United States Patent [19]

Fischer

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[45] **Oct. 16, 1973**

[54] **ROTARY APPARATUS FOR TREATING PARTICULATE MATERIAL**

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[73] Assignee: **The Patterson-Kelley Co. Inc.,** East Stroudsburg, Pa.

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[52] **U.S. Cl.** **34/136,** 432/107, 34/138, 34/141

[51] **Int. Cl.** **F26b 11/02**

[58] **Field of Search** 34/128, 136, 138, 34/140, 141, 142; 432/107

[56] **References Cited**

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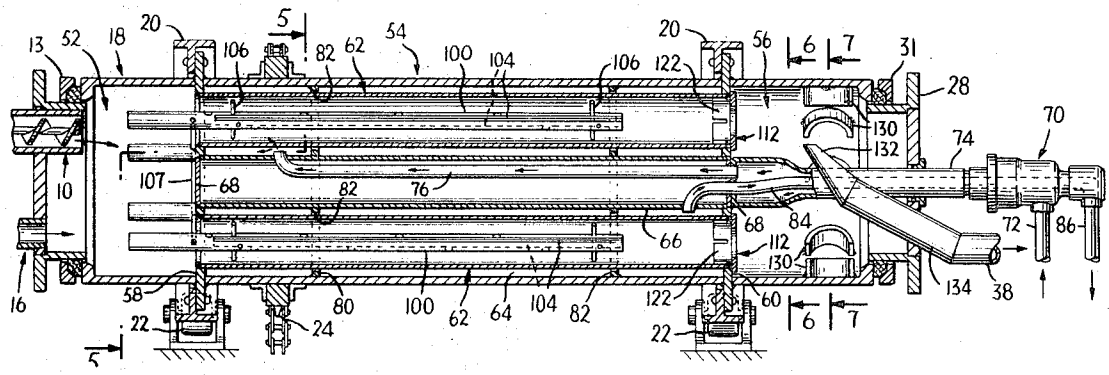
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Primary Examiner—Carroll B. Dority, Jr.
Assistant Examiner—Larry I. Schwartz
Attorney—Granville M. Brumbaugh et al.

[57] **ABSTRACT**

Apparatus for treating particulate material comprises a multiplicity of tubes mounted within a rotating shell. The material and a treating gas flow together through the tubes, while a heating or cooling fluid is conducted through a closed chamber surrounding the tubes for heat exchange with the tube walls, and thus with the material. The material is aerated as it flows through the tubes by gentle mechanical tumbling agitation. A flow-control dam near the outlet end of each tube provides a controlled fill of each tube and ensures a controlled retention time for the material.

23 Claims, 20 Drawing Figures



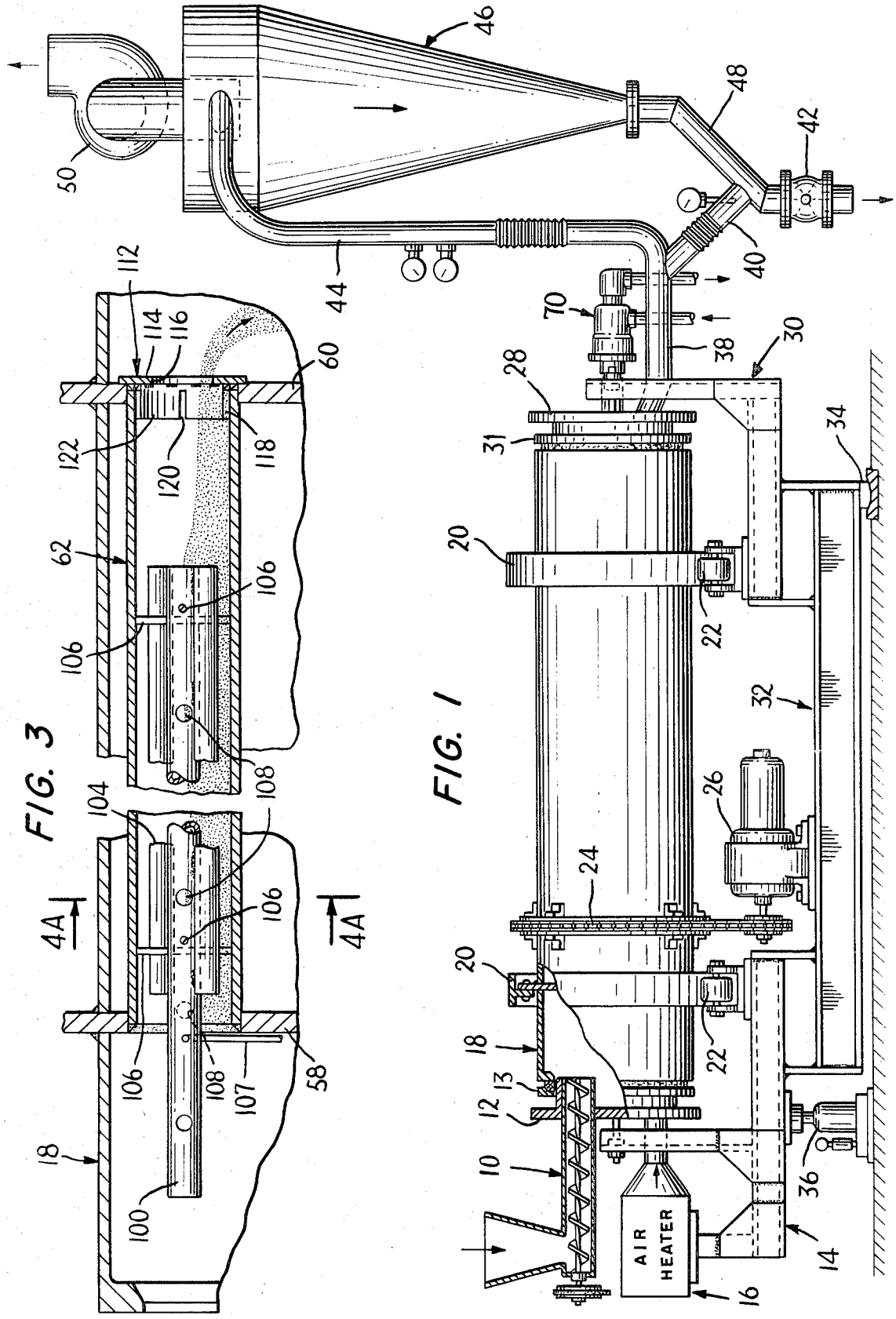


FIG. 1

FIG. 3

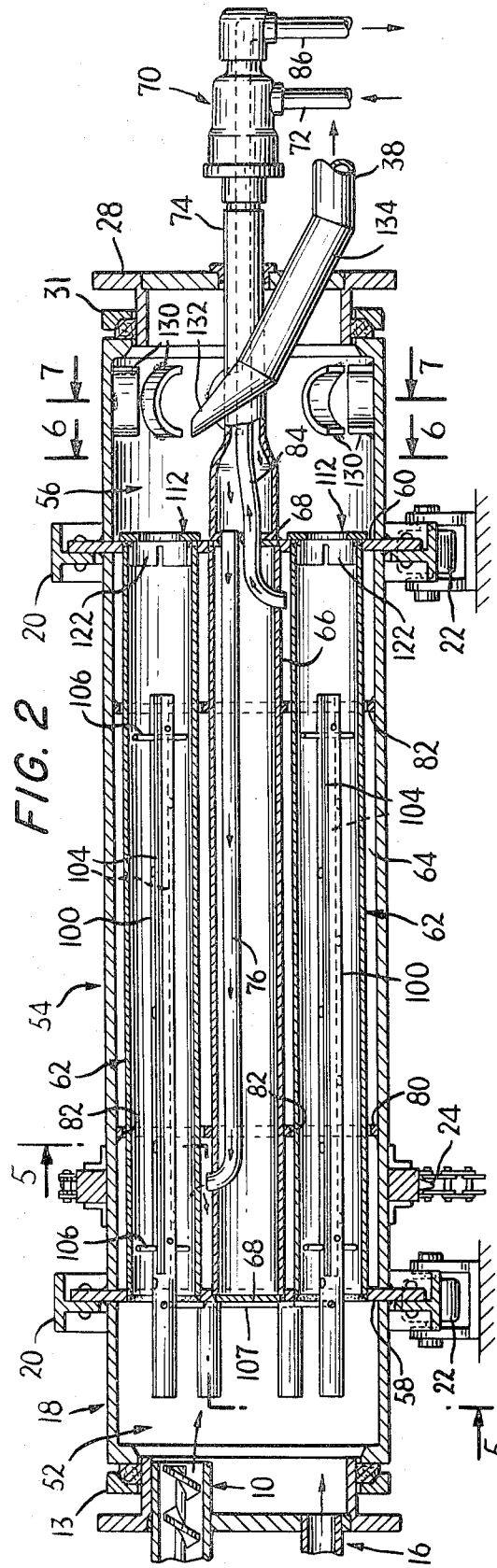


FIG. 2

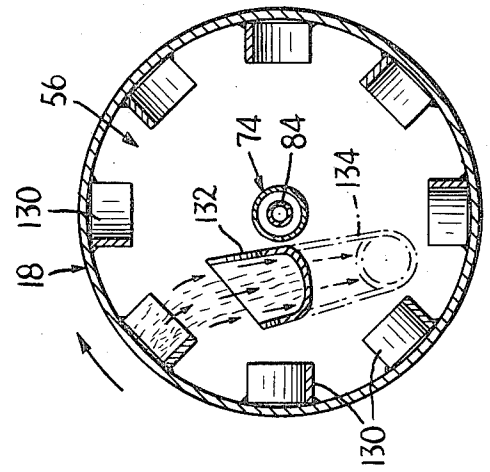


FIG. 7

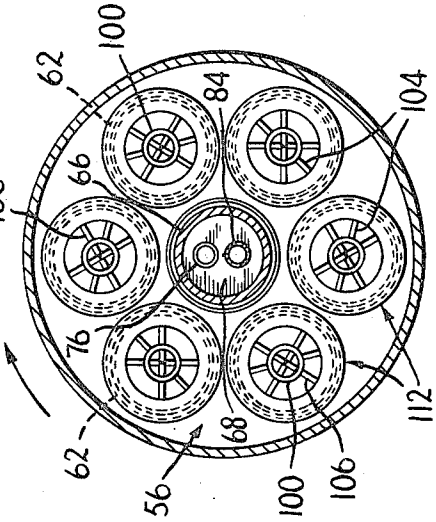


FIG. 6

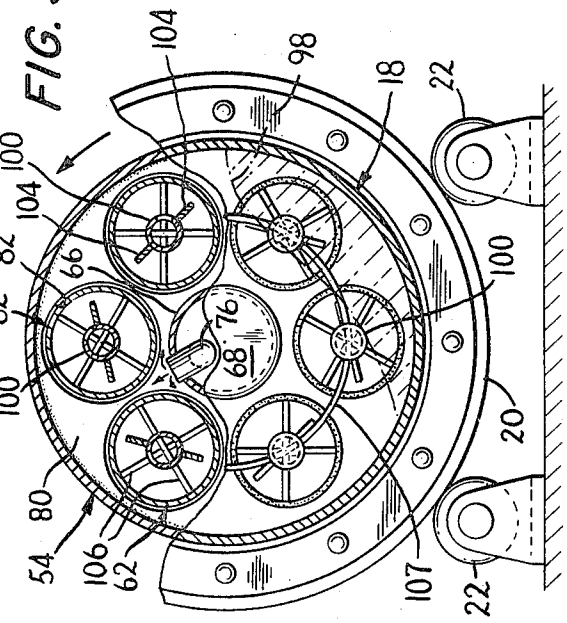


FIG. 5

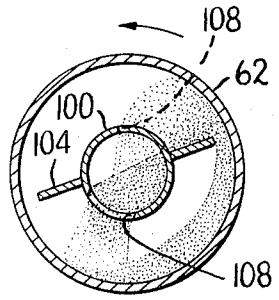


FIG. 4B

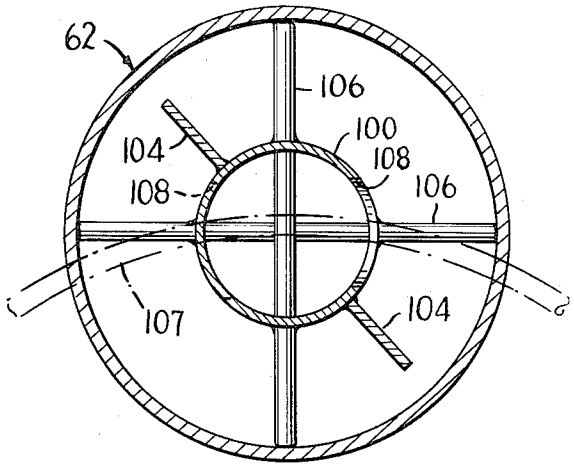


FIG. 4A

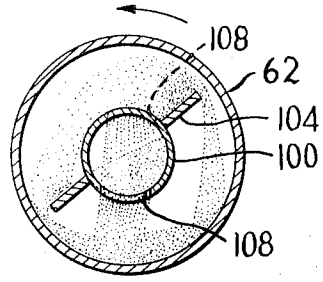


FIG. 4C

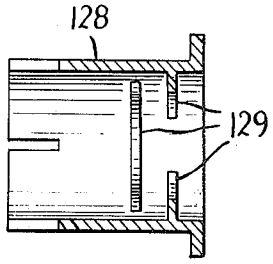


FIG. 12

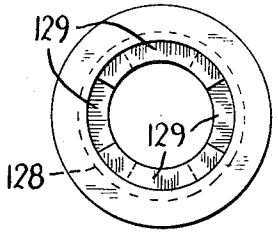


FIG. 13

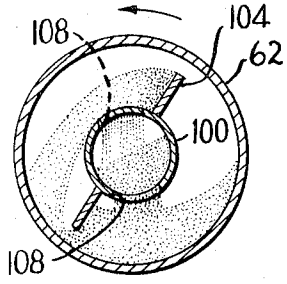


FIG. 4D

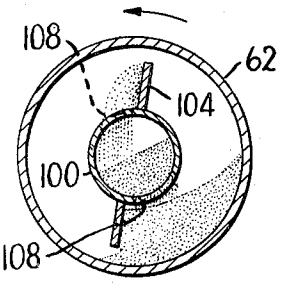


FIG. 4E

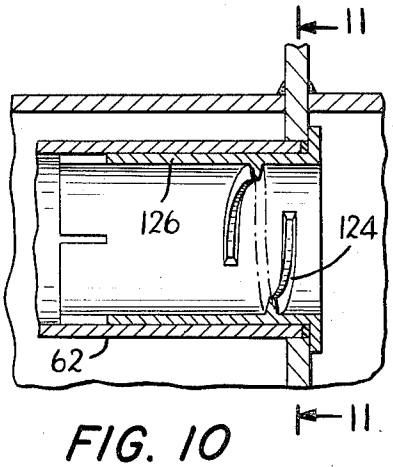


FIG. 10

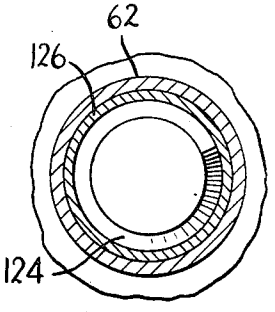


FIG. 11

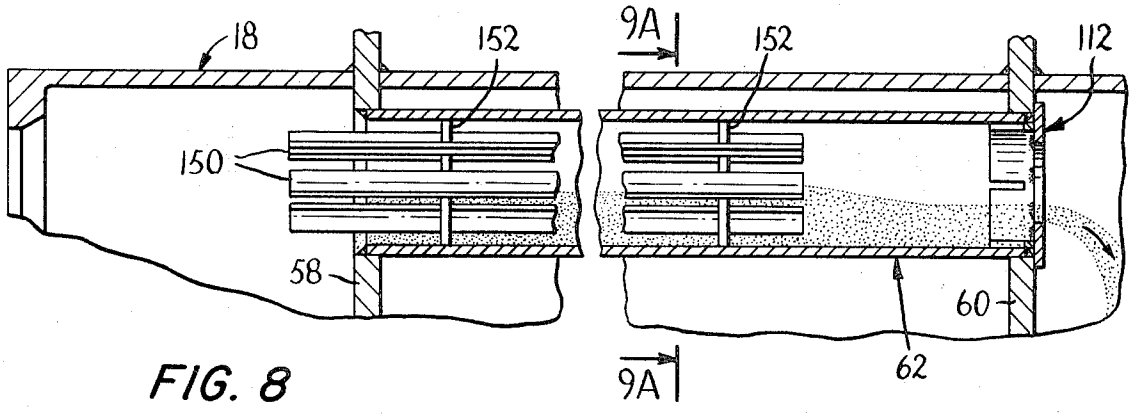


FIG. 8

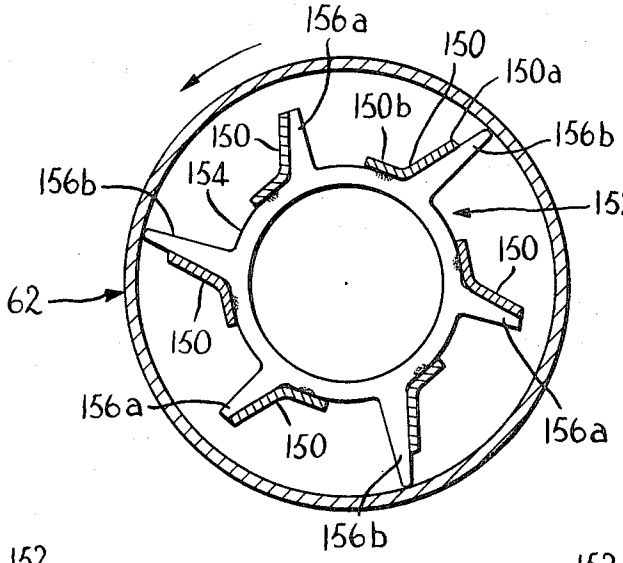


FIG. 9A

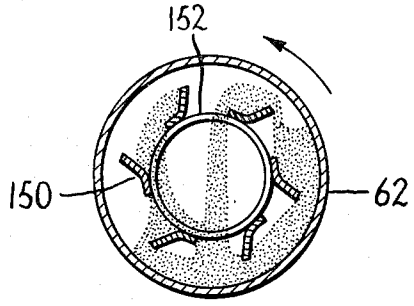


FIG. 9B

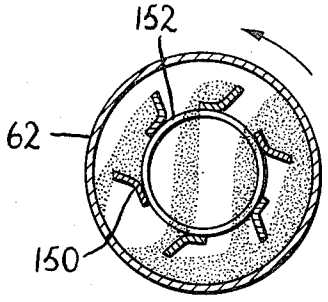


FIG. 9C

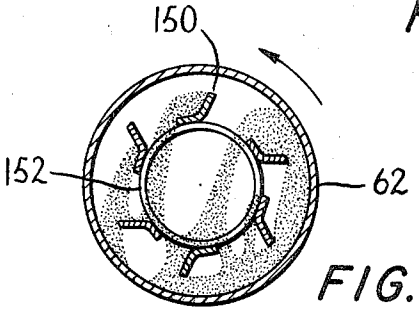


FIG. 9D

ROTARY APPARATUS FOR TREATING PARTICULATE MATERIAL

BACKGROUND OF THE INVENTION

This invention relates to apparatus for treating particulate material and, in particular, to apparatus having considerable versatility and appropriate for various uses, such as heating, cooling or drying particulate materials or promoting chemical reactions between particulate materials and gases.

Various types of equipment have been proposed and used for heating, cooling and drying particulate materials and for reacting particulate materials with gases and vapors. For the most part, such equipment is designed to provide maximum exposure of the material surfaces to a treating gas. In recent years, fluidized bed treatment, a process that involves controlled, partial suspension of material in a vertical bed, by an upwardly flowing gas, has been emphasized in development and use. In a related, though somewhat different, technique which is employed, for example, in so-called flash dryers, the material to be treated is conveyed in a concurrent, high speed flow of gas. Both fluidized bed and concurrent flow treatments require carefully designed and highly specialized equipment tailored to the specific requirements of the process. Moreover, they are effective only with a relatively narrow range of materials having only a very narrow range of particle sizes. The processes are difficult to control and, in general, have not been successful where a high precision output is required.

Fluidized bed drying processes require specific air flow velocities that vary with particle size and density. Fine particles that enter above the bed meet almost saturated gas having almost no drying capability and are blown across the top of the bed to the outlet in an "undry" state. The largest particles tend to settle to and remain at the bottom of the bed where they are subject to overheating and consequent damage. Some materials lose density by swelling when wet and tend to float across the top of the bed to the outlet without drying. Sticky materials are totally unsuited to fluidized bed treatment, since they tend to agglomerate in the bed, thus changing effective particle sizes and destroying fluidization under the gas velocity applicable to the original particle size.

Flash drying processes are useful only with materials having primarily surface moisture, little absorbed or "bound" moisture, fine particle size and, preferably, nearly uniform particle size. With suitable material, drying occurs in a matter of seconds. Such rapid drying, however, makes it difficult to obtain a product output having uniform dryness.

Various types of conveyor and rotary material treating devices have been suggested or employed, these types being preferable or even necessary for processes involving wide particle size variations, considerable bound moisture, friable materials (usually limited to conveyor type systems) or other material characteristics that make fluidized bed and concurrent flow processes inappropriate. The rotary equipment generally employs large diameter shells equipped with wall-mounted lifting vanes that drop the material across a concurrent or countercurrent gas flow. Often the distance that the particles must drop is considerable, thus making many rotary devices unsuitable for treating fragile or friable materials. Gas flow velocities are usually very low, since particle entrainment and premature ejection of material by gas entrainment must be limited as much as possible to ensure an acceptable product.

SUMMARY OF THE INVENTION

There is provided, in accordance with the present invention, an apparatus for treating particulate materials, e.g., heating, cooling, drying or gas (or vapor) reaction, that is highly versatile as to use and very efficient, especially if carefully designed and properly controlled, and, most importantly, may be readily controlled to produce a uniform, precisely conditioned output. Although it is inherently slower than concurrent gas flow equipment, the slow processing rate leads to good control in that drying of the material takes place over a period of minutes, rather than seconds. Thus, it is capable of effectively treating materials having a wide range of particle sizes (i.e., broad size distribution) and relatively large particle sizes, materials that are, at best, difficult effectively to treat by fluidized bed or concurrent gas flow techniques because of the control problems inherent in such techniques. The equipment can handle abrasive materials, which are troublesome in any type of process, with little wear of the equipment or other difficulties.

The apparatus comprises a cylindrical shell mounted for rotation about its axis and appropriately driven in rotation, fixed end covers closing the ends of the shells, and a pair of tube sheets carrying a multiplicity of tubes that extend along the major part of the length of the shell, preferably parallel to the shell axis. The upstream tube sheet and the upstream cover define an inlet zone, and the downstream tube sheet and end cover form an outlet zone. The space between the tube sheets and outside the tubes is a closed chamber and is equipped for supply and flow of a heating or cooling fluid providing heat exchange with the tube walls, and thus with the material.

The material to be treated and a treating gas (or vapor) are introduced at controlled rates to the inlet zone, flow together through the tubes, and are withdrawn from the outlet zone. Agitating devices within each tube and rotating with it provide effective but gentle aeration and intermittent suspension of particles as the material moves along the tube and promote heat transfer between the material and the tube walls, the agitating devices in each tube, and the gases flowing through the tubes. The balance between heat transfer by conduction between the particles and the surfaces they contact and transfer by convection and conduction between the particles and flowing gases is provided, among other things, by varying the temperatures and flow rates of the gas flowing with the material and the heating or cooling fluid in the closed chamber surrounding the tubes. Other parameters of the system, such as throughput rate, the extent of aeration of the material, the degree of heat transfer to or from the material by conduction are also readily varied by adjusting the feed rate of the material, the rate of rotation of the shell, the design of the agitating system and the inclination of the shell axis. These matters are discussed below in more detail.

An important aspect of the control of the equipment is the ability to control the "fill" (i.e., the amount of material contained in) of each tube. Fill is controlled by a flow-control dam element adjacent or at the downstream end of each tube. The dam element is a member

that extends circumferentially, either substantially perpendicular to or helically of the tube axis, of the inner wall of the tube and inwardly from the tube wall a uniform distance. The dam element may be a flat annular disc with a circular, centered outlet opening, a strip of material installed on a generally helical-shaped path (a screw form) and extending in from the wall a uniform distance to define, as viewed from the tube end, a circular hole centered on the tube axis or sections of annular discs in a spaced and staggered arrangement, with ends overlapping. Any of these forms of dam element ensures the retention of a layer of material in the tube, a factor that has been found to be critical to the ability to control the throughput and prevent variations in the linear flow rate of material down the tube and the blowing out of material by the treating gas flowing through the tube at efficient velocities.

The fill of each tube affects the flow pattern of the material and the balance between heat transfer by conduction and treatment by the heating gases. The fill may vary considerably, depending on the material, the treatment, the form of agitating devices used, etc. In general, the filled volume of each tube will average between about 15percent and 30percent of the tube volume. There is usually some gradient in the fill from end to end of the tube, the fill at the upstream end being somewhat greater than the fill at the downstream end. A dam with a height of about 20percent of the diameter of the tube has produced excellent control characteristics for a variety of materials in a dryer constructed in accordance with the invention.

Various forms of agitating devices may be employed in the apparatus, the form used being somewhat dependent on the material and the treatment being performed. A gentle tumbling action with good surface exposure but only a moderate degree of intermittent particle suspension is attained with an axial solid or hollow core pipe that extends part way down the center of each tube and has one or more external fins or vanes extending generally radially and longitudinally of the tube. Advantageously, the agitating device extends upstream from the inlet end of each tube some distance into the inlet zone of the shell, the projecting end aiding the feed of material to each tube and providing beneficial aeration of the material in the inlet zone. A hollow core pipe may have holes at spaced locations along its length for flow of materials and gases into and out of the interior of the pipe.

It will generally be advisable not to have any aerating devices in a region near the downstream end of the tube. The dam element is a constriction in the gas flow cross-section where gas flow velocity increases, and the influence of the increased velocity extends somewhat upstream from the dam element. A lack of agitating devices near the end of the tube ensures maintenance of the desired layer of material behind the dam element and restricts entrainment of material in the gas in the region near the outlet where the material might be blown out by the more rapidly flowing gas.

Other forms of agitator systems may be employed. For example, several circumferentially spaced-apart U-shaped or L-shaped vanes extending lengthwise of the tube and spaced from the tube wall with the cavity of the "U" or "L" shape generally facing the tube wall lift material up and then let it gently tumble off in free fall (intermittent suspension) back to the bottom of the tube. The spacing of such agitating vanes from the tube wall provides a large material-tube contact area for heat transfer. The shape, size, number, location and orientation of the vanes can be varied to provide desired agitating effects.

High efficiency of heat transfer between the tubes and the heating or cooling fluid in the closed chamber around the tubes is promoted by baffling the flow in the chamber. Preferably, a baffle at the upstream end of the chamber defines with the upstream tube sheet a fluid inlet zone, the fluid being brought by a conduit to the inlet zone. A second baffle near the downstream tube sheet forms an outlet zone for the fluid. Annular throttling orifices in each baffle immediately around each tube promote an annular flow stream for good heat transfer between the fluid and the tubes.

Among the important advantages of the apparatus of the invention are an ability to provide close control of a process and produce a precisely conditioned product, even with difficult materials (e.g., broad size distribution, bound moisture, friable, sticky, etc.), high heat transfer efficiency, and low power requirements. On the last point, because the material load is essentially balanced by distribution around the rotating shell axis, high rates of rotation in the range of, say, from 20 to 40 r.p.m., which provide highly effective agitation and promote efficiency and enhance control capability, are attainable with very little horsepower input.

DESCRIPTION OF THE DRAWINGS

For a better understanding of the invention and a further description of preferred features and/variations of the apparatus of the invention, reference may be made to the following description of exemplary embodiments, taken in conjunction with the figures of the accompanying drawings, in which:

FIG. 1 is a side elevational view of one embodiment of the apparatus;

FIG. 2 is a side view in cross-section taken generally along a diametrical plane of the rotary part and some of the adjacent structure of the apparatus of FIG. 1, the view being on a slightly larger scale than FIG. 1;

FIG. 3 is a side view in cross-section of one form of tube and agitating structure employed in the rotary section of the apparatus shown in FIGS. 1 and 2, the view again being on a larger scale and having a portion broken away;

FIG. 4A is an end view in cross-section of the inlet end of the tube of FIG. 3, the view being taken generally along the lines 4—4 of FIG. 3 and in the direction of the arrows and being on a larger scale than FIG. 3;

FIGS. 4B, 4C, 4D and 4E are diagrammatic illustrations showing the flow pattern of material treated in apparatus having tubes with agitating devices of the form illustrated in FIGS. 3 and 4A;

FIG. 5 is a cross-sectional view of the rotary part of the apparatus of FIGS. 1 to 4, the view being broken away in two partial end sections taken generally along planes indicated generally by the lines 5—5 of FIG. 2 and taken in the direction of the arrows;

FIG. 6 is an end sectional view of the rotary part of the apparatus of FIGS. 1 to 5 taken at generally the outlet end along the lines 6—6 and in the direction of the arrows in FIG. 2;

FIG. 7 is another end sectional view of the outlet end of the rotary part of the apparatus of FIGS. 1 to 6, the view being taken generally along the lines 7—7 of FIG. 2 and in the direction of the arrows;

FIG. 8 is a cross-sectional view, taken generally along a diametrical plane, of another form of tube for the apparatus, the tube having a different type of agitating device;

FIG. 9A is an end view in cross-section of the form of tube illustrated in FIG. 8, the view being taken generally along the lines 9A—9A of FIG. 8 and in the direction of the arrows;

FIGS. 9B to 9D are diagrammatic end sectional views showing the flow pattern of material in a tube with agitators of the form of FIGS. 8 and 9A;

FIG. 10 is a cross-sectional view taken generally along a diametrical plane of the exit end of a tube that is equipped with a screw-type of flow control dam;

FIG. 11 is an end view of the flow control dam illustrated in FIG. 10;

FIG. 12 is a side cross-sectional view of the outlet end part of a tube having another form of flow control dam; and

FIG. 13 is an end view of the flow control dam of FIG. 12.

DESCRIPTION OF EXEMPLARY EMBODIMENT

Referring first to FIG. 1, a particulate material to be treated in the apparatus of the invention is supplied at a controlled rate through an appropriate form of feeder, such as a screw-type feeder 10 shown to the left in the figure. In some instances, it will be desirable to use an airlock type of feeder, such as a rotary-valve type, for material sensitive to compression or extrusion. The outlet of the feeder extends through an end cover 12 that is mounted in a fixed position on an appropriate supporting structure 14. The embodiment of the invention illustrated in the drawings and described herein is a general purpose dryer, and FIG. 1 illustrates, schematically, an air heater 16, which is also mounted on the frame structure 14, that supplies hot air to the inlet end of the apparatus through the fixed end cover plate 12. Heated or cooled air, other gases or vapors or ambient air may be supplied through the inlet opening in the end cover plate 12.

The fixed end cover plate 12 closes (and is sealed by a seal 13 to) the open end of a rotating cylindrical shell 18 in which the material treatment, in this case, drying, takes place. Spaced apart tires 20 affixed to the outer surface of the shell 18 ride on supporting rollers 22, and the shell 18 is driven in rotation through a chain drive 24 by a motor 26. The outlet end of the rotating shell, which is to the right in FIG. 1, is closed by a fixed end cover 28 that is appropriately mounted on another portion 30 of the supporting framework and is sealed to the shell by a seal 31. The frame, which is designated generally by the reference numeral 32, is supported at one end by a pivot block support 34 and at the other end by a hydraulic jack 36 which can be driven to raise and lower the input end of the apparatus, relative to the output end, and thereby vary the inclination of the apparatus to an appropriate extent to alter the rate of flow of material through the apparatus.

The particulate material treated in the dryer and the hot exhaust gases are discharged from the apparatus through a conduit 38 leading out through the downstream end cover plate 28. A lateral 40 on the conduit system takes the relatively larger particles of the material from the conduit and delivers them directly to a rotary-type valve 42 for discharge. The major part of the gases and the fine particles of material entrained in the gas flow are conducted through a conduit branch 44 into a cyclone 46 for separation, the particulate material separated in the cyclone being discharged from the lower end of the cyclone through a conduit 48 for outfeed through the rotary valve 42 and the gases being taken off from thetop of the cyclone by a blower 50. The cyclone or any other form of separating system and apparatus for further handling of the solids and gases treated in the apparatus of the invention form no part of the present invention and may be of various types that are well-known to those skilled in the art. For example, the equipment may employ a closed-circuit gas recirculating system, such as when the apparatus is used in an inert atmosphere, or for solvent recovery. Closed-circuit systems will often have condensers or scrubbers for drying out the recirculated gas and heat exchangers for reheating in the case of drying, chillers for cooling, and other types of ancillary equipment, the nature of which will depend upon the use to which the apparatus of the invention is being put.

Referring next to FIG. 2 of the drawings, the rotary part is divided into three sections, an inlet section designated generally by the reference numeral 52, a treatment section 54 and an outlet section 56. Lest it be misleading to term the section 54 a treatment section, it is appropriate to mention that a significant degree of treatment of the material occurs both in the inlet and outlet zones, as well as in the aforesaid treatment zone. The subdivision of the rotary part or shell 18 into the above-mentioned sections is provided by a pair of transverse, longitudinally spaced-apart tube sheets 58 and 60. The tube sheets 58 and 60 are sealed to the outer walls of the shell and carry a series of spaced-apart, longitudinally-extending tubes 62. The ends of each tube are sealed, such as by welding, to the tube sheets 58 and 60 so that the space between the tube sheets 58 and 60 and outside of the tubes constitutes a closed chamber. As an optional feature, the center portion of the chamber 64 contains a central tube 66, the ends of which are blanked off by closures 68, for supplying and removing fluids to and from the chamber.

The closed chamber within the treating portion 54 of the shell 18 receives, in the case of the apparatus employed as a dryer or heater, a heated fluid, such as hot water, hot oil or steam, that is conducted into the chamber 64, circulated through the chamber and discharged through a rotary union 70 of any appropriate form installed in the downstream end cover plate. The chamber may be built as a pressure vessel for operating at liquid or steam pressures well above atmospheric.

A heating fluid is supplied to the chamber through an inlet pipe 72 connected to the union, passes through an annular space within an outer rotating conduit 74 of the union 70 and then is conducted through a supply pipe 76 that extends through the center pipe 66 within the chamber to a point near the upstream end of the chamber, where it turns laterally and extends out through the wall of the center tube 66 for release of the fluid into the chamber. Where a liquid is used, it is desirable to provide baffles to control the flow of the liquid. In the illustrated embodiment, a baffle plate 80 distributes the fluid evenly throughout the cross-section of the chamber 64 in the region thereof downstream (or to the right relative to FIG. 2) of the baffle. The fluid flows through the center portion and out of the center portion of the chamber 64 through a second baffle plate 82. As may best be seen in the upper part of FIG.

5 of the drawings, each of the baffles (only the upstream baffle **80** is shown in FIG. **5**) is formed with an annular throttling orifice **82** around each tube. Accordingly, the baffles provide for a substantially uniform distribution of heating fluid and for a flow of an annular curtain or stream of heating fluid along the outer surface of each tube **62.**

The heating fluid is withdrawn from the chamber **64** through an outlet pipe **84,** the upstream end of which extends into the downstream end of the center tube **66** and then turns outwardly through the wall of the tube **66** for communication with the chamber **64** and the downstream end of which leads to the union **70.** The fluid leaves the union through an outlet pipe **86.**

The lower portion of FIG. **5** illustrates, by a phantom line designated by the reference numeral **98,** an appropriate fill level in the bottom of the inlet section **52** for material fed into the apparatus by the feeder **10.** The fill level line is drawn to represent the material free surface with the shell rotating in operation. The fill level should be such that the exposed open ends of each tube are partly covered by the rolling bed of particulate material contained in the lower region of the inlet section **52.** The precise shape and the flow pattern of the body of material in the inlet section will, of course, vary with the flow characteristics of the material and various other aspects of the operation of the equipment. The objective of the feed system, however, is to provide a layer of material that covers at least a part of the open end of each tube so that the material flows into each tube as it successively rotates by the body of material. Meanwhile, the body of material is being rolled and turned by the natural action of the rotation of the shell. In addition, an appropriate system for inducing agitation of the material in the inlet section may be provided. Such a system may be part of the agitator structures associated with the tubes **62.**

FIGS. **1** to **7** show one form of agitator structure for the apparatus of the invention. The agitator structure, as best seen in FIGS. **3, 4A, 5** and **6,** includes a hollow core pipe **100** extending axially through each tube **62** and projecting back from the tube end some distance into the inlet zone **52** (see FIG. **2**). The upstream ends of the core pipes are closed so that gas does not enter them at the upstream ends. The portions of the core pipes that project back into the inlet zone **52** assist in feeding the material and provide a degree of agitation in the body or bed of material in the inlet zone, as should be evident from FIG. **5**; as each tube **62** rotates with the shell structure through the rolling body of material in the inlet section, the projecting end portion of each core pipe **100** stirs and lifts and tends to create an open area beneath it for stirring and aeration of the bed of material.

The core pipe **100** extends over most of the length of the tube and has its axis coincident with the axis of the tube. A pair of fins or vanes **104,** which are secured to the outer wall of the core pipe **100,** extend longitudinally along most of the length of the core pipe and extend radially, in opposite directions from lengthwise lines diametrically opposite each other on the core pipe **100.** The outer edges of the vanes **104** are spaced from the inner wall of the tube **62.** The core pipe **100** and vanes **104** are mounted in each tube by support bars **106** near the ends of the core pipe. The support bars for the aerating structure fit relatively loosely into the tube **62** so that the entire aerating structure may be relatively easily and quickly removed for cleaning, and for cleaning of the tube, and then replaced in the tube. The entire aerating assembly is located and held in proper position in the tube by a retainer ring **107** that is common to all core pipes, is passed through holes in each of the core pipes, and engages the upstream tube sheet **58,** thereby keeping the aerating structures from being blown or carried by material in a downstream direction in the tubes.

There are two sets of openings **108** along generally diametrically opposite positions around the circumference of each core pipe. Each set of openings is immediately adjacent to one of the vanes **104,** and the set of openings associated with one of the vanes is offset longitudinally from the other set of openings associated with the other vane.

The flow pattern of material handled in the apparatus of FIGS. **1** to **7** is illustrated diagrammatically in FIGS. **4B** to **4E.** In each of those figures, the arrowed line designates the direction of rotation, and each figure illustrates a tube **62** with the vanes **104** oriented at a different angular position and is thus indicative of different stages during one cycle of rotation of a given tube.

As each tube **62** rotates with the shell, the vanes **104** move relatively through the bed of material that accumulates in the lower part of the tube. The material has an inclined free surface that results from the centrifugal and frictional forces generated upon rotation of the tube. Each vane picks up a body of material and carries it upwardly in a trough defined by the vane surface and a portion of the surface of the core pipe **100** adjacent the vane (see FIG. **4B**). The parts of the picked up material that are near the holes **108** adjacent the vane that is then moving upwardly through the bed of material pass through the holes and enter the interior of the core pipe. Inasmuch as the holes through which such material enter are opposite a solid wall portion of the core pipe, the material entering the interior of the core pipe is retained and tumbles in a general rolling manner across the lower portion of the core pipe. Gas moving through the tube also enters and leaves the core pipe through the holes **108.**

At the same time, the material within the core pipe is moving in a downstream direction by gravity forces resulting from an inclination of the axis of the rotary section and forces induced by the flow of gases through the tube. Some of the material entering the core pipe through a given opening **108** will fall back out into the bed of material in the bottom of the tube through the same hole **108** through which it entered after **180°** of rotation, but a portion of the material entering through a given hole **108** is retained in the core pipe and flows downstream in the core pipe until it reaches another hole **108,** at which point it will drop out through that hole and be comingled with the bed of material in the bottom of the tube **62.**

In regions where there is no hole **108** immediately adjacent to a vane **104,** the body of material will be retained in the trough defined between the vane and the adjacent part of the surface of the core pipe (see FIGS. **4C** and **4D**). As a given vane passes beyond the position illustrated in FIG. **4B,** the surface layer at the free surface of the body of material captured and lifted on the vane begins to roll off the core pipe and falls back to the bottom. From that point on, the material gradually rolls off the core pipe and becomes temporarily

suspended in the gas flowing through the tube and then settles back to the bottom of the tube.

It should be evident from examining FIGS. 4B to 4E of the drawings that the form of aerating device employed in the embodiment of FIGS. 1 to 7 of the drawings provides a gentle tumbling action with a moderate amount of free-falling or temporarily suspended material. Nonetheless, there is a substantial surface area exposure of the material to gases flowing through the tube. The lower portion of each tube remains covered by a layer of material at all times, that is at all orientations of the aerating structure. Accordingly, heat transfer between the material and the tube walls is never interrupted, thereby efficiently employing the heat transfer capability of the tube walls. The high rate of rotation of the rotary section further enhances effective use of the heat transfer capability of the tubes and flowing gas by rapid cycling of each particle of material.

The gentle agitation and tumbling afforded by the form of aerating device employed in the embodiment of FIGS. 1 to 7 provides a good balance between heat transfer from the tube walls into the material and heat and vapor transfer between the material and gas flowing through the tube. The agitating structure provides continuous, repeated cycling of each particle of material in the body of material being treated between a free surface exposure to hot gases, a free-falling exposure to the gases and a contact engagement with a hot surface, either the surface of the tube or the surface of the core pipe or vanes.

Near the downstream end of each tube, the fill level is relatively low, and aeration devices provide only limited effectiveness. Accordingly, the aeration device does not extend to the downstream end of the tube **62** but stops some distance from the end. Moreover, an important feature of the invention is the provision at the outlet end of each tube of a flow-control dam element. The height of the dam element is uniform along the circumference of the tube. The dam ensures the retention of a layer of material in the bottom of the tube, an aspect of the apparatus that has been found to be extremely significant.

More particularly, a completely open tube end provides a relatively smooth surface for material to be blown out through the end of the tube by gas flowing through the tube at an efficient velocity. Small variations in the characteristics of the material and the gas flow conditions can produce very significant variations in the amount of blow out of material in such an outlet. In contrast, the flow-control dam prevents material from being blown out of the tube end and provides a uniform layer of material at the outlet end which, in turn, controls the flow of material all the way back to the inlet end. Consequently, the flow-control dam plays a critical part in maintaining a uniform flow rate through each tube, all other things being equal.

The height of the dam may vary somewhat, depending upon the gradient of the fill level along the length of each tube and the extent to which the flow cross-section for gas flow may be reduced at the outlet end of each tube. Very good results have been obtained with a dam having a height of approximately 20percent of the diameter of the tube.

One form of dam element, which is best seen in FIG. 3 of the drawings, is an annular, flat disc **114** that has a centrally located circular opening **116** and is affixed to a cylindrical sleeve **118**, such as by welding. The sleeve is received within the downstream end portion of the tube **62** and has a multiplicity of longitudinal slot **120** that subdivide its free or inner end portion into a multiplicity of segments **122**. The sleeve **118** is made of a resilient material and the segments **122** are slots outwardly slightly so that when the dam element **112** is installed, the resiliency and geometry of the segments **122** provide firm frictional engagement with the tube walls so that the dam element is held in place in the end of the tube **62**. Nonetheless, the dam element may be readily removed for cleaning and for cleaning of the inside of the tubes **62**.

An alternate form of flow-control dam for the outlet end of each tube is a screw form (see FIGS. **10** and **11**) provided by a strip **124** of material installed as a helix within a sleeve **126**, the helical strip **124** having at least one full pitch, and preferably somewhat in excess of one full pitch. The screw form provides additional control in that it produces a positive feeding action and thus provides more direct control over the output of each tube and therefore control of throughput and retention time.

A third form of dam structure (shown in FIGS. **12** and **13**) is composed of the resilient form of sleeve **128** and a series of annular segments **129** that are longitudinally spaced-apart, and overlap each other. The material can pass between the ends of those segments that are in a given plane, but the segments in aggregate provide a dam effect against axial blow-out of material.

Upon leaving each tube, the material being treated falls into the bottom of the outlet zone **56** of the apparatus. Referring to FIGS. **2** and **7** of the drawings, the downstream end of the outlet zone **56** has a multiplicity of lifting cups **130** having concave surfaces facing in the direction of rotation of the rotary section of the apparatus. The material in the bottom of the outlet zone **56** is picked up in the concavity of each lifting cup **130** and is carried upwardly for discharge into an upwardly open outlet funnel **132**. The funnel leads to an outlet conduit section **134** and into the discharge conduit **38** (see FIG. 1). Gases, together with any fine material that may be entrained in the gases, leave the apparatus through the same conduit section **134** and discharge conduit **38** as the solid material picked up and removed by the lifting members **130**.

FIGS. **8** and **9A** through **9D** illustrate another form of from structure that may be employed in a particulate material treating apparatus according to the invention. The agitating structure shown in those figures comprises a multiplicity of longitudinally extending vanes **150** mounted on a pair (or more) of longitudinally spaced-apart, generally annular support rings **152**. The vanes extend back or upstream some distance into the inlet section and agitate the material in the inlet section to assist in feeding and provide beneficial aeration. The vanes are located at an equal distance from the axis of the tube and equal distances fro each other and extend along most of the length of each tube, though they do stop some distance from the downstream end. Each of the support members **152** includes an annular central portion **154** and a number of outwardly extending leg portions **156*a*** and **156*b***. The legs designated **156*b*** extend outwardly into engagement with the inner wall of the tube and serve as spacers or supports for the entire agitating structure in the tube. The legs designated **156*a*** are somewhat shorter. All of the legs **156*a*** and **156 *b*** are angularly related to the adjacent annular ring

part **154** so as to match an obtuse angle defined between the outwardly facing surfaces of the two leg portions **150***a* and **150***b* of each vane. The vanes are appropriately secured, such as by spot welding, to each of the support members. The supporting legs **156***b* of each of the support members **152** fit relatively loosely within the tube so that the entire agitating structure in each tube may readily be removed for cleaning of the agitating structure and the tube.

As illustrated schematically in FIGS. **9B** to **9D**, each vane moves relatively through the body of material in the lower portion of each tube **62**, picks up some of the material from that layer, carries it upwardly and gradually drops it over the edge of the leg **156B** in a free-falling cascade. As a given blade reaches approximately the 12 o'clock position (see FIG. **9D**), the material falling over the edge of that blade tends to drop onto the back of a blade two positions ahead of the 12 o'clock blade. The blade which that falling material impinges upon deflects the material and redrops it back into the bottom of the tube. In almost all instances, as a matter of fact, the material falling from a blade in an upper position in the tube falls onto a blade in a lower position and redistributes the flow of material for release back into the bottom of the tube. The aerating device illustrated in FIGS. **8** and **9A** to **9D** thus provides a substantial amount of freely cascading material, and all particles of material in the body of material being treated in each tube are cycled at frequent intervals through a free-falling cascade, a residence period in contact with a hot surface, such as either the surface of a blade or the wall of the tube, or a tumbling or rolling flow along a layer of material falling off a vane. Such cycling of each particle of material provides a combination of heat transfer by conduction into the material from a hot surface and heat and vapor transfer by conduction and convection between the hot gases conducted through the tubes and the exposed surface layers of bodies of material as well as the exposed particles in free-falling areas.

As mentioned above, the apparatus of the invention is highly versatile, and the mode of operation of apparatus of a particular design may be controlled to permit that apparatus to handle a wide variety of specific process conditions. There is, of course, a great deal of knowledge in the art concerning the processing of particulate material, and those skilled in the art will readily be able to determine, either by calculations, by experimentation, or both, the appropriate treatment conditions to be effected in apparatus constructed in accordance with the invention.

Taking a dryer as an example, the two most important factors in drying a material are the particle size and the particle structure. These factors are interrelated, except in the case when the material is relatively non-absorbant and holds only surface moisture. Surface moisture is readily evaporated, regardless of particle size, provided that the surfaces of the particles are sufficiently exposed to hot gases and provides that an appropriate mean temperature difference and mean vapor pressure difference between gas and solids exists. On the other hand, when the particle structure is dense and the particle contains internal or "bound" moisture, the moisture must be diffused to the surface before it can be evaporated. The rate of diffusion varies considerably from one material to another, but in a given material it is, of course, more difficult to achieve diffusion of bound moisture to the particle surface in relatively larger size particles. The extent to which a material contains bound moisture and the rate of diffusion of the moisture to the surface are, therefore, important factors that will be considered in establishing drying conditions in a dryer of the invention.

Among other important variables that are susceptible of wide variation in establishing the conditions of the apparatus are the mean temperature difference between the gas and the solids and the means difference in the vapor pressures, i.e., the difference between the partial vapor pressure and the vapor pressure at saturation at the surface temperature of the solid. The temperature difference and vapor pressure difference may be controlled in the apparatus, such as by controlling the temperature and flow rate of gases in the apparatus.

The degree of aeration by gentle tumbling agitation of the material treated in apparatus according to the invention depends primarily on the particle size and structure. In general, the smaller the particles being treated, the greater will be the need for aeration to ensure that the surfaces of all particles are contacted by the gas. The need for a relatively high amount of agitation must be balanced against the flow rate and temperature to ensure that there is an appropriate temperature difference and vapor pressure difference in the operation of the system so that an excessive amount of fine particles are not entrained and swept through the apparatus without being sufficiently dried. In general, however, relatively fine particles can be picked up and carried out and at the same time be adequately dried, inasmuch as entrained particles are highly contacted by the gas and will dry rapidly in a manner resembling the very rapid drying attained in flash dryers. For materials having a wide range of particle size, for newly-formed agglomerates and for fragile or abrasive particles, a high amount of agitation is generally detrimental. In treating such materials in the apparatus, a form of agitating structure providing only a relatively gentle tumbling or rolling action and a minimum of free-falling falling will be preferred and may be provided. In addition to employing different forms of agitating structures in the apparatus, the rate of rotation of the rotary section also materially affects the total amount of agitation of the material as it is processed through the apparatus.

Among the variables affecting the retention time of material in the apparatus are the form and dimensions of the flow-control dam, the velocity of the gas moving through the tubes, the rate of rotation of the rotary section, and the degree of inclination of the axis of the rotary section. In should be mentioned that the apparatus of the invention provides a feeding action, even in a horizontal position, since that part of the material making at a given instant a free-fall tends to be blown downstream by the gases flowing through the tube. Thus, the apparatus may, in some applications, be operated with its axis very nearly horizontal. The ability to vary any of the variables affecting retention time, however, provides another important factor in the versatility of the apparatus and in the ability to achieve excellent control of operating conditions.

The embodiments of the invention described above are merely exemplary, and those skilled in the art will be able to make various variations and modifications of the embodiments without departing from the spirit and scope of the invention. All such variations and modifi-

cations are intended to be included within the scope of the invention as defined in the appended claims.

I claim:

1. Apparatus for treating (e.g., drying, heating, cooling or reacting) particulate material comprising a cylindrical shell mounted for rotation about its axis, means for rotating the shell, fixed end covers closing the ends of the shell, first and second transverse tube sheets fixed within the shell at spaced-apart locations, the first tube sheet and one end cover defining an inlet zone in the shell, the second tube sheet and the other end cover defining an outlet zone in the shell, and the two tube sheets defining a closed chamber between them, means for introducing the particulate material to be treated into the inlet zone at a controlled rate, a multiplicity of tubes mounted in the tube sheets in spaced-apart relation, the tubes communicating the inlet zone with the outlet zone for flow of the material and a gas therethrough, a material flow-control dam element mounted in each tube adjacent the downstream end thereof and providing a controlled fill of material in each tube, each dam element being a member extending circumferentially of and inwardly from the tube wall a uniform distance, means in each tube for agitating the material flowing therethrough, means for conducting a flow of gas through the tubes, means for conducting a flow of a heating or cooling fluid through the closed chamber outside the tubes for heat exchange with the tube walls, and means for removing the material and gas from the outlet zone of the apparatus.

2. Apparatus according to claim 1 and further comprising means in the inlet section of the apparatus for agitating the material received therein.

3. Apparatus according to claim 2 wherein the agitating means in the tubes and the agitating means in the inlet section include common elements.

4. Apparatus according to claim 1 wherein the means for agitating the material in each tube includes a core pipe element extending axially through at least an upstream portion of each tube.

5. Apparatus according to claim 4 wherein each core pipe projects from the upstream end of the respective tube a substantial distance into the inlet zone thereby to agitate material in the inlet zone.

6. Apparatus according to claim 4 wherein the core pipe element has openings in the wall thereof for flow of gases and the material being treated between the interior of the core pipe element and the annular space within the tube and outside of the core pipe element.

7. Apparatus according to claim 1 wherein the agitating means includes a multiplicity of vanes in each tube extending generally lengthwise thereof and spaced from each other and from the tube axis.

8. Apparatus according to claim 7 wherein the vanes are spaced from the wall of the tube.

9. Apparatus according to claim 7 wherein each vane includes in cross-section first and second spaced-apart portions defining an obtuse angle between them thereby to define a cavity for reception and lifting of material.

10. Apparatus according to claim 9 wherein the vanes are generally L-shaped in cross-section.

11. Apparatus according to claim 10 wherein the vanes extend upstream from the tubes into the inlet section thereby to agitate material received in the inlet section.

12. Apparatus according to claim 1 wherein a downstream end portion of each tube adjacent the flow-control dam element thereof is free of agitating means thereby to restrict aeration in such end portion, permit an accumulation of material behind the dam element, and limit entrainment of material in the gas flow.

13. Apparatus according to claim 1 wherein the aqitating means includes an axially extending centrally located hollow core pipe element and at least one vane mounted on the exterior of the core pipe element and extending generally radially outwardly from and longitudinally of the core pipe element.

14. Apparatus according to claim 13 wherein the core pipe element has spaced-apart openings in the wall thereof for flow of gases and the material being treated between the interior of the core pipe element and the annular space within the tube and outside of the core pipe element.

15. Apparatus according to claim 14 wherein there is at least one pair of vanes, the vanes of said pair being located at diametrically opposite positions on the core pipe element and wherein the core pipe element openings are located downstream, relative to the direction of rotation of the tube, from each vane, the openings associated with each vane being staggered lengthwise of the core pipe element such that material picked up by the vanes enters and leaves the core pipe element through the openings.

16. Apparatus according to claim 1 wherein the agitating means is removably received within each tube so that it is readily removed for cleaning and for cleaning of the tubes.

17. Apparatus according to claim 1 wherein each flow-control dam element is a substantially flat annular plate mounted with its major surfaces substantially perpendicular to the axis of the tube.

18. Apparatus according to claim 1 wherein each flow-control element is a strip of material of uniform width disposed helically adjacent the end of the tubes.

19. Apparatus according to claim 1 wherein the flow-control dam element includes a multiplicity of longitudinally spaced-apart overlapping annular segments, each of which has its ends spaced from an adjacent element and all of which in aggregation define an annular obstruction to longitudinal material flow of essentially uniform height measured radially inwardly from the tube wall.

20. Apparatus according to claim 1 wherein the dam element is removably received in each tube so that it is readily removed for cleaning and for cleaning of the tubes.

21. Apparatus according to claim 1 wherein the means for conducting a flow of fluid through the closed chamber includes baffle plates disposed transversely across the chamber, a first baffle plate being positioned adjacent the first tube sheet and defining therewith a fluid supply zone and a second baffle plate being positioned adjacent the second tube sheet and defining therewith a fluid discharge zone, a fluid supply conduit communicating with the supply zone for supply of fluid to the chamber, and a fluid discharge conduit communicating with the fluid discharge zone for removal of fluid from the chamber.

22. Apparatus according to claim 21 wherein each baffle plate includes an annular fluid flow-control orifice around each tube for inducing an annular flow stream along each tube.

23. Apparatus according to claim 1 wherein the shell and end covers are mounted for adjustment of the inclination of the axis of the shell.

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