April 11, 1967 J. R. CRAWFORD ETAL 3,313,035

APPARATUS FOR DRYING PARTICULATE MATERIAL

Filed March 14, 1966 3 Sheets-Sheet 1

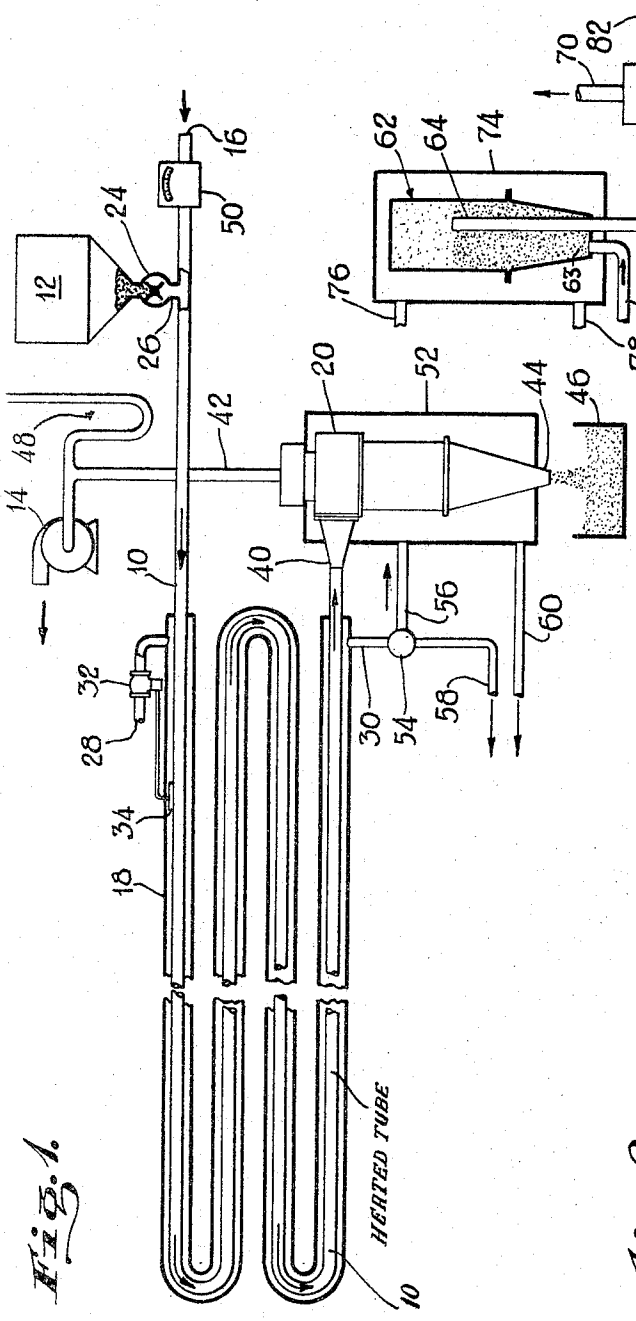


Fig. 1.

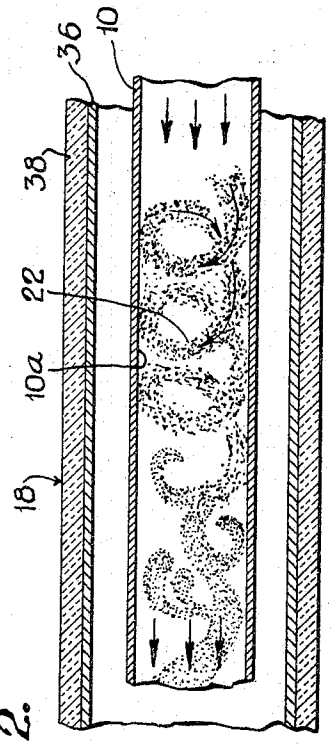


Fig. 2.

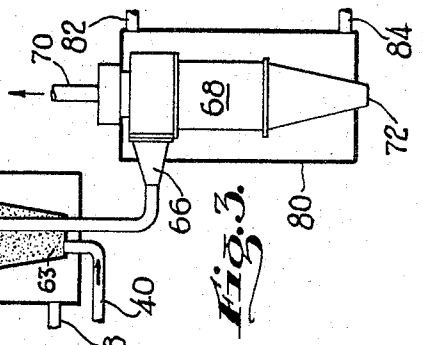


Fig. 3.

James R. Crawford
Richard Hooker, Jr.
INVENTORS

BY Robert H. Ware
ATTORNEY

April 11, 1967 J. R. CRAWFORD ETAL 3,313,035

APPARATUS FOR DRYING PARTICULATE MATERIAL

Filed March 14, 1966 3 Sheets-Sheet 2

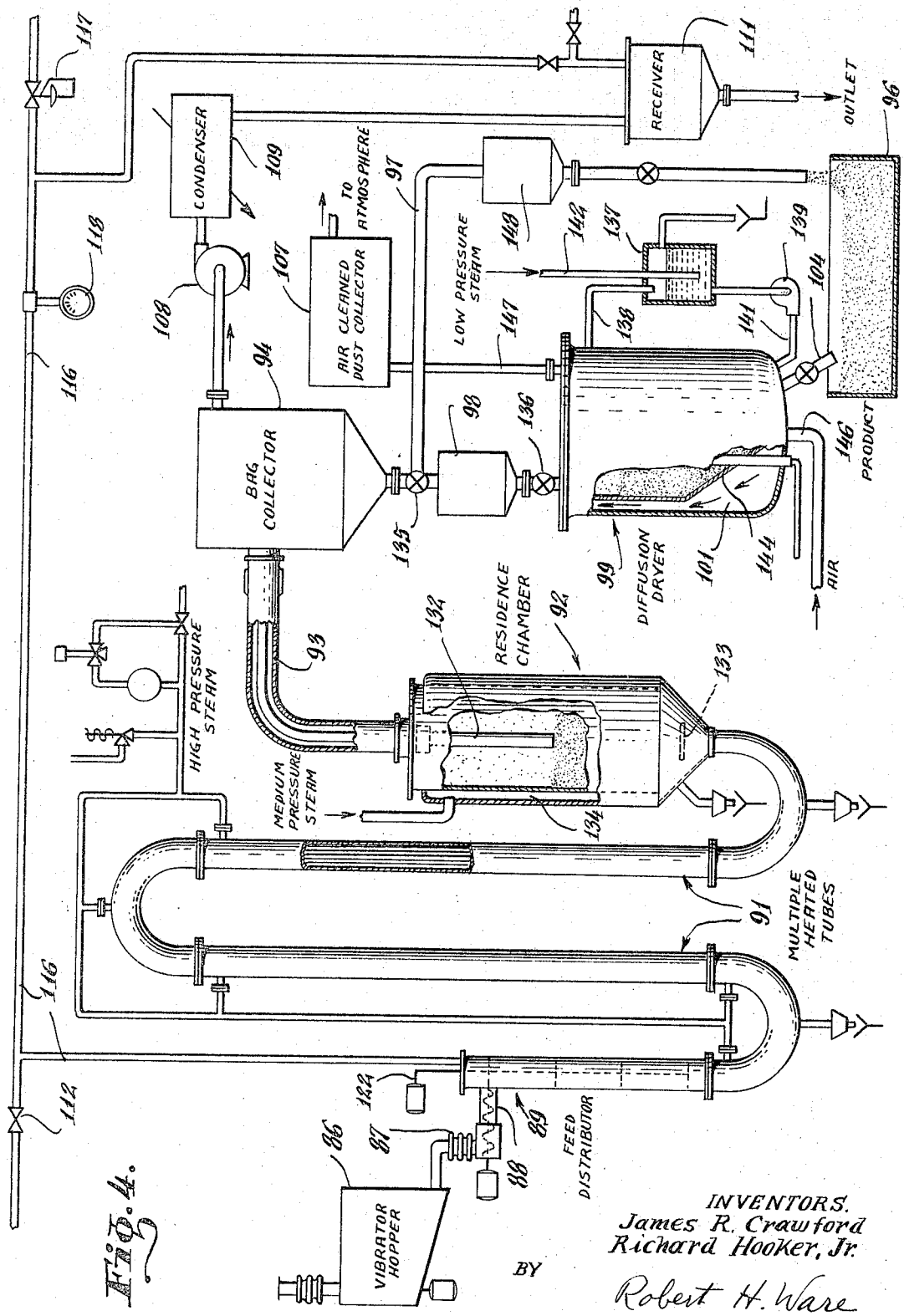


Fig. 4.

INVENTORS.
James R. Crawford
Richard Hooker, Jr.

BY

Robert H. Ware
ATTORNEY.

April 11, 1967 J. R. CRAWFORD ETAL 3,313,035

APPARATUS FOR DRYING PARTICULATE MATERIAL

Filed March 14, 1966 3 Sheets-Sheet 3

Fig. 6.

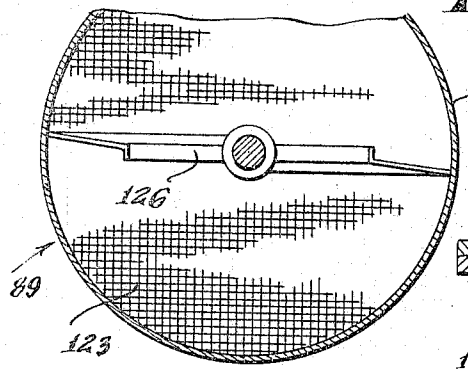


Fig. 8.

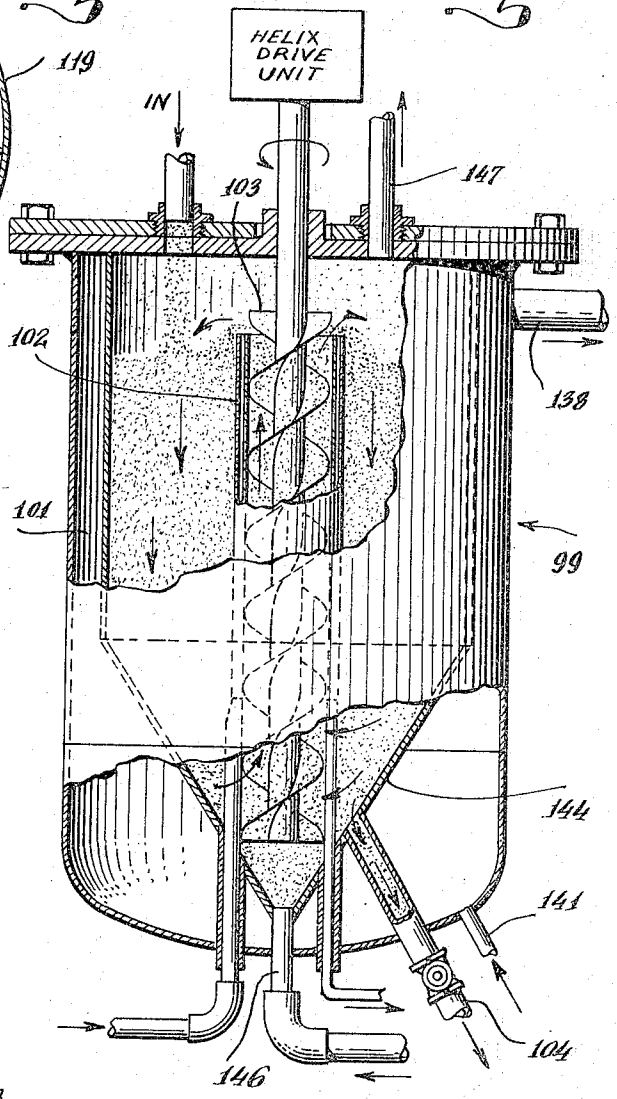


Fig. 5.

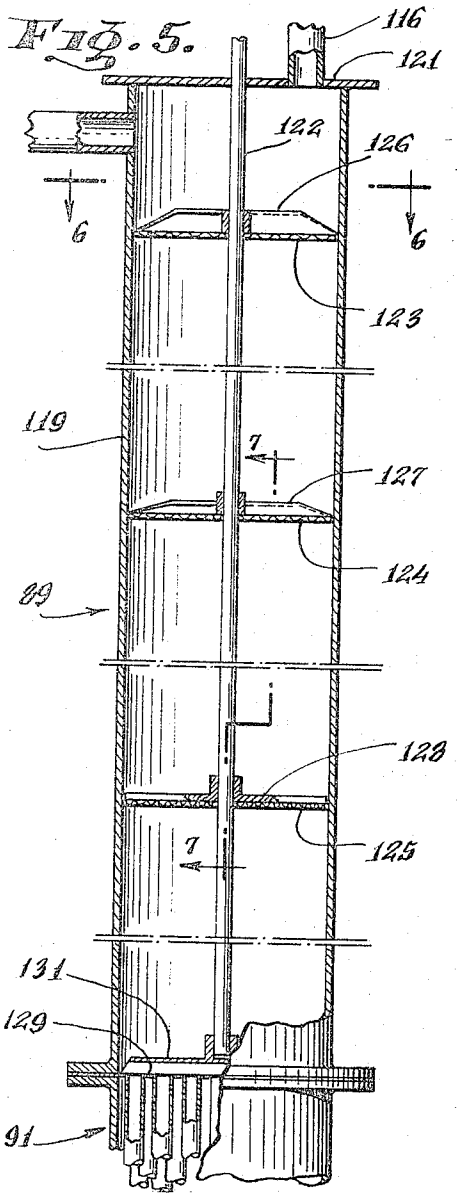
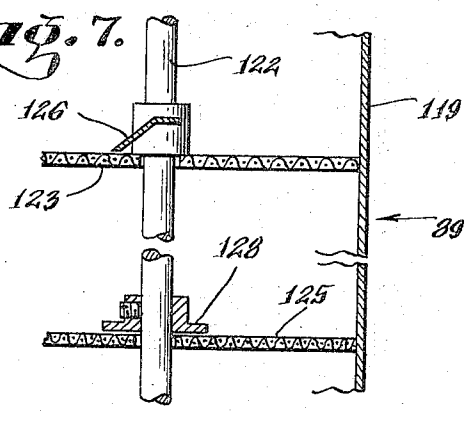


Fig. 7.



United States Patent Office 3,313,035 Patented Apr. 11, 1967

3,313,035

APPARATUS FOR DRYING PARTICULATE MATERIAL

James R. Crawford, New Canaan, Conn., and Richard Hooker, Jr., Mount Kisco, N.Y., assignors to Crawford & Russell Incorporated, Stamford, Conn.

Filed Mar. 14, 1966, Ser. No. 534,171
4 Claims. (Cl. 34—57)

This is a continuation-in-part of co-pending application Ser. No. 280,213, filed by Richard Hooker, Jr., on May 14, 1963, now abandoned. This invention relates to methods and apparatus for the drying of materials and more particularly to the drying of particulate materials which may be moved by flowing fluids.

Particulate or granular material at various stages of production or processing often has a considerable amount of liquid on the surface of the particles or entrained therein which must be removed before the next processing step for the material. Conventional methods of removing these liquids from the particulate material are generally of three types. These are: (1) mechanical drums wherein the material is tumbled in the presence of heated air to remove the moisture; (2) fluidized beds where drying heat is supplied by heated air or gas moving through the material to be dried; (3) flash drying systems wherein the material is heated to a high temperature under pressure and then is exposed to air or super heated vapor to flash off the moisture.

The above systems have a number of disadvantages. The cost of manufacture of equipment for these prior art systems and the operating costs for these methods is excessively high. In rotary dryers and fluidized beds in particular, a great amount of heat energy is required per unit weight of dried material. In the case of fluid beds heat is transferred to the wet particles by heated air or gas with a substantial amount of heat energy lost in the recycling of the heated air or gas. Heat transfer from a gas to a solid requires a substantial amount of heated gas to heat and dry a given amount of solids. Granular lumps of polymer require special handling, and particular polymers exhibit "diffusion-controlled" slow drying rates during vaporization of the last few percentage points of volatiles, which must diffuse outward through capillary crevices to the particle surface before they can be vaporized.

Mechanical driers employ very large rotating drums which are expensive to manufacture and to maintain in operation. A particular problem with such driers lies in the seals that must be employed on the rotating drum, since seal leakage wastes material and seals are expensive to maintain. Flash drying also requires a great amount of heat, and the pressure pumps for the material are very costly.

A further problem exists when drying materials which will decompose or undergo degradation at higher temperatures. In such instances many rotary driers are not practical since the material being dried will be deteriorated by excessive drying heat. These conventional driers also require extended residence time at high temperatures to dry a substantial charge of material. Thus the extended exposure to high temperatures of material that is already dried also leads to decomposition or degradation of a portion of the material.

Accordingly, it is an object of this invention to provide methods of drying particulate material which are efficient and economical.

Another object of the invention is to provide methods of the above character wherein the material to be dried is exposed to rapid intermittent contact with a heated surface in the drying apparatus.

A further object of the invention is to provide methods

of the above character wherein the material to be dried is moved through the drying stages by turbulent air or gas.

Another object is to provide such drying methods accommodating widely varying sizes of granules or particles, and material with widely different drying rates.

Another object of the invention is to provide apparatus for carrying out methods of the above character.

A further object of the invention is to provide apparatus of the above character which is economical to manufacture and maintain in operation.

Other and more specific objects will be apparent from the features, elements, combinations and operating procedures disclosed in the following detailed description and shown in the drawings, in which:

FIGURE 1 is a schematic view in partial section of the initial drying units in one form of the invention;

FIGURE 2 is an enlarged partial side sectional view of a drying tube and jacket shown in FIGURE 1;

FIGURE 3 is a schematic side view in partial section of an alternate material recovery portion of the invention;

FIGURE 4 is a schematic diagram of a different embodiment of the invention, with several units of apparatus partly broken away for clarity;

FIGURE 5 is a sectional side elevation view of a sifting unit shown in FIGURE 4, where lumps of feed material are broken up into particulate form;

FIGURE 6 is a sectional top plan view of the unit of FIGURE 5;

FIGURE 7 is an enlarged fragmentary sectional elevation view of the unit of FIGURE 5, and

FIGURE 8 is a side elevation view of the diffusion dryer unit shown in FIGURE 4, partly cutaway to show its preferred internal construction.

In general the invention involves the drying of particulate material by moving the material with a stream of air or gas through one or more heated tubes of relatively small diameter in proportion to its length, preferably followed by further gas-agitation in one or more heated holding tanks or residence chambers. The velocity of the moving air stream should be high enough to create a great amount of turbulence in the particulate material being moved through the drying tube. It has been found that such turbulence causes the particulate material to impinge upon the heated walls of the drying tube rapidly but frequently enough to cause heat transfer from the drying tube directly to the particles as well as to the air or gas moving through the tube.

As shown in FIGURE 1, the drying tube **10** is supplied with particulate material from a hopper **12** which is moved through the tube by a partial vacuum created at tube exit **40** by blower **14**. The drying tube **10** has a heat exchange jacket **18** for heat transfer to the material. A material separating cyclone **20** is provided at the exit end **40** of the tube to deposit the dried material in bit **46** and send the moisture laden air through conduit **42** for venting or vapor recovery.

As shown in FIGURE 2, the material **22** passes through the tube **10** with great turbulence due to the velocity of the air or gas moving the material through the relatively small diameter tube. As the partial vacuum draws the material through the tube **10** there is little chance of the tube plugging. The vacuum also lowers the vapor pressure of the moisture present and permits lower tube temperature for moisture removal.

The invention will now be described more specifically. Referring now to FIGURE 1 it will be seen that the drying tube **10** is supplied with particulate material from the hopper **12** through a rotary gate **24** which controls the feed rate into the drying tube. As the particulate material to be dried enters the tube at **26** adjacent air

entrance end **16**, it is carried rapidly through the tube in a direction of the arrows by high velocity air which is drawn through the tube **10** and cyclone **20** by blower **14**.

The tube **10** is preferably made of stainless steel and may vary in length from 20 to 300 feet or more. Tube **10** is enclosed over the greater part of its length by a heat exchange jacket **18** having an inlet **28** and an outlet **30** for steam or hot water which is to be circulated through the jacket. A valve control **32** may be operated by a thermostat **34** to control the flow of heat exchange fluid within the jacket **18**.

The cyclone **20** may be enclosed by a heat exchange jacket **52** which is connected to steam outlet **30** through regulator **54** and conduit **56**. Thus the cyclone **20** is maintained at a temperature below that of the drying tube **10** but hot enough to prevent condensation of vapors therein. The regulator **54** is used to reduce steam pressure to the cyclone jacket **52**, as the velocity of material is greatly reduced in the cyclone and high cyclone temperature may cause degradation of some materials as they are separated from the air-vapor stream. Steam return conduits **58**, **60** direct the steam from the jackets **18** and **52** respectively to the steam source (not shown).

As shown in FIGURE 2, the heat exchange jacket **18** is comprised of a steel wall **36** which is preferably covered by heat insulation **38**.

The tube **10** and its heat exchange jacket **18** may have U-shaped bends over its length as shown in FIGURE 1, or it may be straight over its length if such a configuration is practical from the standpoint of space. Sharp bends in the drying tube should be avoided to prevent build up of material and consequent plugging of the tube.

At its exit end **40** the tube **10** is connected to cyclone **20** which separates the dried particles from the moisture laden air or gas which has been drawn through the tube. From the cyclone **20** the moisture laden air or gas passes from the system via conduit **42** where the gases may be vented to the atmosphere or recovered for other uses. The dried material empties from the cyclone **20** at spout **44** into a bin **46** or onto a conveyor (not shown).

A manometer **48** may be connected to conduit **42** between the cyclone **20** and the blower **14** for indication of vacuum level in the system. A velometer **50** may also be positioned at the entrance end **16** of tube **10** to measure the velocity of air being drawn into the tube.

As shown in FIGURE 2, the material **22** in the drying tube **10** is moved with a great amount of turbulence so that the particles of material are vigorously impinged against the inner surface **10***a* of the drying tube. The heat in the drying tube is thus effectively transferred to the particles during this rapid and successive impingement. The heat thus transferred from the drying tube in conjunction with the heated air moving through the tube effectively and efficiently removes moisture from the particles. Because of the rapidity of the particle impingement there is no degradation of the material as it passes through the drying tube.

It has been found that turbulence of the material in the drying tube depends upon the diameter of the drying tube itself in relation to the velocity of the stream of air moving the material through the tube. Thus for some applications a number of small diameter tubes, e.g., one inch or less in diameter, may be used instead of a few tubes of larger diameter.

In the following pilot plant test examples the drying tube was 40 feet in length with an O.D. of ½" with a .035" wall thickness. The tube material was stainless steel. Except as otherwise noted, the cyclone residence time for separation of solids was less than 1 minute. Steam under pressure of from 25 to 100 p.s.i. was used in the heat exchange jacket.

EXAMPLE I

A batch of particulated polycarbonate material having a moisture content of 59.2% was fed into one end of the tube at the rate of 4 lbs. per hour. A vacuum of 5.0 in. of Hg was pulled on the exit end of the tube to draw the particulated material through the 40-ft. tube. During the drying operation the temperature of the exit air from the drying tube was maintained at 330° F. by control of the steam jacket temperature. The polycarbonate traversed the 40 feet of drying tube in approximately 1 second and upon analysis was found to contain 6.4% moisture after its pass through the drying tube. The condition of the polycarbonate was very good, showing no signs of decomposition or damage after passage through the tube.

EXAMPLE II

A second run under the same conditions as in Example I was made with particulated polycarbonate wherein the polycarbonate, after passing through the tube, was retained in the cyclone for a period of 10 minutes. After this 10-minute residence time in the cyclone the moisture content of the polycarbonate material was found to be 1.0%.

EXAMPLE III

Granular polypropylene having a 22% moisture content was fed into one end of the 40-ft. tube at the rate of 18 lbs. per hour. A vacuum was maintained on the exist end of the tube equivalent to 4.0 in. of Hg, and the temperature of the exit air was maintained at 249° F. The polypropylene material took slightly over 1 second to traverse the 40-ft. drying tube and contained 1.4% moisture when recovered from cyclone at the exit end of the tube. Under these conditions the polypropylene showed no degradation or tendency to agglomerate and was in excellent condition for further processing.

EXAMPLE IV

Polypropylene was dried under the same conditions as in Example III above but was retained in the cyclone for a period of 3 minutes. After this 3-minute cyclone residence time, the moisture content of the polypropylene was measured and found to be .15% and the condition of the dried polypropylene was excellent as in Example III above.

EXAMPLE V

Particulated polyethylene having a moisture content of 18.8%, the moisture being substantially hexane, was fed into the 40-ft. tube at the rate of 15 lbs. per hour. The material was drawn through the drying tube by a vacuum of approximately 1.5 in. of Hg and the temperature of the air leaving the drying tube was maintained at 240° F. Upon analysis after recovery from the cyclone the polyethylene is found to be completely dried and contains no moisture. The condition of the polyethylene is excellent and ready for further processing.

EXAMPLE VI

Particulated polyethylene which contains 25.5% moisture in the form of methanol was fed into the tube at the rate of 25 lbs. per hour and was moved through the tube by a vacuum of approximately 1.5 in. of Hg at the exit end. The air exit temperature was maintained at 240° F. Moisture analysis of the polyethylene passed through the tube indicates a moisture content of .2%, and the polyethylene itself is unchanged physically and chemically.

EXAMPLE VII

Granular Teflon (tetrafluoroethylene polymer) with a moisture content of 30.0% was fed into the tube at a rate of 8 lbs. per hour. The Teflon was moved through the tube by a vacuum of 2.5 inches of mercury at the tube exit and the heating jacket temperature was maintained to provide an air exit temperature of 240° F. After passage through the drying tube, the Teflon moisture content is .05% and the condition of the Teflon was unaltered either physically or chemically by the drying process.

Further pilot plant drying tests on polycarbonate and

polypropylene were made with a stainless steel drying tube having the same diameter as above, but having a length of only 20 feet. Approximately the same steam temperatures and pressures were maintained in the jacket surrounding the tube as were used above in Examples I and III respectively.

EXAMPLE VIII

Particulated polycarbonate having a moisture content of 59.2% was fed into the open end of the 20-ft. tube at the rate of 4 lbs. per hour and was drawn through the tube by a partial vacuum equivalent to 5.0 inches of mercury. The temperature of the exit air from the tube was 318° F. The moisture content of the polycarbonate was 12.4% upon recovery.

EXAMPLE IX

Granular polypropylene having 22% moisture was fed into the tube at the rate of 18 lbs. per hour and was drawn through the 20-ft. drying tube by a partial vacuum equivalent to 4.0 inches of mercury. The temperature of the exit air from the tube was measured at 238° F. and the recovered polypropylene had a moisture content of 2.5%.

As shown in the above examples, the shorter 20-ft. tube resulted in a slight lowering of the temperature of the exit air from the drying tube. Also, from the reduced amount of contact of the material with the tube walls the amount of moisture left in the material after it passed through the 20-ft. tube was somewhat higher than when passed through the 40-ft. tube under the same conditions. Even after passing through the 20-ft. tube, however, the amount of moisture removed is quite substantial, and the material thus dried would be suitable for further processing in a great number of instances.

The drawing of the particulate material through the tube by a partial vacuum is preferred for a number of reasons. Creation of a partial vacuum reduces the vapor pressure of the moisture, aiding in its removal from the material. Further, the vacuum aids in preventing the plugging of the tube as the material is drawn therethrough. It is to be pointed out, however, that for some materials blower pressure at the feed or entrance end of the tube may be used within the scope of the invention.

It has been found that the ratio of length to diameter of the drying tube may be varied for different materials, different particle sizes, and different types of moisture which are contained in the material. The length to diameter ratio of the drying tube however should be from 300 to 2500 to one. A length to diameter ratio of around 1200 has been found to be generally suitable for most materials. Thus in providing a drying tube for large scale drying operations the tube may have, for example, an inner diameter of 3 inches and a length of 300 feet. For many materials a plurality of tubes having an inner diameter of from one-half to one inch may be employed with a common heat exchange jacket around them. When using a plurality of small diameter tubes, the material may be drawn therethrough by a single vacuum system communicating with the cyclone or other separator. Each tube should be fed with material at a substantially uniform rate to provide uniform tube travel time and exposure to drying heat. Such an elongated drying tube may be bent at a number of points along its length to conserve space with the tube bends preferably being smooth and gradual to prevent material build up in any sharp bends within the tube.

As pointed out above, the material may take from 1 to 2 seconds to traverse a 40-ft. drying tube with a diameter of slightly under one-half inch. At these speeds it is preferable to maintain the temperature of the tube itself within 10° F. of the melting point or degradation point of the material being dried.

The amount of vacuum applied to the exit end of the tube should be from 1 to 6 inches of mercury. The higher vacuums draw the material through the tube at a greater velocity and therefore expose the material to heat for a shorter period of time. Any reduction in vapor pressure when applying higher vacuums, however, will at least in part compensate for the shorter period of time the material is exposed and impinged against the inner surface of the drying tube. In the claims the term "gas" includes air as a conveying medium.

As shown in FIGURE 3 the cyclone separator **20** may be replaced by a multi-stage separator comprising a residence chamber **62** (shown in section) which has the drying tube exit **40** emptying into lower end **63**. An upstanding tube **64** removes material and vapor from chamber **62** and passes it to cyclone **68** via connection **66**. The height of tube **64** may be varied to provide varying residence time in chamber **62** before transfer to cyclone **68**.

In cyclone **68** the material is separated from the vapors and is removed through spout **72**. Vapors are passed from cyclone **68** through conduit **70** which is connected to the vacuum blower as cyclone **20** is connected to blower **14** in FIGURE 1. Heat exchange jackets **74**, **80** preferably surround chamber **62** and cyclone **68** respectively. Heat exchange fluid inlets **78**, **84** and outlets **76**, **82** are connected to a heat exchange fluid source to maintain the chamber and cyclone at a temperature above the condensation point of the vapors being removed from the material.

Thus, for some materials the amount of remaining moisture may be reduced by increasing residence time in the heated chamber **62**, before final separation in cyclone **68**. Examples II and IV above are illustrative of cases wherein increased separator residence time may be desirable.

A great number of materials may be dried, in accordance with the invention including, for example, styrene, maleic anhydride, polyvinyl chloride, polychlorofluoroethylene and polymerized acrylics as well as the materials used in the above examples.

The impingement of the particles against the walls of the drying tube thus greatly increases heat transfer from the tube to the material particles. The quantity of air required to move the particles through the drying tube is greatly reduced in comparison to prior art drying apparatus and methods. Thus the invention provides not only for inexpensive apparatus but also for substantially increased economy in operation.

A preferred embodiment of the invention in a transport dryer for drying acrylic polymer is shown schematically in FIGURE 4. In this dryer, acrylic polymer of 80 to 120 mesh particle size is dried from a feed moisture content of between 7 and 15%, to a delivery moisture content of about 0.5%, in a total handling time of less than five minutes. In FIGURE 4, the incoming granulated wet polymer is stored in a vibrator hopper **86** and delivered therefrom through a flexible conduit **87**, via a motor-driven screw feed unit **88**, to a feed distributor **89** shown in detail in FIGURES 5, 6 and 7.

Distributor **89** breaks up lumps of granular polymer into particulate material of a predetermined maximum particle size which then passes directly into the elongated multiple tube drying unit **91**, for turbulent stream drying of surface moisture as described above.

From tube unit **91**, the stream of gas carrying the polymer particles enters a heated residence chamber or holding tank **92**, where it is agitated in a fully or semi-fluidized state for a predetermined drying period, thereafter being drawn through a heated conduit **93** to a conventional bag collector **94** discharging dried polymer directly into a delivery container **96** through conduit **97**, or into a storage tank **98** from which a continuous stream or suitable batches can be discharged into a diffusion dryer **99**, shown in detail in FIGURE 8.

Diffusion dryer **99** is used to provide additional drying time for vaporizing absorbed or occluded moisture diffusing through capillary-like interstices within each particle toward the particle surface. Dryer **99** is heated by

an external heating jacket **101** and by an internal double-walled draft tube **102** through which the polymer particles are raised by a helical impeller **103**. Dried polymer is discharged through a valved product port **104**, and purge air enters the diffusion dryer **99** at the lower end of the draft tube **102**, and leaves it via a top outlet conduit **106**, preferably leading into an air-cleaned dust-collector **107** incorporating a porous dust-bag, such as the "Flex-Kleen" unit manufactured by the Flex-Kleen Corporation of Chicago, Illinois, which traps the fine polymer dust in the exhaust air stream and periodically shakes and empties the trapped dust, returning it through conduit **106** to diffusion dryer **99**.

Blower **108** draws gas through feed distributor **89**, tubes **91**, residence chamber **92**, conduit **93** and bag collector **94**, delivering solvent vapor to a condenser **109** draining into receiver **111**.

If atmospheric air is used as the drying gas, inlet valve **112** is opened, supplying air to feed distributor **89**, and outlet valve **113** is opened, venting receiver **111** to atmosphere.

If solvent vapor is to be retained in a closed system, valves **112** and **113** are closed and a vapor return valve **114** is opened, conducting receiver **111** through a return conduit **116** to feed distributor **89**. Conduit **116** is provided with a pressure relief or safety valve **117** and a flow meter **118**.

Feed distributor

The feed distributor **89** includes an upright cylindrical housing **119** having a top plate **121** with a central axial aperture accommodating a vertical power driven driveshaft **122**. Spanning housing **119** are a spaced plurality of transverse perforated plates or screens **123–125**, preferably having diminishing mesh sizes from top to bottom of distributor **89**.

As shown in FIGURES 5 and 7, a corresponding spaced plurality of diametric sifter blades **126–128** are anchored to the shaft **122**, one blade being positioned just above each of the screens **123–125**. The uppermost blade **126** preferably has a substantial rake angle, converging with its underlying coarse screen **123**. As shaft **122** rotates, blade **126** crumbles the lumps of polymer fed through screw feed unit **88**, trapping them between itself and its underlying screen **123**, and thus forcing them through screen **123** to succeeding blades, which may have smaller rake angles. The final blade **128** co-operating with the finest screen **125** may be substantially flat, as shown in FIGURE 7.

Granular polymer material entering distributor **89** through feed unit **88** falls by gravity through successive screens **123–125**, with blades **126–128** successively reducing its particle size. The downward progress of the polymer particles is also aided by the drying gas stream entering housing **119** through conduit **116**. Gas and particles thus travel through screens **123–125** toward the multiple tube unit **91**, whose open portal ends are welded flush into spaced apertures in a tube plate **129** spanning the lower end of distributor **89**.

A feeder blade **131** anchored to the lower end of shaft **122** revolves just above plate **129**, serving to distribute the polymer particles continuously into the tubes **91**. The distributor unit **89** thus reduces the particle size of fresh feed polymer, breaking any lumps and supplying a continuous stream of fine polymer particles for rapid drying in subsequent stages of the system.

Multiple tube unit

The multiple tube unit **91** enclosed within a high pressure steam jacket provides a plurality of parallel drying paths along with the polymer particles are tumbled and agitated rapidly by the advancing gas stream drawn through the system by blower **108**.

The multiple tube unit is designed to provide sufficient heat transfer area for drying the polymer to a moisture content which is optimum based upon its drying rate curve. Thus if surface moisture accounts for all but the last 3% of volatiles, which require diffusion to reach the particle surface, the polymer particles may be dried to 5% moisture content in tube unit **91**, leaving the final, diffusion-controlled drying to be performed in subsequent drying stages.

In the multiple tube unit **91**, heat is supplied to the polymer both by conduction and by radiation from the tubes' internal wall surfaces. In most cases, tube temperatures can be higher than the melting point of the polymer because the surfaces of the cooler polymer particles cannot reach this temperature as long as moisture is present on the particle surfaces. Radiation from the tube walls has the effect of increasing the wet bulb temperature of the surface of the polymer particles, producing a corresponding increase of as much as 30% in the rate of mass transfer of moisture from inside each particle to its surface.

Residence chamber

In the system of FIGURE 4, the holding tank or residence chamber **92**, like chamber **62** in FIGURE 3, serves to arrest the rapid turbulent advance of the polymer particles in a fully or partially "fluidized" mass within the chamber. An adjustable downpipe **132** extends downward into the heated chamber **92**, providing an outlet for delivery of the polymer particles through heated conduit **93** to bag collector **94**, exhausted by blower **108**. By raising or lowering the adjustable downpipe **132**, the volume of polymer agitated in the heated chamber **92** can be changed, with a corresponding change in the residence time of the material. The multiple tubes **91** enter the lower end of chamber **92**, and downpipe **132** extends downward from the upper end of the chamber. If multiple tubes **91** and downpipe **132** are substantially coaxial or otherwise aligned, fast-moving polymer particles may be carried directly through chamber **92** by the advancing gas stream. To avoid such a "wind tunnel" effect, a baffle plate **133** may be positioned by suitable supporting struts in chamber **92** between the entering multiple tubes **91** and the exhaust portal end of pownpipe **132**. Baffle plate **133** interrupts the gas stream delivered by tubes **91**, creating turbulent, billowing agitation of the polymer particles for extended residence time in chamber **92**, heated by its medium pressure steam jacket **134**.

As the advancing stream of gas passes through the system of FIGURE 4, the pressure differential created by the blower is balanced by the successive pressure drops through conduit **116**, feed distributor **89**, tubes **91**, chamber **92**, conduit **93** and bag collector **94**. Accordingly, the pressure in chamber **92** is appreciably lower than the pressure within multiple tubes **91**.

The high-velocity turbulent motion of the polymer particles through heated tubes **91** combined with their abruptly arrested, agitated residence in the lower-pressure, heated residence chamber **92** produces unexpectedly effective drying of the particles. The high mass transfer rate produced by high temperature heating in the tubes **91** apparently plays a part by initiating migration of internal moisture toward the particle surfaces, where it is vaporized with high effectiveness during the particles' residence in chamber **92** at temperatures below the polymer melting point and at pressures below those in tubes **91**.

Bag collector **94** performs the same function as cyclone **20** or **68** by separating the polymer particles from the advancing gas stream drawn into the blower.

For products dried sufficiently in the foregoing stages, the three-way exit valve **135** beneath bag collector **94** may be turned to direct the particles continuously through conduit **97** to delivery container **96**.

Many products require additional drying, particularly those in which the final increments of solvent moisture can be vaporized only at diffusion-controlled slow drying rates.

Diffusion dryer

Final, diffusion-controlled slow drying of polymer particles is performed in diffusion dryer **99**, shown in FIGURES 4 and 8. If three-way exit valve **135** is turned to shunt the conduit **97**, and storage tank **148** interposed therein, polymer particles from collector **94** are delivered directly to a storage tank **98** having an exit valve **136** connecting it to dryer **99** for delivering batches of material thereto. For continuous operation valve **135** may be opened to connect collector **94** to tank **98**, and valve **136** may be replaced by a continuous screw-type feeder to deliver material against the slight pressure in dryer **99**, affording a vacuum seal between tank **98** and dryer **99**. The storage tanks **98** and **148** are interposed to provide air locks blocking atmospheric pressure or the pressure in dryer **99** from reversing the normal delivery flow through exit valve **135**.

As shown in FIGURE 4, the diffusion dryer **99** is heated preferably to a temperature lower than the temperature of chamber **92** by a steam-water mix or hot water circulating through its jacket **101**, connected to a return sump **137** by an overflow conduit **138** and a circulating pump **139** and supply conduit **141**. Water in sump **137** is heated by low pressure steam supplied through a steam conduit **142**; accumulating water produced by condensation of this steam is removed from sump **137** by an overflow drain **143**.

Circulation of polymer particles in diffusion dryer **99** is produced by central helical impeller **103** carrying the material upward inside the double-walled draft tube **102**, which is heated by a separate supply of low pressure steam or by the steam-water mix or hot water circulating through jacket **101**. The lower end of draft tube **102** is open, communicating with the conical-walled lower end **144** of the dryer chamber at the bottom of which a surge air inlet **146** supplies a stream of air to carry away vaporized moisture via air outlet **147** connected to an air-cleaned dust collector, such as the "Flex-Kleen" unit sold by the Flex-Kleen Corporation of Chicago, in which a dust collector bag is periodically shaken to return fines to the dryer **99**.

Product is delivered from dryer **99** via valved product port **104** to the delivery container **96**, although a reverse flight helical screw impeller mounted coaxially below impeller **103** may be employed for continuous product delivery.

Highly efficient diffusion-controlled drying of the polymer particles is achieved by the repeated circulating exposure of the material to the heat from jacket **101** and draft tube **102**. Residence time is selected to produce the desired degree of dryness.

The effectiveness of the transport drying system shown schematically in FIGURE 4 is demonstrated by the following examples of drying runs performed on acrylic polymer, summarized in Table I, and on vinyl chloride and vinyl acetate, summarized in Table II, Table III and Table IV.

TABLE I.—ACRYLIC POLYMER DRYING RUNS, USING SINGLE TUBE 10 OR MULTIPLE TUBE UNIT 91

Run No.	Type Tube Unit C&R Transport Dryer	Tube Jacket Temp., ° F.	Polymer, Wt. Percent Vol.		Product Rate, lbs./hr.	Heat Transfer Rate, B.t.u./hr.-ft.² ° F.
			Feed	Product		
S-1	20 ft. single	307	7.5	0.8	7.5	
S-2	40 ft. single*	307	7.5	0.6	15.8	
S-3	20 ft. single*	307	7.5	0.6	7.5	
S-4	40 ft. single	281	7.5	1.0	13.9	
S-5	do	281	7.5	0.8	7.5	
S-6	do	281	15.0	1.0	6.9	3.8
M-1	40 ft. multiple* (10)	270	7.7	0.4	91.9	2.7
M-2	do.*	270	7.7	0.75	134.0	3.8
M-3	do.*	270	7.7	0.9	167.5	4.1
M-4	do.*	270	7.7	1.1	214.4	4.8

*Fluidizing residence chamber 92 used, as shown in FIGURE 4.

TABLE II.—VINYL CHLORIDE-VINYL ACETATE COPOLYMER DRYING RUNS USING SINGLE TUBE UNIT 10

Date 1964	Run No./ Dur. of Run, Min.	Type C&R Dryer	Dryer Tube Length, Ft.	Dryer Tube Jacket Temp., ° F.	Cyclone Jacket Temp., ° F.	Cyclone Vacuum, in. Hg	Feed Rate, lbs./hr. Wet Basis	Feed, Vol. percent Wet Basis	Product, Vol. percent Wet Basis	Tube Unit Vapor Disch. Temp., ° F.	Remarks
10/14	1/5	S.T	40	174 H_2O	174 H_2O	2.5	11.5	20.0	12.0	[a] 170–160	Ran well; cyclone clean.
10/14	2/5	S.T	60	174 H_2O	174 H_2O	4.5	11.5	20.0	10.0	[a] 170–165	Same as Run 1.
10/14	3/5	S.T	60	198 H_2O	198 H_2O	4.6	11.5	20.0	8.0	[a] 196–189	Do.
10/14	4/3	S.T	40	269 Steam	232 Steam	3.6	11.5	20.0	5.3	[a] 258–248	Do.
10/15	5/3	S.T	60	do	do	4.5	11.5	20.0	4.6	[a] 258–252	
10/15	6/2[b]	S.T	60	do	do	3.7			3.5	[a] 259–255	
10/15	7/3	S.T	60			4.0	11.5	20.0		[a] 214–203	
10/18	9/28	S.T	60			5.0	11.5	20.0	5.0 [c](0.2)	[a] 210–197	

[a] Air Temp. at start of run before adding feed. S.T.=Single Tube Unit.
[b] Feed crumb slurried—2 water washes—210° F.
[c] Fluidizer on stream. H.U.T. 22 min. in fluidizer. Jacket heat on fluidizer. Bed vol.=0.148 ft.³. Use of fluidizing residence chamber 92 in 28-minute Run No. 9 reduced moisture content from 5.0% to 0.2%.
[d] Straight run tube in fluidizer—i.e., negligible hold-up time. Feed polymer=Escambia lot 102764.

TABLE III.—VINYL CHLORIDE-VINYL ACETATE COPOLYMER DRYING RUNS USING MULTIPLE TUBE UNIT 91 OR SINGLE TUBE 10 WITH FLUIDIZING RESIDENCE CHAMBER 92

Date 1964	Run No./Dur. of Run, Min.	Type C&R Dryer	Dryer Tube Length, Ft.	Dryer Tube Jacket Temp., ° F.	Fluidizer Jacket Temp., ° F.	Cyclone Jacket Temp., ° F.	Feed Rate, lbs./hr. Wet Basis	Feed Vol. Percent	Fluidizer Vapor Disch. Temp., ° F.	Tube Vapor Disch. Temp., ° F.	Dryer Vapor (air) Vol. Ft.³/min.	Fluidizer Disch. Prod., Vol. Percent
10/28	1&2/15	M.T	40	235	249	----------	35	20.0	[d] 233 [d] 219	[a] 240 204	28	3.5.
10/29	3	M.T	40	247	247	250	34.7	20.0	[d] 228	180	30	4.5.
10/30	4	M.T	40	245	245	250	34.7	20.0	[d] 226	230	27	3.9.
11/2	5	S.T	60	268	None	----------	11.5	30.0	None	----------	----------	6.2—1 pass. 0.4—3 passes.
11/3	6	S.T	60	247	163	163	11.5	30.0 approx.	[d] 162	[a] 226 220	----------	5.0—1 pass.
11/3	7	S.T	60	260	None	None	11.5	5.0	----------	----------	----------	

See footnotes at end of Table II.

TABLE IV.—VINYL CHLORIDE-VINYL ACETATE COPOLYMER DRYING RUNS: CONDITIONS MAINTAINED AND OBSERVED DURING BATCH DRYING IN DIFFUSION DRYER 99

Date 1964	Run No.	Drying Time, Hrs.	Air Temp. In., ° F.	Air Flow, In. Ft.³ Hr.	Jacket Temp., ° F.	Bed Temp., ° F.	Prod. Disch. Vol., Percent	Screw, r.p.m.	Remarks
10/28	1	0	----------	----------	----------	----------	3.5	0	
	1	.0833	180	20	181	170	3.0	110	Screw pumping polymer.
	1	0.416	180	20	179	175	1.0	110	Do.
	1	0.917	180	20	180	178	0.7	110	Do.
10/28	2	0	----------	----------	----------	----------	3.5	0	
	2	0.25	160	20	160	155	2.5	110	Do.
	2	0.5	160	20	161	154	1.8	110	Do.
	2	0.66	160	20.5	165	159	1.3	110	Do.
	2	1.0	160	20.5	165	165	1.1	110	Do.
	2	1.25	160	20.5	165	165	0.9	110	Do.
	2	1.75	164	20.5	164	160	0.9	110	Do.
10/30	3	0	----------	----------	----------	----------	4.5	0	Do.
	3	0.25	173	20.5	170	156	3.0	110	Do.
	3	0.50	173	20.5	168	161	2.0	110	Do.
	3	0.75	173	20.5	168	161	1.3	110	Do.
	3	1.0	168	20.5	167	160	1.0	110	Do.
	3	1.25	168	20.5	170	167	0.8	110	Do.
	3	1.75	169	20.5	165	168	0.8	110	Do.
10/30	4	0	----------	----------	----------	----------	3.9	----------	
	4	0.25	160	51.5	167	135	2.9	110	Disch. air visually saturated.
	4	0.5	175	51.5	170	158	1.5	110	Do.
	4	1.0	170	29.4	170	168	1.0	110	Disch. air not saturated.
	4	1.5	170	29.4	178	167	0.8	110	Do.

The drying systems of this invention dry with high effectiveness and without degradation or discoloration such heat sensitive materials as vinyl acetate copolymers, polyvinyl chloride and ABS polymers. One unexpected advantage of these drying systems is the fact that they require only one-fifth of the quantities of drying air normally required in conventional, continuous, direct rotary dryers.

While the objects of the invention are efficiently achieved by the preferred forms of the invention described in the foregoing specification, the invention also includes changes and variations falling within and between the definitions of the following claims.

We claim:

1. Drying apparatus for removing moisture from particulate material comprising in combination

(A) particulate material feed means,

(B) elongated, open-ended drying tube means surrounded by a heating jacket, having

(1) an effective cross-sectional area A,

(2) an input end, and

(3) a delivery end,

(C) a residence chamber surrounded by a heating jacket, having

(1) an entrance port centrally positioned in the lower portion thereof and connected to the tube delivery end, and

(2) an exit portal,

(D) a blower operatively connected to draw gas through the heated tube means and the residence chamber,

(E) and a separator operatively connected to separate particulate material from the gas drawn through the tube means and the residence chamber by the blower,

(F) with the residence chamber having an effective cross-sectional area substantially greater than A, producing abrupt deceleration of the gas delivered thereto through the entrance port and turbulent fluidizing agitation of the particulate material throughout its residence in the residence chamber by the gas drawn therethrough by the blower,

(G) with the feed means including a feed distributor incorporating

(1) a vertical-elongated housing,

(2) a spaced plurality of perforated, horizontal transverse screens spanning the housing, all having aligned central apertures, and all arrayed from near the top to near the bottom of the housing, with successively diminishing mesh sizes,

(3) a rotatable power-driven drive shaft extending vertically through the aligned central apertures in the screens, and

(4) at least one transverse sifter blade anchored to the shaft above each screen to agitate material entrapped thereon.

2. The apparatus defined in claim **1** wherein the separator is connected to deliver partially dried material to a diffusion dryer surrounded by a heating jacket and having a central, open-ended, double-walled, heated draft tube surrounding a power-driver helical impeller, whereby the particulate material is propelled longitudinally through the draft tube and recirculated outside the draft tube for repeated circulating movement within the diffusion dryer.

3. The apparatus defined in claim **2** wherein the diffusion dryer includes an inner chamber having a converging lower end with a dried material product port formed therein.

4. The apparatus defined in claim **2** wherein the dif-

fusion dryer is provided with means forming a purge air inlet entering through its lower end, and means forming an air outlet in its upper end.

References Cited by the Examiner

UNITED STATES PATENTS

1,766,843	6/1930	Soderlund et al.	34—10
2,293,728	8/1942	Freund	34—10 X
2,465,963	3/1949	Beardslee	34—10
2,853,241	9/1958	Gindoff et al.	34—57
3,068,584	12/1962	Schaub et al.	34—57 X
3,078,588	2/1963	Mark	34—57
3,145,019	8/1964	Clute	263—21

FREDERICK L. MATTESON JR., *Primary Examiner.*

D. A. TAMBURRO, *Assistant Examiner.*