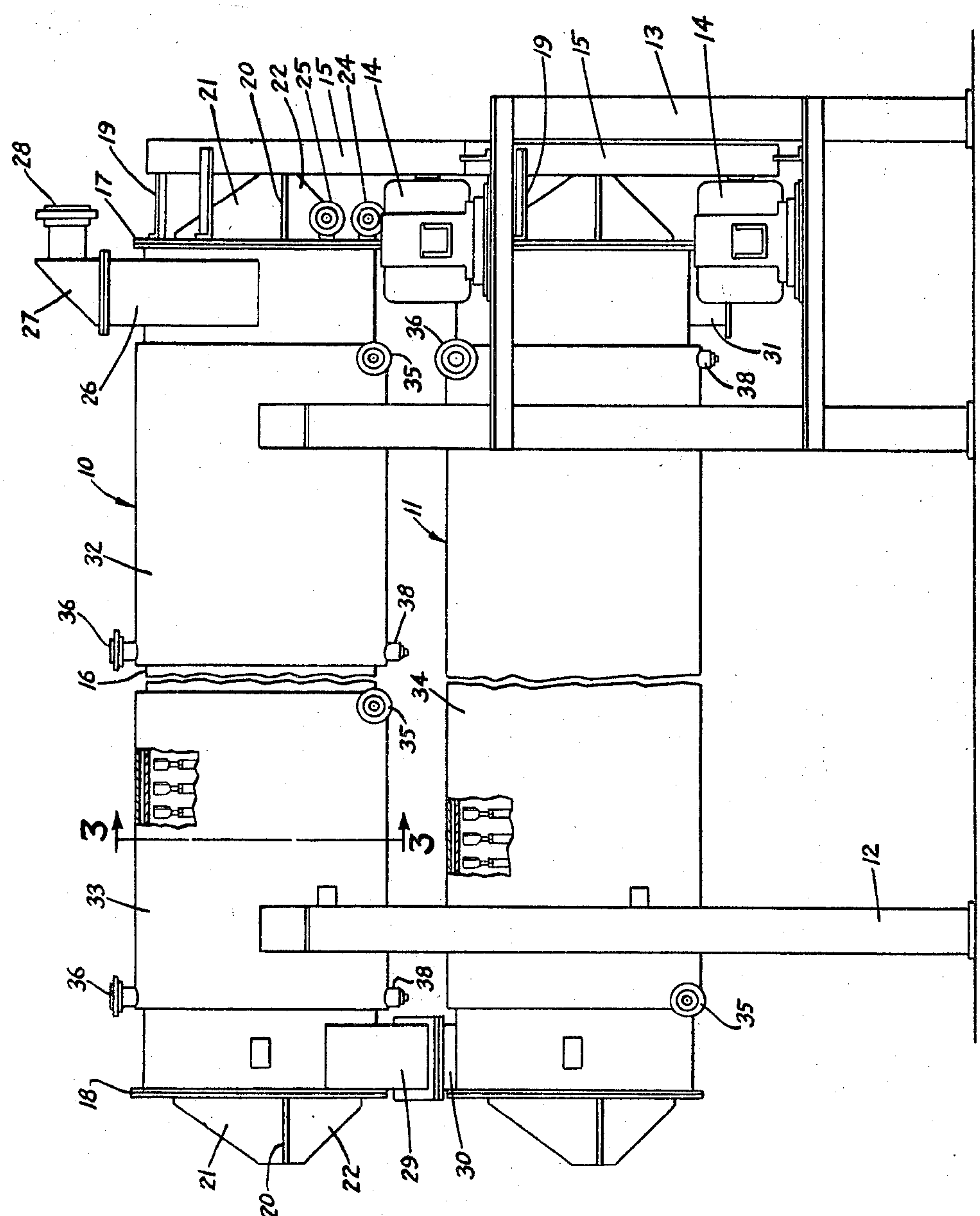

FIG. 1

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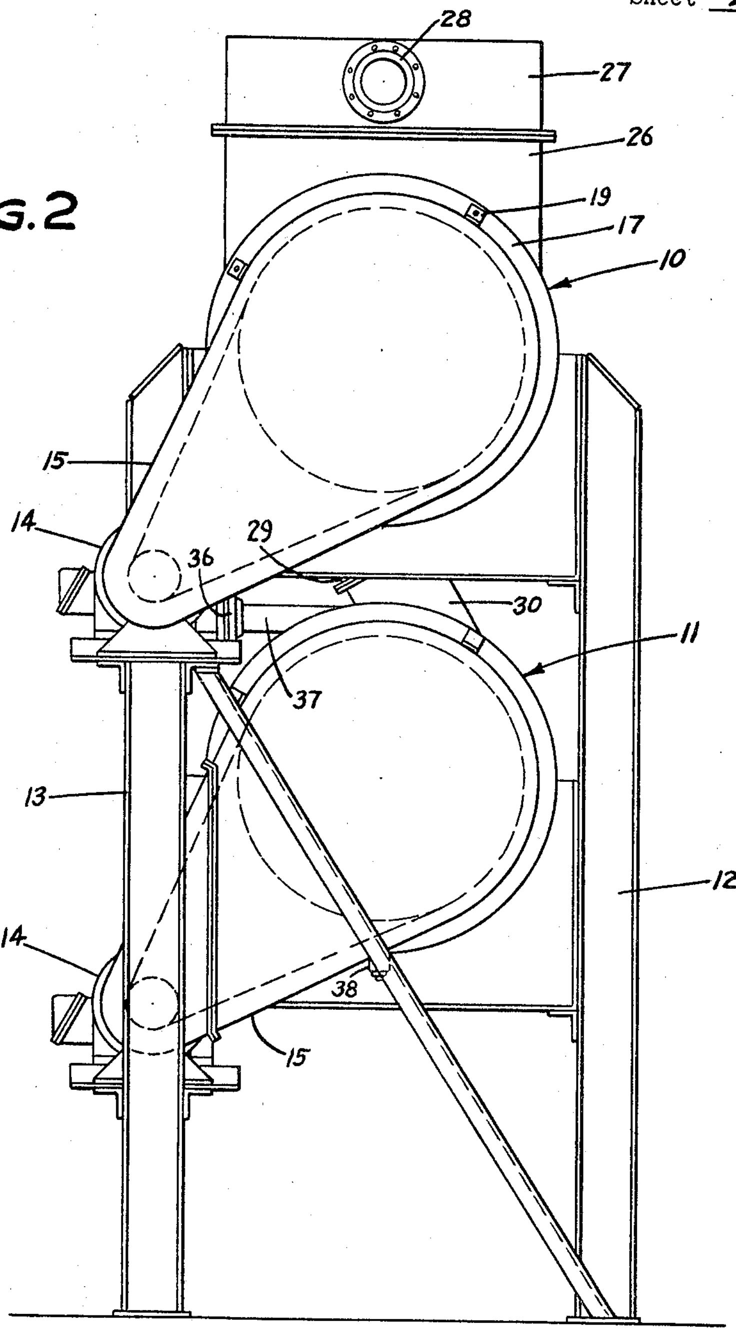
FIG. 2



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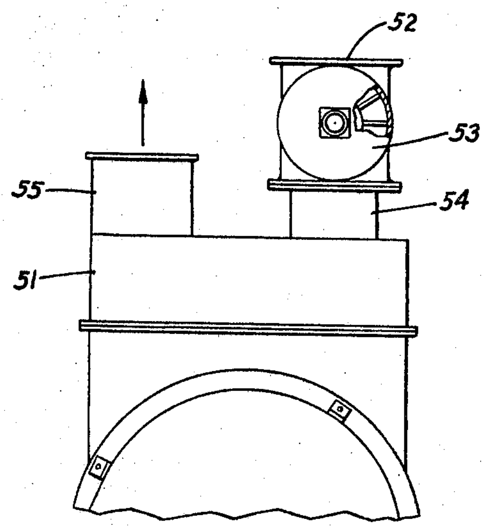

FIG. 2A

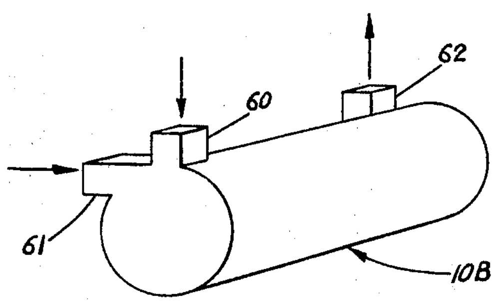

FIG. 2B

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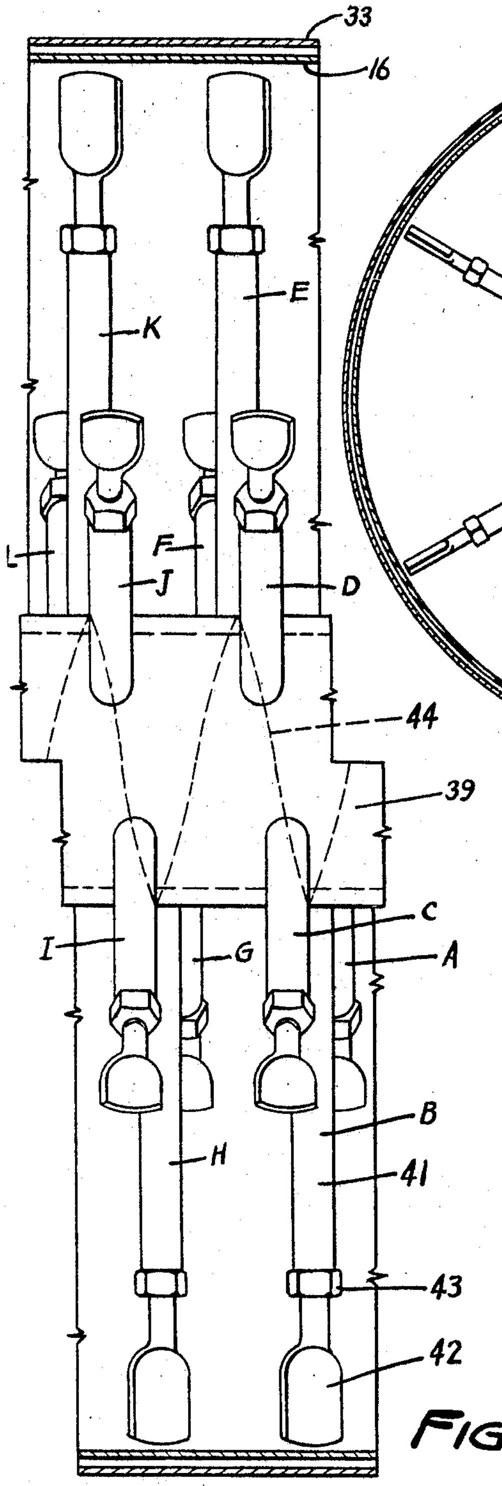

FIG. 4

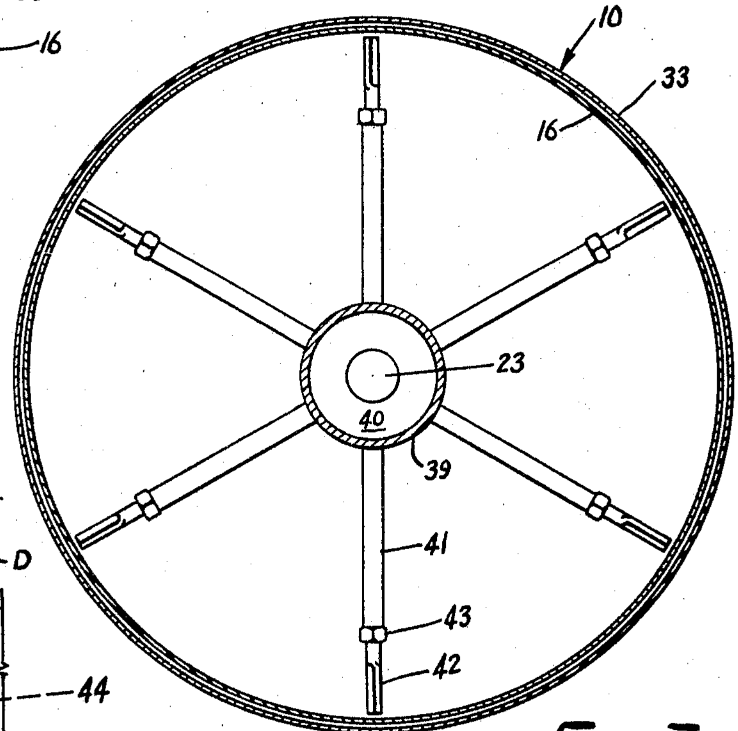

FIG. 3

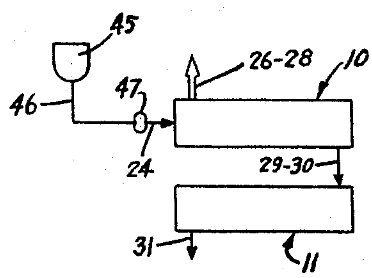

FIG. 5

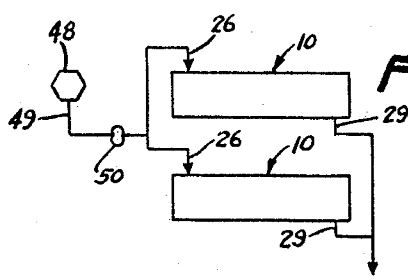

FIG. 6

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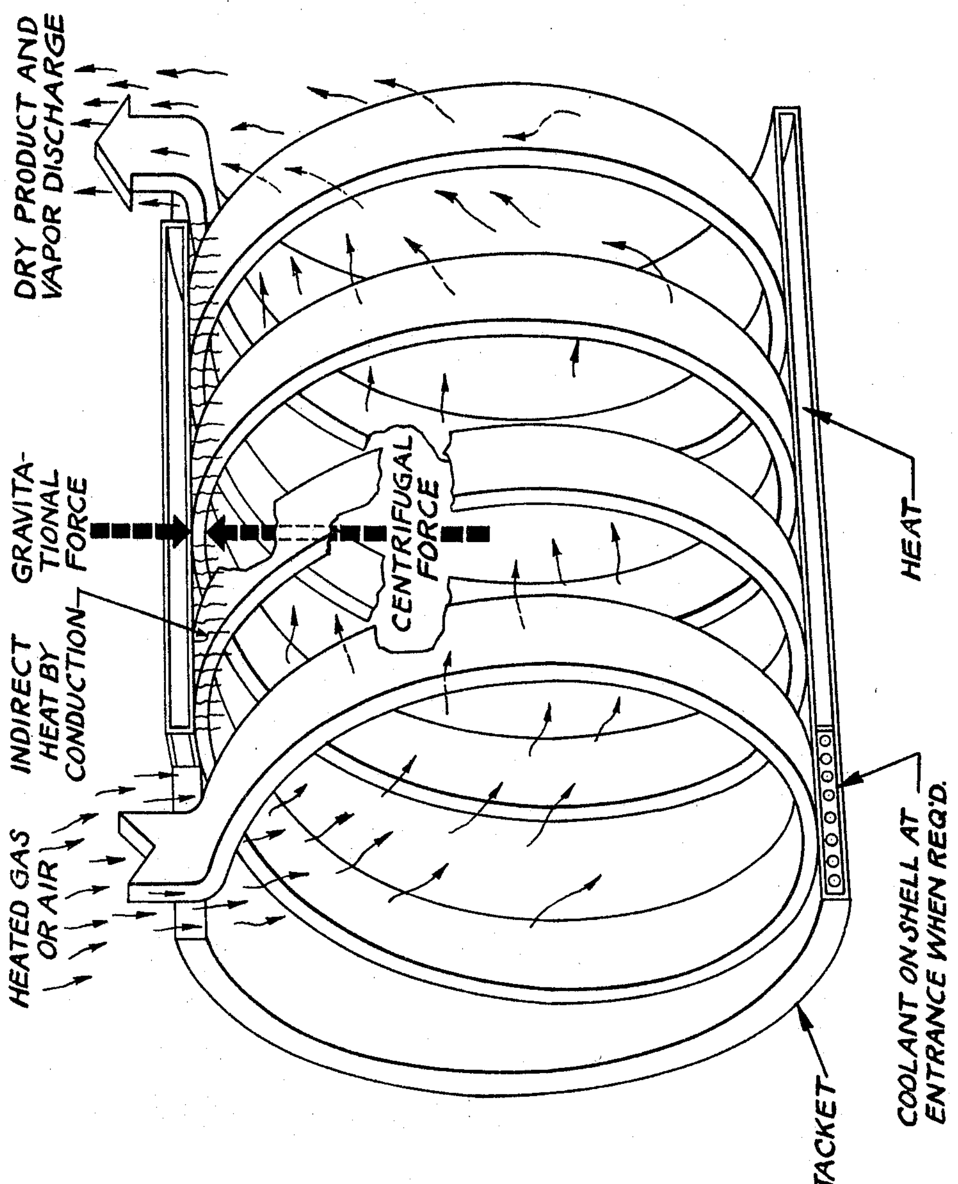

FIG. 7

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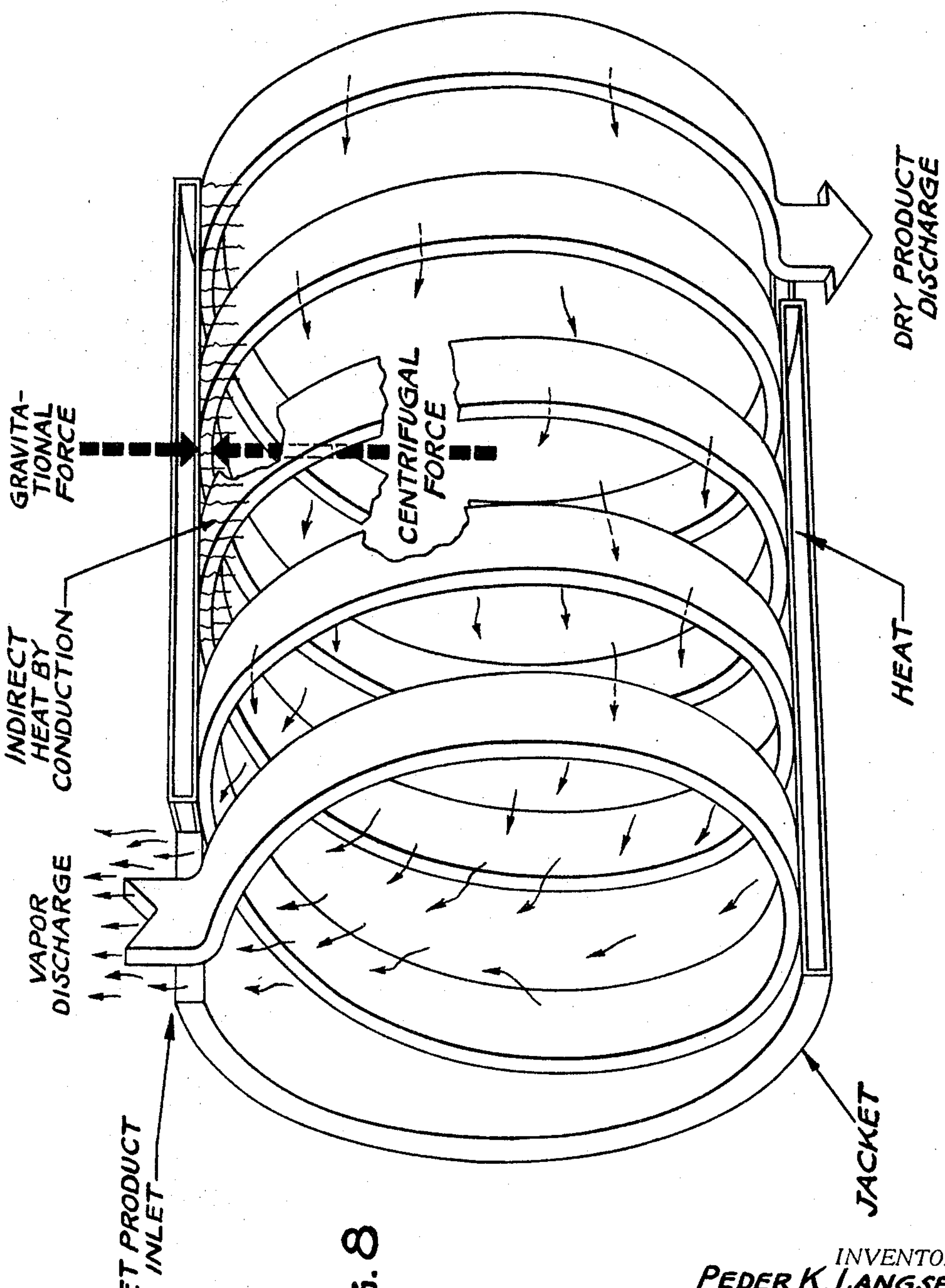

FIG. 8

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3,425,135

ROTARY SOLIDS PROCESSING APPARATUS AND METHOD

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U.S. Cl. 34—8 17 Claims
Int. Cl. F26b *3/24, 11/04;* B01f *7/04*

This invention relates to an apparatus and method for processing solids. Typical applications include drying and heating, cooling, contacting a solid with a fluid, and the like. The apparatus and method are ideally suited for drying by removing a liquid from a solid particulate material, either powdered or granular, by evaporation on a continuous basis.

Solids processing is carried out in an elongated vessel of substantially circular cross-section having an axially mounted rotatable shaft provided with paddle blades or vanes radially mounted and extending substantially to the inside wall of the vessel. The vessel is disposed generally horizontally, that is on either a horizontal or upwardly or downwardly inclined axis. The vessel is desirably jacketed to permit the circulation of a heating or cooling fluid so as to control the temperature of the inside wall of the vessel. Wet or dry solids are introduced to one end of the vessel.

The paddle bearing shaft is rotated at a speed high enough to cause the paddle blades or vanes to strike and agitate the particles of solids within the vessel to such an extent that the mass of solids is maintained as an annular fluidized bed. The shaft is rotated fast enough that the centrifugal forces on the particles are greater than the force of gravity so as to maintain the circulating annular bed, which on most materials has an observable inner boundary. The annular ring of material is maintained in constant turbulence and intimate contact between particle and drying or treating gas.

The fluidized bed is stratified radially with the largest particles thrown outwardly adjacent to the inner wall of the vessel and smallest particles spaced inwardly in the direction of the rotating shaft. For convection drying, with co-current gas flow, the paddle blades are in their outermost portions adjacent the vessel wall desirably provided with a backward pitch. The largest and wettest particles (which need the longest residence time in the drying vessel in order to be dried) are thrown centrifugally outwardly to the area around the periphery of the vessel where they are contacted by the backward pitched paddles and thrown backward for longer retention time in the vessel. Conversely, smaller particles which require shorter residence time circulate toward the center of the annular fluidized bed where they are not affected by the paddles and may be entrained in an internal gas classification flow for advancement through and discharge from the vessel.

For conduction drying, with no gas flow or small gas flow, either co-current or countercurrent, the paddles are set substantially flat through the greater portion of the length of the vessel. If longer residence time is necessary, paddles at the vessel outlet end are set with reverse pitch, or an annular dam ring is provided at the outlet.

The apparatus of the present invention is adapted to direct drying, heating or cooling using an appropriate convection gas flow or indirect drying, heating or cooling by conduction through vessel wall, or a combination of convection and conduction. Because of the high speed paddles and greater agitation, more effective use is made of the vessel wall surface in conduction drying, heating or cooling.

The method and apparatus according to the present invention have been found to be especially useful in drying materials such as resins, chemicals, pharmaceuticals, herbicides, insecticides, pigments and the like. The feed to the apparatus may be a concentrated or a dilute slurry, filter cake or centrifuge cake, or the like. For maximum capacity with minimum space requirements, vessels may be vertically stacked. The vessels may be provided with multiple jackets disposed serially along the vessel to provide varying zone temperature control.

The apparatus according to the present invention offers numerous advantages to the chemical processing industries and others. The apparatus is compact and adaptable to existing structures for additional drying capacity. It is adaptable and very flexible. Higher efficiency is attained because of higher overall heat transfer coefficients. The vessels are readily combined into multiple units for multistage drying or for establishing long retention when necessary. The vessels can easily be sealed for use under pressure or vacuum or for blanketing with inert gases when hazards of solvents demand such handling. Total solvent removal with a single recovery system is possible by the use of this apparatus as a dryer. Because of the smaller size of the units, they may be produced in high cost corrosion resistant materials at lower total cost. The fact that the vessel is stationary facilitates the incorporation of inlets and outlets for various purposes, such as for the introduction of purging gases or blanketing gases and the like.

The invention is illustrated by the accompanying drawings in which the same numerals are used to identify corresponding parts and in which:

FIGURE 1 is a side elevation of an apparatus comprised of two vertically stacked vessels of slightly different structure;

FIGURE 2 is a right hand end elevation of the apparatus of FIGURE 1;

FIGURE 2A is a fragmentary end elevation of a modified form of apparatus in which the inlet end of the apparatus is provided with means for feeding material to be dried in cake form and providing for discharge of counter-current vapor flow;

FIGURE 2B is a schematic representation of another form of the apparatus in which the material to be dried may be fed in cake form and simultaneously entrained in co-current convection heating gas;

FIGURE 3 is a vertical transverse enlarged and partial section through one vessel of the apparatus, on the line 3—3 of FIGURE 1 and in the direction of the arrows;

FIGURE 4 is a further enlarged fragmentary side elevation, partly in section, showing the arrangement of paddles on the axial rotatable shaft of the apparatus;

FIGURE 5 is a schematic view showing one typical configuration of vertically stacked drying vessel units;

FIGURE 6 is a further schematic view showing another typical configuration of vertically stacked drying vessel units;

FIGURE 7 is a schematic representation of the drying process according to the present invention utilizing both direct and indirect heat; and

FIGURE 8 is a similar schematic representation of a drying process utilizing indirect heat only.

For convenience, the apparatus will be described in detail as a drying apparatus. It will be understood, however, that the same or similar apparatus is adapted to other solids processing applications.

Referring now to the drawings, and particularly to FIGURES 1 and 2, there is shown a dryer apparatus according to the present invention in which two horizontal dryer units are stacked vertically. The upper dryer unit, indicated generally at **10**, and the lower dryer unit, indicated generally at **11**, are mounted in a frame **12** of appropriate size and ruggedness to support the units. The frame includes a motor platform **13** on which are mounted electric motors **14** of sufficient size and capacity to rotate the shafts and paddles of the dryer units, the drive being by means of belts or the like enclosed within a drive housing **15**.

Each of the dryer units includes an elongated tubular cylinder **16** which comprises the dryer housing and each is fitted with end plates **17** and **18**. The belt cover **15** is supported from end plate **17** by means of brace members **19**. A bearing bracket including a horizontal plate or platform **20** supported by gussets **21** and **22** is mounted on the outside face of each of the end plates and supports a bearing (not shown) to journal a shaft **23** (FIGURE 3) on which is mounted the paddle assembly which extends the length of each dryer unit.

The entry end of the upper dryer unit **10** is provided with flanged fittings **24** and **25** secured to end plate **17** to provide communication with the interior of cylindrical housing **16**. Depending upon the particular application of the apparatus, fittings **24** and **25** may be utilized as feed inlets. For example, when the material to be dried is introduced to the dryer in the form of a slurry it may be pumped to the dryer housing through fitting **24** or **25**, or both. When an inert gas is utilized in the drying process this may likewise be introduced through one of these fittings.

In the form of apparatus illustrated in FIGURES 1 and 2, the entry end of the upper drying unit is also provided with a duct **26** which intersects the upper surface of the housing **16**. In the modified form of apparatus shown in FIGURE 2A duct **26** may be provided with a feed inlet to the dryer housing for non-pumpable materials to be dried, such as filter cake or centrifuge cake. In the illustrated apparatus (FIGURES 1 and 2) duct **26** is shown provided with a tight fitting hood **27** having a flanged fitting **28** through which solvent vapors may be passed to a suitable recovery system, for use where the liquid to be removed from the material to be dried is of sufficient value to warrant recovery. In other instances, the vapors are simply vented to the atmosphere.

The discharge end of the upper dryer unit **10** is provided with a tangential flanged discharge duct **29** which, in the assembly shown, mates with a tangential material entry duct **30** at the entry end of lower dryer unit **11**. The opposite end of lower dryer unit **11** is provided with a tangential discharge duct **31**. In the arrangement of units shown, the material passes in one direction through the upper dryer unit and in the opposite direction through the lower dryer unit. This is largely a matter of convenience and space limitations. Substantially the same result would be produced in a single dryer unit having a total length totaling that of the plural units.

Each of the dryer units is preferably jacketed. To illustrate the versatility and adaptability of the apparatus upper dryer unit **10** is shown with a plurality of jackets **32** and **33** to provide for zone temperature control. Lower dryer unit **11** is shown provided with a single jacket **34**. Each jacket is provided with a flanged fitting **35** communicating with the lower side of the jacket at one end for introduction of the heat transfer medium. Each jacket is likewise provided with a fitting **36** communicating with the upper side of the opposite end of the jacket for discharge of the heat transfer medium. For convenience of access the discharge fitting from jacket **34** of the lower dryer unit is at the end of a tangential discharge pipe **37** (FIGURE 2). Each of the jackets is also desirably provided with a drain **38**.

Depending upon the particular material being dried, or the particular solids treating process being carried out, either a hot or cold fluid may be circulated through the jackets. This may be, for example, steam, hot water, hot oil, brine or other refrigerated liquid, or the like. Again, depending upon the material being dried or otherwise treated, the same or different heat transfer mediums may be introduced to each of several jackets to provide zones of the same or different temperatures, as required.

Within each tubular housing **16** there is provided a shaft-enlarging tube **39** surrounding and coaxial with journal shaft **23** and secured thereto for rotation therewith by means of annular reducing plugs **40** (FIGURE 3) at each end. Spaced about the periphery of shaft tube **39** are a plurality of paddle arms **41**. Each arm extends radially outwardly and is provided with a paddle blade or vane **42** at its outer extremity. Each paddle blade or vane **42** extends virtually to the inner wall surface of the cylindrical dryer housing **16** leaving enough clearance for rotation of the paddle assembly. Each paddle blade or vane **42** is preferably adjustably secured to the end of the arms **41** by means of a nut **43** or threaded collar or the like to permit presetting of the pitch of each blade or vane **42**.

As seen in FIGURE 4, the radial paddle arms **41** are desirably secured to the shaft tube **39** in a spiral or helical path, as indicated by broken line **44**. Reading from right to left it will be noted that the farthest right hand paddle arm A extends angularly rearwardly away from the shaft tube. The next arm B extends vertically and is spaced ⅙ of the periphery of tube **39** away from arm A and slightly to the left, such that the paths of travel of the respective blades or vanes at the ends of the arms overlap. The next arm C extends angularly forwardly and is similarly spaced around the periphery of the tube and slightly to the left of arm B. The other arms D, E, F, etc., are similarly spaced around the spiral path **44**.

The paddle arms are desirably positioned so as to define a forward screw to move the fluid bed of material being dried through the cylindrical housing. Then, in many instances, the individual paddle blades or vanes **42** are desirably set with a backward pitch to retard movement of that portion of the fluid bed adjacent the housing wall and prolong the residence time of the particles circulating there.

In FIGURE 2A there is shown a fragmentary end view of a further embodiment of the apparatus adapted to the feeding of the solid material to be dried in cake form. According to this form of the apparatus, a housing **51** is fitted to the top of the duct **26** at the inlet end of the vessel **10A**. A feed hopper **52** is adapted to receive the solid material in cake form and pass it through an air lock conveyer or feed unit **53** and duct **54** into the top of the vessel. A further gas discharge duct **55** is provided for the purpose of venting vapors or discharging countercurrent flow convection gas when such is used.

In FIGURE 2B there is shown schematically a further modified form of apparatus in which the vessel **10B** is provided at one end with a top feed inlet duct **60** adapted to receive solid material to be dried in cake form. There is also provided a tangential drying gas inlet **61** whose path of entry into the vessel intersects the path of entry from the materials inlet **60**. With this arrangement the solid material fed into the vessel is entrained in the stream of drying gas immediately upon its entry into the vessel. The material flows through the vessel in a spiral path traveling along the periphery of the vessel and the material and gas are discharged through a tangential outlet duct **62** and past to a cyclone or other conventional separator and collector means (not shown).

Two exemplary arrangements of vertically stacked dryer units are shown in FIGURES 5 and 6. The arrangement shown schematically in FIGURE 5 is similar to that shown in FIGURES 1 and 2 and is especially adapted to the drying of material, such as high density polyethylene in pentane, for example, from which the solvent is recovered. For example, as shown in FIGURE 5, a slurry of polyethylene may be pumped from a vessel **45** through a pipeline **46** by means of pump **47** to the inlet fitting **24** of the upper dryer unit **10**. The polyethylene solids pass through the length of dryer unit **10** and are discharged through outlet duct **29** into inlet duct **30** of the lower dryer unit **11**. The solids are passed through the length of this lower unit and discharged through duct **31**. Meanwhile, the solvent vapors are passed through hopper **26**, hood **27** and fitting **28** to a solvent recovery system. This stacked series arrangement of units permits a long travel path through the dryers with minimum space requirements. It is especially adapted to solvent recovery.

In FIGURE 6 there is shown a further schematic arrangement in which two similar dryer units are stacked vertically for operation in parallel arrangement to provide increased capacity without increasing space requirements. A slurry of materials, such as a 50% solids slurry of clay, may be discharged from a nozzle centrifuge **48** to a pipeline **49** and pumped by means of a pump **50** to the inlet feed hoppers **26** of the stacked dryer units. The material is passed through the length of one of the dryer units and the discharge from ducts **29** is combined.

The apparatus of the present invention is intended to be operated at relatively high speeds which are well beyond those previously employed in this art. While speed is important, it is not for the sake of speed alone, but for the sake of efficiency. In order to produce the desired radially stratified annular fluidized bed of material it is necessary that the paddles be rotated above the critical speed at which the particles are held against the top surface of the housing wall instead of falling back by gravity. This critical speed is equal to or greater than that necessary to achieve the theoretical point of equilibrium and may be defined as: r.p.m.$=>76.7/\sqrt{D}$ where D is the diameter of the rotor in feet. When operating above the speed equal to the theoretical point of equilibrium, the material is being held against the periphery of the wall. If operated below the critical speed, the material is merely stirred as it passes through the lower part of the cylindrical housing. Increased efficiency is thus achieved by utilization of the full 360° of jacket surface. The material being held by pressure against the wall achieves a higher rate of heat transfer.

In FIGURE 7 there is a simplified schematic representation of a process of drying a wet product in the apparatus according to the present invention utilizing both direct and indirect heat. The wet product to be dried is introduced into one end of the vessel along with hot air or other heated gas. The force of the rotor paddles rotating above the critical speed causes the material to pass through the cylindrical housing in a spiral flow pattern against the vessel wall. The centrifugal force of the rotor traveling above the critical speed is sufficient to overcome the force of gravity to maintain the material pressed against the wall at the top of the vessel, as well as on the side walls and bottom. At the same time the fluid bed of solid materials is stratified so that the largest, densest and wettest particles are pressed into contact with the wall surface.

A hot heat transfer medium, such as steam or hot oil or the like, is circulated in the jacket surrounding the vessel, although in some instances it may be desirable or necessary to circulate coolant in that portion of the jacket at the inlet end. (It will be apparent that the spiral ribbon illustrating the flow path is an exaggerated representation for illustrative purposes only.) Much of the heated gas passes axially through the vessel, carrying with it the finer dryer particles. The dry product, along with the vapor discharge and exhaust convection gas, are discharged from the opposite end of the vessel to a suitable separator and collector means.

In FIGURE 8 there is shown a schematic representation illustrating a drying method in the apparatus according to present invention and utilizing indirect heat. The wet product is introduced into one end of the vessel and by action of the rotor passed in spiral flow against the housing wall through the vessel. Drying is by conduction from the heat transfer medium circulating through the jacket of the vessel. Vapor discharge is withdrawn in

countercurrent flow from the inlet end of the vessel and the dry product is discharged from the opposite end.

The following exemplary specifications are typical of actual processing units, although it will be understood that these specifications are illustrative only and do not impose any limitations upon the invention. Overall unit lengths have ranged from 14 to 21 feet with diameters ranging from 16 to 48 inches. These have resulted in units having jacket areas ranging from about 40 to 200 square feet. Average volume of product retained in each unit has varied between about 7 and 96 cubic feet. Horse power requirements per unit have ranged from about 5 to 75. Overall coefficient of heat transfer (U) has ranged from 15 to 200 B.t.u./° F./sq. ft./hr., depending upon the transfer medium and condition of the product as follows: Using steam as the transfer medium the overall coefficient has ranged from 40 to 200 for a wet product and 20 to 150 for a dry product. Using a liquid transfer medium the coefficient has ranged from 30 to 200 for a wet product and 15 to 150 for a dry product. The apparatus has been designed for housing temperatures up to 500° F., inlet gas temperatures up to 1200° F. or higher, internal pressures of up to 100 p.s.i.g., jackets pressures up to 200 p.s.i.g., and rotor tip speeds ranging from 850 to 4,000 feet per minute. Retention time has range from about 10 seconds to 15 minutes.

The versatility and efficiency of the method and apparatus according to the present invention in carrying out heat transfer and mass transfer solids processing treatments, is illustrated by the following examples.

EXAMPLE I

Polyethylene resin was dried at the rate of 2500 pounds (dry basis) per hour using two 42 inch diameter units each 14 feet long and arranged in series and stacked vertically. The units were jacketed for 14.9 p.s.i.g. steam. The rotor paddles were set parallel to the axis of the shaft which was rotated at 190 r.p.m. The feed was a slurry of 20% polyethylene solids in pentane. The vapors were vented from the material inlet in countercurrent flow. No purge gas was introduced. Less than 1% of the pentane remained with the discharged product. The feed was introduced at about 95° F. The product upon discharge had a temperature of about 167° F. The resin entraied in volatile pentane vapor is scrubbed by the incoming slurry to minimize resin in the vapor for economical recovery of the pentane.

EXAMPLE II

Polyethylene flake was dried at the rate of about 4200 pounds (dry basis) per hour in a single 48 inch diameter drying vessel having an overall length of 21 feet and jacketed for 14.9 p.s.i.g. steam. The rotor speed was 110 r.p.m. All of the rotor paddles were set parallel to the axis of the shaft. The feed contained about 25% water and the material was dried to 10% or less of water, which was the desired moisture content. The water vapor was vented from the material inlet end in countercurrent flow. No purge gas was introduced.

EXAMPLE III

Acrylonitrile-butadiene-styrene resin (ABS) containing 45% water was dried to less than 1% water at the rate of 4200 pounds (dry basis) per hour using one 42 inch diameter 21 foot long drying vessel and one 36 inch diameter 17 foot long drying vessel in series. Each vessel was jacketed for 30 p.s.i.g. steam. The rotor speed of the 42 inch diameter unit was 130 r.p.m. and the rotor speed of the 36 inch diameter unit was 150 r.p.m. All of the rotor paddles were set at 45° backward pitch in such a way as to retard material flow through the units. Hot convection air at 7000 s.c.f.m. split into 4000 s.c.f.m. to the 42 inch diameter unit and 2000 s.c.f.m to the 36 inch diameter unit was introduced at an inlet temperature of 323° F. for co-current flow with the material.

EXAMPLE IV

Polyvinylchloride resin (PVC) containing 20% water was dried at the rate of 3000 pounds (dry basis) per hour to a moisture content of 0.2% in a single 36 inch diameter drying vessel having an overall length of 17 feet and jacketed for 14.9 p.s.i.g. steam. All of the rotor paddles were pitched backwardly 45° to the axis to retard flow of material and the rotor speed was 220 r.p.m. Convection air at 2000 s.c.f.m. was introduced at 325° F. for co-current flow with the material.

EXAMPLE V

A weed control chemical powder (2–4–D) containing 5% of a mixture of solvent and water was dried to less than 0.5% liquid at the rate of 625 pounds (dry basis) per hour in a single 16 inch diameter 14 foot long drying vessel jacketed for 14.9 p.s.i.g. The actual temperature of the jacket was 238° F. All of the rotor paddles were pitched 45° backwards and the rotor speed was 390 r.p.m. A convection air stream of 600 to 800 s.c.f.m. was introduced at an entry temperature of 325° F. for co-current flow with the product.

EXAMPLE VI

Polypropylene resin was cooled at the rate of 2000 pounds per hour in a 16 inch diameter vessel 14 feet long and jacketed for cooling water. The material as fed to the vessel had a temperature of 200° F. Water at 80° F. was used as the cooling medium. The product was discharged at 100° F. No cooling gas was used so that no solids-gas collection equipment was necessary. The high transfer coefficient minimized the vessel size and cooling water flow rate.

EXAMPLE VII

Granulated vinyl compound was cooled at the rate of 8000 pounds per hour in a 42 inch diameter vessel 21 feet long and jacketed for cooling along 10 feet of its length. The material, which was pulverized floor tile scrap, was fed at 280° F. and quickly cooled to 160° F. at high capacity and delivered to storage for further processing. Water at 75° F. was the cooling medium.

EXAMPLE VIII

Phthalocyanine Blue pigment was dried from 80% water to less than 1% at the rate of 600 pounds per hour (dry basis) in a two stage system. The first stage consisted of a 42 inch diameter, 21 foot long unit operating 260 r.p.m. with a 30 H.P. drive. The unit was jacketed for 15 p.s.i.g. steam. Co-current hot air was used at 3500 s.c.f.m. at 700° F. The rotor paddles were set in backward pitched position. The second stage was a 24 inch diameter, 14 foot long unit operating at 450 r.p.m. with 10 H.P. drive. Air flow was co-current at 1500 s.c.f.m. and at a temperature of 350° F. There was no jacket heat in the second stage. The paddles were backwardly pitched.

EXAMPLE IX

Copper hydrate was dried from about 40 to 45% water to less than 1.5% at the rate of 1875 pounds per hour in four 24 inch diameter, 14 foot long units all operating at 450 r.p.m. and each with 30 H.P. drive and jacketed for 10 p.s.i.g. steam. The paddles were set flat. A small amount of air, approximately 50 c.f.m., flowing countercurrent to the product was used to assist steam discharge from the units.

We claim:

1. Apparatus for processing particulate solid material comprising:

(A) a substantially closed elongated cylindrical housing,

(B) a rotor assembly within said housing journaled for rotation about a generally horizontal axis extending longitudinally through said housing substantially coaxial therewith,

(C) a material feed inlet at one end of said housing and a material discharge at the other end thereof, and a substantially unimpeded longitudinal passage through the housing connecting the inlet and discharge,

(D) high speed motor drive means operatively connected to said rotor assembly for rotating said rotor above the critical speed necessary to overcome the force of gravity upon the particulate solid material sufficient to maintain a relatively deep annular radially stratified turbulent fluidized bed of dispersed gradated particulate solid material circulating in said housing,

(E) said rotor assembly including a multiplicity of relatively small and relatively widely spaced apart rigid radial paddle blades,

(F) each of said blades extending outwardly from a radial arm and each having its outer extremity adjacent the housing wall surface, and

(G) said blades being present in number between about ½ to 3 for each square foot of cylindrical housing surface.

2. Apparatus according to claim 1 further characterized in that said housing is double walled throughout at least part of its length to define a heat transfer jacket surrounding said housing, and is provided with an inlet to and outlet from said jacket for circulation of a fluid heat transfer medium therethrough.

3. Apparatus according to claim 2 further characterized in that said housing is provided with a plurality of heat transfer jackets each provided with a separate inlet and separate outlet for circulation of separate fluid heat transfer mediums for zoned temperature control.

4. Apparatus according to claim 1 further characterized in that said blades are disposed uniformly about said shaft in a spiral pattern, said blades being spaced longitudinally by a distance less than the width of said blades.

5. Apparatus according to claim 4 further characterized in that said rotor blades are rotatable relative to said shaft about the axes of said blades for variation of the pitch of said blades and means are provided for securing said blades at a predetermined pitch.

6. Apparatus according to claim 1 further characterized in that said material feed inlet is a fitting adapted for connection to a flow line to receive a pumpable slurry of high solid material content.

7. Apparatus according to claim 1 further characterized in that said material inlet is a spout intersecting the top portion of one end of said housing to receive nonpumpable solid material.

8. A method of drying a wet particulate solid material which comprises:

(A) introducing said wet material to one end of a substantially closed elongated drying zone of substantially circular cross-section,

(B) subjecting said material to high speed rotary agitating beating action above the critical speed to disperse the material in gas to produce a turbulent fluidized bed and to produce centrifugal forces to maintain a relatively deep annular radially stratified turbulent fluidized bed of gradated material circulating in said zone,

(C) the outermost layers of largest wet solid particles of said annular fluidized bed circulating in intimate contact with a heated surface surrounding said drying zone,

(D) simultaneously subjecting at least part of said material to longitudinally applied forces to move the material through the drying zone, and

(E) removing the dried material from the opposite end of said zone.

9. A method according to claim 8 further characterized in that a heated drying gas is introduced to said drying zone along with said solid material for co-current flow therewith.

10. A method according to claim **8** further characterized in that the smallest solid particles circulating in the innermost layers of said annular fluidized bed are entrained in an axial flow toward the discharge end of said drying zone.

11. A method according to claim **8** further characterized that liquid from said wet solid particles is vaporized in said drying zone and entrained in a countercurrent flow for discharge from the inlet end of said drying zone.

12. A method of processing particulate solid material which comprises:

(A) introducing said material to one end of a substantially closed elongate processing zone of substantially circular cross-section,

(B) subjecting said material to centrifugal forces to maintain an annnular radially stratified turbulent fluidized bed of gradated material circulating in said zone,

(C) the outermost layers of coarsest and densest particles of said annular fluidized bed circulating in contact with a heat exchange surface surrounding said zone,

(D) simultaneously passing a co-current flow of gas through said processing zone to entrain the finest and lightest particles of said annular fluidized bed separated by said centrifugal forces and circulating in the innermost layers of the bed to advance said particles through the processing zone,

(E) simultaneously subjecting said outermost layers of coarsest and densest particles of said annular fluidized bed to reverse longitudinally applied forces in the direction toward the inlet end of said processing zone to prolong the residence time of said coarsest and densest particles in said processing zone, and

(F) removing said resulting processed material from the opposite end of said processing zone.

13. A method according to claim **12** further characterized in that said reverse longitudinally applied forces in the direction toward the inlet end of said processing zone are applied by backward pitched paddle blades revolving in said zone adjacent the outer periphery thereof.

14. A method of drying a wet particulate solid material which comprises:

(A) introducing said wet material to one end of a substantially closed elongated drying zone of substantially circular cross-section,

(B) subjecting said material to centrifugal forces to maintain a relatively deep annular radially stratified turbulent fluidized bed of gradated material circulating in said zone,

(C) the outermost layers of largest wet solid particles of said annular fluidized bed circulating in intimate contact with a heated surface surrounding said drying zone,

(D) simultaneously passing a co-current flow of gas through said drying zone to entrain the dryest, finest and lightest particles of said annular fluidized bed separated by said centrifugal forces and circulating in the innermost layers of the bed to advance said particles through the drying zone,

(E) simultaneously subjecting said outermost layers of largest wet solid particles to reverse longitudinally applied forces in the direction toward the inlet end of said drying zone to prolong the residence time of said largest particles in said drying zone, and

(F) removing the dried material from the opposite end of said zone.

15. A method according to claim **14** further characterized in that said reverse longitudinally applied forces in the direction toward the inlet end of said drying zone are applied by backward pitched paddle blades revolving in said zone adjacent the outer periphery thereof.

16. A method of processing particulate solid material which comprises:

(A) introducing said material tangentially to one end of a substantially enclosed elongate processing zone of substantially circular cross-section and substantially unimpeded axial passage,

(B) subjecting said material to high speed rotary agitating beating action above the critical speed to disperse the material in gas to produce a turbulent fluidized bed and to produce centrifugal forces to maintain an annular radially stratified turbulent fluidized bed of gradated material circulating in said zone,

(C) the outermost layers of coarsest and densest particles of said annular fluidized bed circulating in contact with a heat exchange surface surrounding said zone,

(D) simultaneously subjecting at least part of said material to longitudinally applied forces to move that material in substantially uninterrupted passage through the processing zone, and

(E) removing said resulting processed material tangentially from the opposite end of said processing zone.

17. A method of processing particulate solid material which comprises:

(A) introducing said material to one end of a substantially closed elongate processing zone of substantially circular cross section,

(B) subjecting said material to high speed rotary agitating beating action above the critical speed to disperse the material in gas to produce a turbulent fluidized bed to produce centrifugal forces to maintain an annular radially stratified turbulent fluidized bed of gradated material circulating in said zone,

(C) the outermost layers of coarsest and densest particles of said annular fluidized bed circulating in contact with a heat exchange surface surrounding said zone,

(D) simultaneously subjecting at least part of said material to longitudinally applied forces to move the material through the processing zone,

(E) entraining the smallest solid particles circulating in the innermost layers of said annular fluidized bed in an axial flow through the processing zone toward the discharge end of said processing zone, and

(F) removing said resulting processed material from the discharge end of said processing zone.

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