April 29, 1958 W. B. SEGRAVES 2,832,545

SUPERSONIC JET GRINDING MEANS AND METHOD

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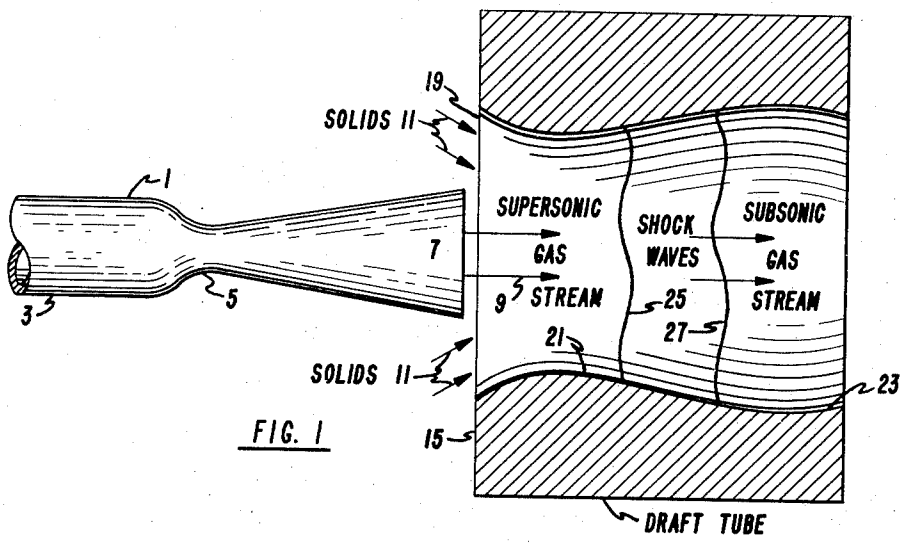

FIG. 1

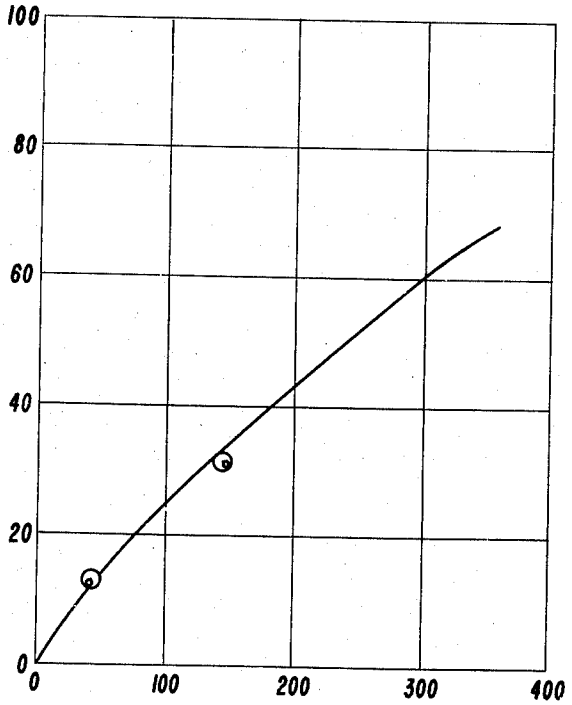

FIG. 2

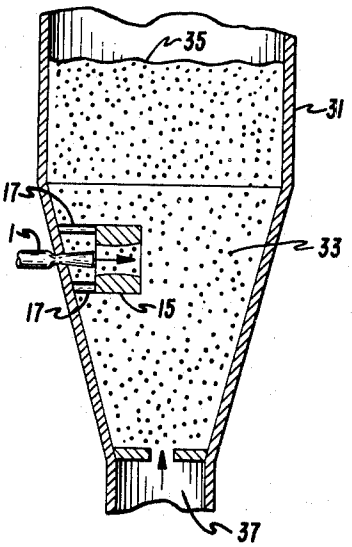

FIG. 3

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SUPERSONIC JET GRINDING MEANS AND METHOD

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7 Claims. (Cl. 241—1)

The present invention relates to an improved supersonic jet grinding means and method such as is suitable for grinding finely divided particulate solids into finer particles by impact and attrition. More particularly, the invention relates to means for employing supersonic jets to grind small petroleum coke particles such as are produced and utilized in the fluid coking process for converting heavy oil to coke and other products.

In recent years highly successful processes have been developed for utilizing fluidized masses of finely divided solid materials for supplying thermal and/or catalytic requirements in various conversion processes. For example, finely divided solid particles, catalytic in nature, have been used for cracking petroleum products, for reforming naphthas and for various other purposes. A more recent development is the utilization of finely divided and relatively inert particles for supplying heat to produce thermal conversion of oils and the like. The so-called fluid coking process, for example, employs large masses of petroleum coke particles which may vary in size from about 20 to 400 microns or more in particle diameter. These are preheated and brought into the reaction zone where they are fluidized and contacted with the feed to be converted. The thermal energy contained in the preheated particles is sufficient to accomplish the desired conversion, normally resulting in production of more coke which is deposited upon the original particles causing them to grow in average particle size.

Obviously in the coking process just described, the growing particles would soon become too large for efficient use in the sysetm. This is true even though the particles may be reheated by partial combustion which would tend to reduce their average size. Most coking processes produce more coke than is needed for conversion requirements by combustion, and consequently, some of the coke must be withdrawn from the system as a by-product.

The coke retained in the sysetm must also be reduced in particle size to an appropriate level for operating efficiency. Small or "seed" particles are desirable in large numbers to serve as nuclei for the deposition of coke formed by the pyrolytic conversion of the feed. As these particles grow, they must be repeatedly broken up into smaller particles to keep the system operating effectively and efficiently. This gives rise to the requirement for grinding or attrition of the coke particles. The present invention has as a major object the efficient grinding or attrition of such particles to supply seed requirements to the system. The invention, however, is not limited in its application to particles of coke. It is equally applicable to other materials which need size reduction and may be applied to catalytic or non-catalytic materials of any type so long as they are hard, brittle and subject to size reduction by impact, attrition and particle breakage.

The present invention is based upon the discovery that by suitable jet nozzle design, preferably in combination with a draft tube arrangement, a gasiform fluid may be injected into a mobile mass of solid particles so as to

draw some of the particles into the draft tube and break them up. The particulate solids are preferably a suspended or fluidized mass of solids. The apparatus is designed to draw the solid particles directly into the path of the jet and thereby cause impact or collision and shock to the particles sufficient to break them up into smaller sizes. Specifically it has been found that the design of the nozzle should be such that the sum of its outlet velocity head, plus the static pressure head of the emerging stream per se is only moderately higher than the ambient pressure within the zone into which the stream is being injected. This means that the static pressure head of the stream per se must be substantially lower than the ambient pressure head within the zone where grinding and attrition are to take place. By such an arrangement solids surrounding the nozzle and in the general vicinity thereof are drawn, because of reduced pressure, into the emerging gas stream. This gas stream must be above supersonic velocity as it first contacts the particles. Conditions must be such that the jet velocity is quickly reduced to subsonic, with the consequential production of severe shock waves. These shock waves, which take place within the restricted draft tube or draft zone, produce high turbulence and pronounced impact and collision between the particles. They also cause collision between the particles and surrounding structural elements where such are present. In this way they produce substantial breakage and grinding of the solid particles which are drawn into the path of the fluid jet.

The invention will be more clearly understood and its objectives more readily apparent by reference to a detailed desecription of a presently preferred embodiment.

Referring to the attached drawings, Fig. 1 shows, on a relatively large scale, a high velocity nozzle for a gasiform fluid such as steam. It shows also, an axially aligned draft tube having a relatively enlarged inlet end, an intermediate reduced section and a still larger outlet end of a continuous passageway. The inlet end of the draft tube and, in fact, its smallest cross-section is larger in diameter than the outlet end of the nozzle.

Fig. 2 shows certain graphical relations between upstream pressure and the sum of outlet static head plus velocity in a nozzle of suitable design.

Fig. 3 shows in relatively small scale a vessel containing the nozzle and draft tube arrangement of Fig. 1.

Referring in more detail to the drawings, Fig. 1 shows a nozzle 1 forming the terminal portion of a tube 3 having a constriction or vena contracta 5 and a flared tip portion 7 at its outlet end. The design of this nozzle is preferably such that the following conditions exist:

Nozzle outlet static head+velocity head=$(1+x)$ bed pressure, or

$$P_0+\frac{V^2\rho_0}{2g\cdot 144}=(1+x)P_B$$

where,

P_0=static pressure at outlet of nozzle in p. s. i. a.
V=gas velocity in ft./sec. at the outlet of the nozzle.
ρ_0=gas density in lb./ft.^{3} at the outlet of the nozzle.
g=gravitational force constant.
x=margin of safety for excess head desired over that necessary to feed gas into the bed (as a fraction of the bed pressure).
P_B=static pressure of the bed in p. s. i. a.

With a nozzle designed as above, the static head in the outlet gas stream indicated by arrows 9 is substantially below the ambient pressure within the system where the nozzle is operating. As a result, solid particles surrounding the nozzle are rapidly drawn into the path of the stream as indicated by arrows 11.

The velocity of the incoming gas stream which, as noted above is supersonic, that is, above about 11000

feet per second and preferably 1200–3000 or more feet per second, is rapidly reduced as the stream or other gasiform fluid expands. Consequently, as it passes through the sound barrier, shock waves are produced giving extremely high turbulence and heavy impact and collision between the particles entrained in the stream. It is here that attrition or grinding takes place.

While the nozzle 1 may be used alone, under some conditions, it is preferably used in combination with a draft tube indicated at **15**. This tube is suitably mounted, within the zone where grinding is to take place, by any suitable means such as supporting brackets **17** shown in Figure 3. It is also mounted so that the passageway through the draft tube is in direct axial alignment with the axis of nozzle **1**. The particular design of the draft tube per se may be varied somewhat. The inlet end of the passageway, indicated at **19**, is shown as substantially larger in cross-sectional area than the outlet 7 of the nozzle. In the embodiment shown in Fig. 1, the passageway gradually reduces in cross-section, moving to the right in Fig. 1 to pass through a minimum section **21** which may be sort of vena contracta. Thereafter the passageway is enlarged gradually so that the outlet **23** is larger than the mid-section and it may be larger than inlet end **19**. The shape shown has proved to be satisfactory but the passageway may be cylindrical, if desired, with substantially equivalent results, so long as the draft causes the desired flow of particles from the general mass of the bed into the path of the supersonic velocity jet.

With the arrangement just described, the supersonic velocity gas stream emerging from the nozzle flared end 7 into inlet **19** of the draft tube is at very low static pressure. This pressure is preferably sub-atmospheric and may be as low as 1 or 2 lbs. per square inch absolute. A desirable range ordinarily is from 3 to 10 or 12 lbs. absolute pressure when the ambient pressure is atmospheric. The pressure within the system or the main bed at the nozzle is normally at least atmospheric and may be from 0 to 50 lbs. or more gauge pressure. For some purposes it may go as high as 200 p. s. i. g. or higher in which case the absolute pressure at the nozzle outlet may be higher in proportion. Under the conditions described above, the solid particles flow rapidly into the stream from around the inlet end of the draft tube and are carried into the shock wave section indicated abstractly by lines **25** and **27** of Fig. 1, without attempting to define their limits or characteristics, which does not appear to be practicable at the present time. Here, in this general area, the gas stream drops from supersonic to subsonic velocity and the shock creates severe impact between particles, and against the draft tube walls. It causes the desired particle grinding mentioned above. The function of the draft tube, obviously, is to control and limit the amount of solids subjected to shock waves for more efficient grinding or attrition than is possible without it.

Referring to Fig. 3, there is shown a container or vessel **31** within which a mass **33** of mobile solid particles is maintained. This mass is indicated as a so-called fluid bed with an interface **35** defining its approximate upper level. It will be understood, of course, that a disperse phase of small particles which are carried out

of the bed usually exists above the interface **35** of a fluid bed of solid particles. It will also be understood that the system is applicable to a suspension or other mass of particles which are not necessarily in the form of a bed having a definite interface. In some cases, the system can be used with a dense bed that is not fluidized or at least not entirely fluidized. In either case the density and mobility of the mass must be such that a substantial number of particles may be drawn into the path of the supersonic fluid stream for grinding.

The nozzle 1 and the draft tube **15** are therefore inserted at any appropriate point in the system. A plurality of such units obviously may be used where needed and in a large vessel **31** several are desirable.

Where the main mass in the vessel is a fluid bed or a suspension, an upflowing stream of gasiform fluid such as steam, hydrocarbon vapors, inert gases, etc., is supplied through an inlet **37** to keep the solid particles fluidized or suspended within the system. The gasiform fluid supplied to the jet nozzle **1** may be of any suitable type. For use with a coker, where coke grinding is needed, the preferred fluid usually is steam which may be saturated or superheated as desired. The pressure of the jet fluid, in any case, should be such that the conditions stated above are maintained. Thus, the sum of static pressure head plus velocity head of the nozzle outlet stream should be only about as high or moderately higher than the pressure within vessel **31**. A factor of safety, more properly a performance factor, may be designated by the term "x," as shown above, and the static head plus velocity head of the incoming gas stream should equal the sum of $(1+x)$ times the pressure within the vessel.

The following table shows the various operating characteristics which are suitable. It also defines satisfactory limits for operation of the invention, where x is as defined above, P_B is absolute pressure within the bed.

TABLE I

x,[1] percent	Jet Nozzle Efficiency,[1] Percent	P_B [1] (p.s.i.a.)	Jet Air Velocity [1] (ft./sec.)	Up-Stream Pressure [1] (p. s. i. a.)	Velocity Head [2]	Outlet Static Pressure (p. s. i. a.) [2]	Density [2] (lb./ft.^{3})
10	85	14.7	1,800	464.7	80.7	18.4	0.1784
10	85	14.7	1,800	294.0	57.3	12.5	0.1283
10	85	14.7	1,800	147.0	30.9	6.8	0.0689
10	85	14.7	1,800	44.1	12.8	3.1	0.0278

[1] Assumed fixed values.
[2] Calculated values.

These figures show nozzle upstream pressure, nozzle outlet pressures and gas densities based on the formulas given above. For the condtions of Table I with a vessel operating at atmospheric pressure, the minimum upstream pressure required is about 65 p. s. i. a. With a system, e. g. a fluid bed, operating at 30 p. s. i. a. pressure and providing a factor x of 10%, the term

$$P_0+\frac{V^2\rho_0}{2g\cdot 144}=33 \text{ p. s. i. a.}$$

Under these conditions the required upstream pressure for the optimum nozzle design is about 150 p. s. i. a.

At some modern petroleum refineries, it is conventional to provide steam at about 465 p. s. i. a. If steam at this pressure were used in the nozzle supplied to a coking bed operating at 30 p. s. i. a., there would be an excess head at the nozzle outlet of about 50 p. s. i. This would be highly inefficient. Obviously, the use of steam at 465 p. s. i. a. instead of 150 p. s. i. a. is wasteful when it is not needed. Elaborate apparatus must be employed for the higher pressure. Obviously, more horsepower hours of energy are required to grind the solids when the higher pressure is used.

To substantiate the foregoing, a series of tests were conducted on fluid coke of particle size within the general

limits mentioned above, i. e. about 20 to 400 microns average particle diameter, using air for the jets. Tests were conducted with apparatus designed for nozzle inlet pressures respectively of 90 and 450 p. s. i. g. Low pressure tests were made at 72 and 83 p. s. i. g. respectively and high pressure tests at 450 and 400 p. s. i. g. The tests indicated that slightly larger quantities of very fine coke were produced by the high pressure jets but operating efficiency in terms of pounds of ground coke per horsepower hour were much higher at low pressures. The conclusion is clear that low pressure jets are superior to high pressure jets for overall efficiency. While the differences are not as great when steam is employed as the grinding medium, because steam pressures can be generated by heat, they are very substantial where other gases such as air are used and where they must be compressed mechanically for use. The differences in investment and operating costs, between air at 90 to 150 lbs. vs. air at 450 lbs. or so, are very great. In either case, however, the low pressure operation requires less expensive equipment and is generally much more economical. The data obtained are summarized in the following table:

Example II.—Comparison of a low pressure jet design with conventional design

Gas	High Pressure Steam	Low Pressure Steam
Outlet velocity, ft./sec.	3,000	3,000
Bed static pressure, p. s. i. a.	30	30
Steam rate, lb./hr.	x	x
Upstream pressure, p. s. i. a.	465	110
Upstream temperature, ° F.	760	660
Outlet pressure, p. s. i. a.	61	11.9
Outlet velocity head, p. s. i.	133	26.7
Total outlet head, p. s. i. a.	194	38.6
Nozzle throat area	A	4.04A
Nozzle outlet area	1.49A	7.39A
Nozzle length	L	Approx. 3L

This second example gives an idea of orders of magnitude and the relative magnitude based on the specific case of Example I above.

The invention contemplates both the apparatus and the method of process aspects and obviously variations may be made therein within the scope of the art without departing from the spirit thereof.

What is claimed is:

1. Means for grinding hard granular material to finer particle size, comprising in combination a flared nozzle, designed for high terminal velocity and having a directional axis, means for supplying a gasiform fluid to said nozzle at such rate and pressure as to cause the fluid to emerge from the flared end of the nozzle as a supersonic velocity jet, and a draft tube of larger internal diameter than the outlet of the nozzle located within a mass of said granules and in axial alignment with said nozzle and in front of its outlet to receive said jet, said draft tube being so designed as to draw a limited supply of said granules into the path of the gasiform fluid stream emerging from the nozzle, whereby the jet passes from supersonic velocity through the sonic barrier within said draft tube thereby creating shock waves within said draft tube and whereby particles within said draft tube are broken up by reason of the shock and consequent impacts imparted thereto.

2. A method of grinding hard, brittle, granular material into finer particle size, which comprises injecting a supersonic velocity jet of gasiform fluid into a relatively quiescent zone wherein a mass of material to be ground is in fluidized suspension, passing the jet immediately into a confined zone of substantially larger cross-section than the nozzle outlet whereby a substantial drop in pressure takes place, thereby causing said material to be drawn into the path of said stream and into said confined zone, and suddenly reducing the velocity of said stream through the sonic barrier within

TABLE II

Supersonic jet attriter data

[Tests conducted in 12" glass jiggler using air for jets and fluid coke]

Nozzle Type	Test Number	Design Pressure (p. s. i. g.)	Operating Pressure (p. s. i. g.)	Operating temperature, ° F.	Flow Rate [2] (s. c. f. m.)	Discharge Pressure [2] (p. s. i. g.)	Discharge velocity [2] (ft./sec.)	Bed Pressure (p. s. i. g.)	Thru 100 Mesh Produced (lb./s. c. f.)	Thru 200 Mesh Produced (lb./s. c. f.)	Thru 100 Mesh Produced (lb./h. p.-hr.) [3]	Thru 200 Mesh Produced (lb./h. p.-hr.) [3]
Low Pressure	[1] 1	90	72	ca. 80	14.7	−6.5	1,620	ca. 2	0.036	[4] 0.025	19.7	[4] 13.7
Do	[1] 3	90	83	ca. 80	15.7	−5.9	1,620	ca. 2	0.029	0.0105	14.6	5.3
High Pressure	5	450	450	ca. 80	21.3	54.4	1,505	ca. 2	0.023	0.022	5.2	4.9
Do	9	450	400	ca. 80	19	44.1	1,530	ca. 2	0.045	0.022	9.6	4.7

[1] Test 1 employed low pressure nozzle with draft tube. Test 3 employed low pressure nozzle without draft tube.
[2] Flow rates, discharge pressures, and discharge velocities are calculated values using 85% for the nozzle efficiency.
[3] Energy values (horse power-hours) were calculated by assuming adiabatic and reversible compression of air from atmospheric pressure and 80° F. up to the operating pressures shown above.
[4] Recycle grinding probably caused these values to be high.

As noted above, the jet nozzle alone can be used with some efficiency but it is preferable to use it in combination with the draft tube. When the draft tube is used, it is preferably of abrasion resistant material since considerable impact with its walls occurs at the point where the shock waves are formed and where the resulting high turbulence causes severe impact, sufficient to break the solid particles.

Specific designs for nozzles and other elements will vary for the particular unit and scale of operation. An example of one attriter is given below:

Example I.—Physical dimensions of test jet attriter

[Designed for use with air at about 80 p. s. i. g. and 80° F.]

Upstream diameter, inches	0.957
Upstream area, square inches	0.72
Throat diameter, inches	0.117
Throat area, square inches	0.0108
Outlet diameter, inches	0.17
Outlet area, square inches	0.0228
Length of nozzle from throat to outlet, inches (approximately)	½
Draft tube diameter, inches	0.957
Draft tube area, square inches	0.72
Solids inlet area to draft tube, square inches (approximately)	0.4

said confined zone to cause shock and collision to particles of said material and thereby break said material into smaller particles.

3. A method of grinding fluidizable solid particles of matter into smaller particles, which comprises establishing a fluidized mass of said particles in a container by passng a gasiform fluid upwardly therethrough at apparent velocity of about 0.1 to 10 feet per second, injecting a supersonic velocity stream of gasiform fluid through a part of said fluidized mass and into a quiescent draft zone of cross-section larger than the injected stream and at substantially lower pressure, the relation of the stream to the draft zone being such that the velocity of said stream rapidly diminishes and passes through the sound barrier within said zone, whereby solids are drawn from said mass into said zone and are broken up by mutual collision and by the high turbulence and shock waves produced as the stream goes from supersonic to subsonic velocity within said zone.

4. Process according to claim 3 wherein the solid particles are petroleum coke particles produced by pyrolysis of heavy oil.

5. Process according to claim 3 wherein the gasiform fluid is steam.

6. In apparatus for grinding particulate solids, the combination of a container for a mass of said solids, means for imparting mobility to at least some of the particles of said mass within said container, a draft tube mounted within said container and normally surrounded by said mass and by some of said mobile particles, said draft tube having a continuous passageway therethrough with a relatively large inlet end, and a high velocity fluid nozzle projecting from a wall of said container substantially to and directly toward the said inlet end, the outlet of said nozzle being substantially smaller in cross-section than said inlet and the nozzle design being such that a supersonic velocity stream of gasiform fluid emerges therefrom into said inlet end at pressure substantially below the ambient pressure within the said mass, whereby a stream of particles is drawn into the draft tube, the design of said draft tube being such that the velocity of the gasiform stream drops from supersonic to subsonic therein, with consequent passage through the sound barrier and resulting high turbulence and shock to cause attrition and grinding of the particles within said draft tube.

7. Apparatus according to claim 6 wherein the nozzle is so designed that the sum of the stream outlet velocity head and the static pressure head is only slightly higher than the ambient pressure within the vessel and the static pressure within the stream per se is very substantially less than said ambient pressure.

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