the impurities may render the material unfit for use, for example where a high degree of purity is necessary or where color is a criterion of value. By way of illustration, zircon is more valuable and salable if it is "white burning," while in rutile the presence of impurities may affect its usefulness as a colorant for ceramics. In addition, the presence of naturally present impurities may render the material less desirable where it might otherwise be useful as an electrical insulating material, particularly at elevated temperatures.

I have found that I can purify materials by

subjecting the material to impact as hereinbefore described, preferably impact of such degree or such degree and kind as will crush or chafe off the outer mantle of impurities but will leave substantially intact the pure "cores" of the particles. In some instances if particles have been penetrated by impurities the crushing resistance of the particle as a whole is decreased and the entire particles may be broken or crushed by impact of a degree less than enough to break or crush pure particles. Therefore material to be purified is passed through a gun or through plural opposed guns, subjecting it to the suitable impact, and the impurities are carried off mostly in the ultimate fines. With reference to the embodiment shown in Figure 1, most of the impurities finally land in the air cleaner 123, and when operating the system for the purpose of purifying the material, the air velocity in the separating system may be so set that most of the impurities will be removed by the separating devices 116 and 123. Of course the purified residue desirably is kept separate from new or raw material, and this may be done by so connecting the separating device 91 that its bottom discharge outlet is into the conduit 135, so that only new material is fed into the hopper 60. However, the purified residue may be again passed through a gun and again ground, the impurities and the ultimate fines being again separated, and so on. Whenever the purified residue has reached a desired degree of purity, whether after a single pass or after more than one pass, then the residue, or one or more separated fractions thereof, may be passed through a gun any desired number of times, either at the same or greater impact.

By way of illustration, I have found that when zircon of a tan or pinkish surface color is run through my grinding means at a desired degree of impact, the first pass produces extreme fines of a comparatively dark color, and the residue is considerably lighter in color. By regrinding that residue separately, I obtain a material which is greatly improved in chemical analysis, is almost white even before burning, and after burning is even more pronouncedly improved in color.

It has been attempted to improve zircon by leaching with chemicals. If this is done before reducing the material to its ultimate fineness the benefit is limited. On the other hand, if it is done after the material has been reduced to its ultimate fineness, such as 200 mesh, or 325 mesh, or finer, while the result is better, the process is expensive. Also, in either case there is the difficulty of removing the leaching agents, as well as the expense of the operation and of removing the leaching agents. Furthermore, leaching ordinarily does not improve more than the extreme outer surface of the particles, and in fact, if the leaching agent did penetrate the particles, it would be very difficult to remove the leaching agent at all.

My invention enables acceptable high grade products to be made from natural mineral deposits, or analogous artificial materials, which are otherwise commercially unacceptable. However, in some instances, of which zircon is an example, the fines which include the outer mantles of the particles removed by my method, constitute a product which still is valuable for certain classes of uses where factors such, for example, as color or high electrical insulating resistance are not important.

My invention also contemplates the separation of co-mingled material particles of different characters having different resistances to impact crushing. More particularly, I may so project the co-mingled particles from a gun that the impact is such as to crush or shatter approximately only the weakest particles, and separate the crushed particles from the substantially uncrushed particles, then so project the substantially uncrushed particles that the impact is such as to crush or shatter approximately only the next weakest particles, and again separate the crushed particles from the substantially uncrushed particles, and so on, the cycle being repeated, with increasing impact for each pass, until the desired separations have been attained. In this way I may separate, for example, various constituents of an ore.

Of course this method of grinding, which I call selective grinding, may be included in or be combined with the removal of mantles from particles, as in the instance of zircon and the like, in which case the first pass would be at an impact sufficient to crush or chafe off the mantles from the pure cores and to crush the impure weak particles, and the succeeding passes would be at successively increasing impact to successively and selectively crush other minerals often found in zircon ore in a state of nature. Also, my apparatus is particularly well adapted to carry out such selective grinding, particularly because of its great flexibility of adjustment, whereby substantially any desired degree of impact may be secured. Furthermore, the apparatus may be calibrated for different materials and different impacts, so that it may be readily adjusted and re-adjusted when changing from the processing of one material to another.

Naturally, in general the plural stage guns are most flexible, by reason of the adjustability of the stages, and with any given gun I may vary the pressure from lower amounts up to pressures of the order of 500 to 1000 pounds per square inch, or even higher, adjusting the amount of air admitted to the breech of the gun and to the accelerating jets respectively to secure the desired grinding quality and quantity. Of course the length of the gun also may be varied, as hereinbefore set forth, to suit particular conditions.

In general, the results desired determine the manner of use, form, and adjustment, of the apparatus. Generally speaking, criteria are maximum hourly production rate of fines in general or fines of any particular mesh, minimum air consumption per ton produced, minimum rehandling of the material, minimum wear of active parts, minimum contamination of the product with material from the equipment, minimum size and weight of equipment, minimum cost of equipment relative to production rate of desired output, universality of application from softest to hardest and most abrasive material, ease of control of texture and fineness of desired product, continuity of the process, safety in manipulating high pressures and from dust, and capacity for further reduction of originally very fine materials, and all of these criteria are satisfied with my invention.

If it is desired to produce aggregates having a relatively uniform division of screen analysis from the maximum to the minimum, I prefer a gun of any desired number of stages, projecting the material against a fixed anvil. This produces a more uniform texture of sharp angular par-

ticles, with a minimum of extreme fines. The gun and anvil combinations may be multiplied as desired, and operated in parallel. On the other hand, if it is desired to produce a maximum amount of extreme fines, it is best to use plural opposed guns, that is, two or more guns the streams from which impinge each other.

My invention makes practical the use of opposed guns. With guns in accordance with my invention, combining positive fluid pressure feed of solids with accelerating jet means, I am able to lengthen the barrels of the guns to get maximum velocity, and also to oppose the guns, even head on, without impairing the solids feed. Furthermore, I am enabled to place opposed guns within a very short distance from each other without creating enough additional back-pressure to materially affect the feed rate, whether the arrangement comprises two or more opposed guns. Such close spacing enables me to project a number of solids streams against each other at very close range, avoiding spreading of the solids streams, thereby maintaining great concentration of the kinetic energy of the solids streams.

Thus, my invention enables control of the grinding texture so that a relative minimum or relative maximum of extreme fines can be obtained, depending on whether the impact is against a fixed anvil or against a counter-stream directly or at some desired angle less than 180°.

Accordingly, it will be apparent that in subjecting material to impact for the purpose of grinding it or purifying it, or both, the material may be subjected to either type of impact, that is, it may be passed either through a gun against an anvil, or through plural guns the streams from which impinge each other, depending on which particular method is most suited to the purpose and to the material treated, and depending on the desired screen analysis of the product. If the material is subjected to one or more subsequent passes, a given pass may be of the same type as a preceding pass or of another type.

My invention is particularly adapted for the production of finely divided abrasives, not only because by use thereof hard abrasive materials may be ground, but because the resultant particles comprising the finely divided product have sharp edges, rendering the product more effective in use as an abrasive.

While I have shown annular conical jets for applying the booster air, my invention includes other jet means suitable for the purpose. Also, while I have mentioned tungsten carbide for various parts particularly subject to wear, my invention includes any suitable wear-resisting material, for example metallic carbides such as the carbides of tungsten, tantalum, titanium, boron, or combinations thereof, and in any form, and for any parts as may be desired. Also my invention contemplates pressures up to one thousand or fifteen hundred pounds per square inch or even higher.

From the foregoing it will be apparent to those skilled in the art that each of the disclosed methods and apparatuses embodying my invention provides a new and improved method, or a new and improved apparatus, respectively, for carrying out the processing of materials, and each of the disclosed products embodying my invention provides a new and improved product, and accordingly, each of the methods and apparatuses and products accomplishes a principal object of my invention. On the other hand, it also will be obvious to those skilled in the art that the disclosed embodiments of my invention may be variously changed and modified, and features thereof, singly or collectively, embodied in combinations other than those disclosed, without departing from the spirit of my invention or sacrificing the advantages thereof, and accordingly, that the disclosure herein is illustrative only, and that my invention is not limited thereto.

I claim:

The method of producing purified material of a certain kind from an impure starting aggregate having at least a part of said kind of material integrally coated with or stained by impurities, said coatings and said stained material having less resistance to disruption by impact than pure material, which comprises, introducing the aggregate and fluid under pressure into a plurality of guns to impart velocity to the aggregate, subjecting the streams of aggregate to disruptive impact by so directing the streams that the streams impinge each other, said impact being selected to be sufficient to disrupt impure coatings or stained material, obtaining a resultant comprising a separable impure fraction comprising the finest particles and containing the highest percentage of impure material, a coarsest fraction materially purer than said starting aggregate, and at least one fraction intermediate in size between said coarsest fraction and said impure fraction and materially purer than said coarsest fraction, and segregating said fractions on the basis of size.

EDWIN L. WIEGAND.