

**Aug. 9, 1966**

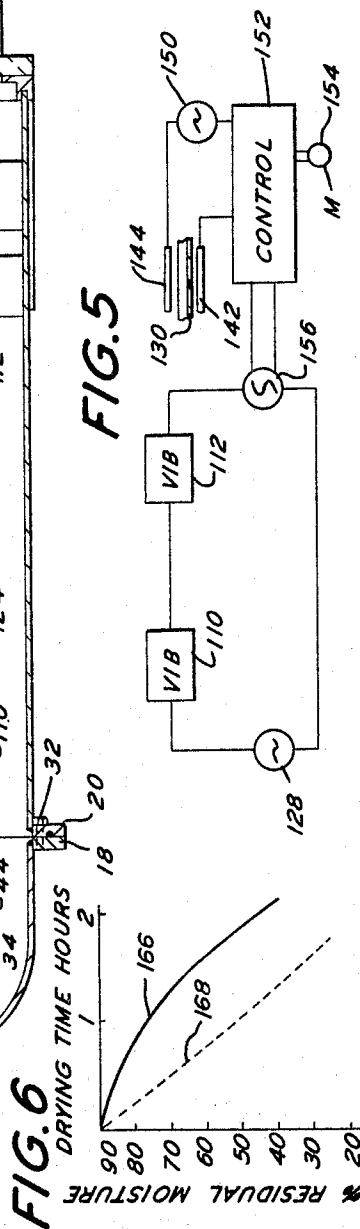
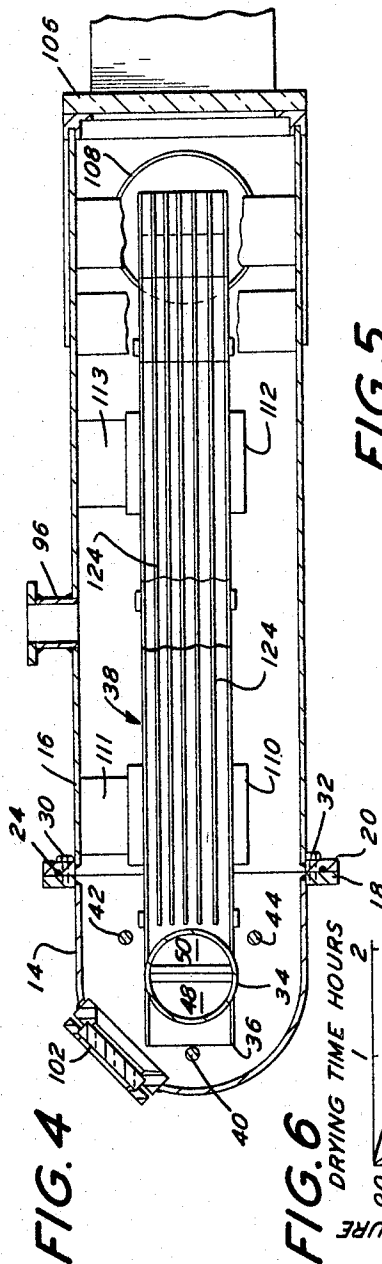
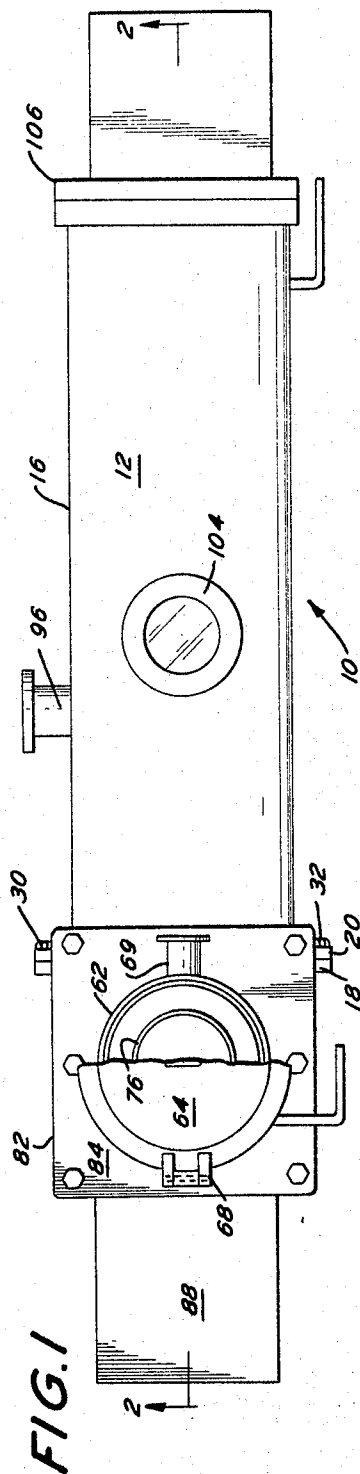
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**3,264,747**

# METHOD AND APPARATUS FOR CONTINUOUS FREEZE DRYING

Filed May 13, 1964

2 Sheets-Sheet 1



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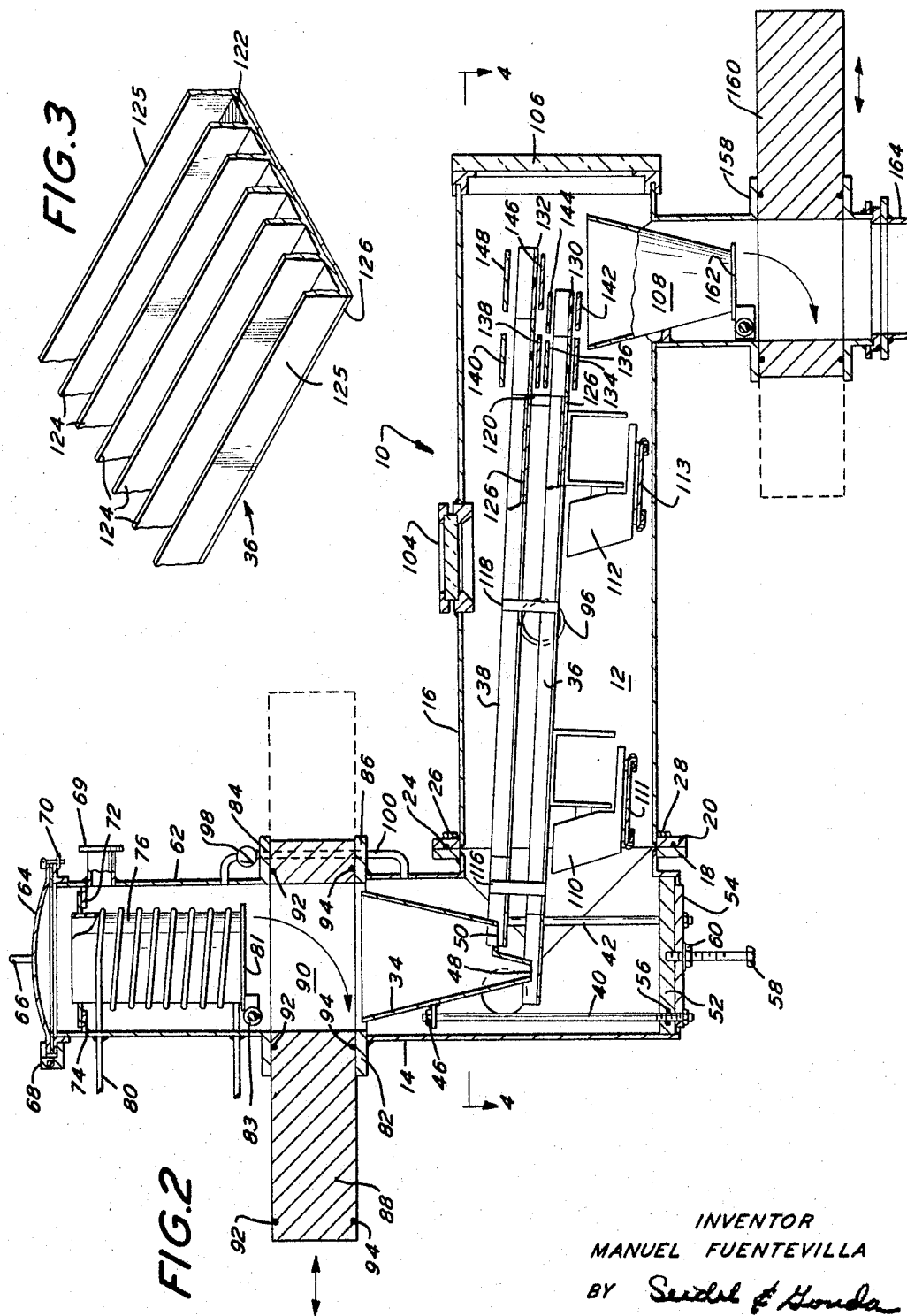
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METHOD AND APPARATUS FOR CONTINUOUS FREEZE DRYING

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2 Sheets-Sheet 2



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## 3,264,747 METHOD AND APPARATUS FOR CONTINUOUS FREEZE DRYING

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This invention relates to an apparatus and method for drying aqueous materials. More particularly, this invention relates to an apparatus and method for continuously freeze drying aqueous materials.

Heretofore, it has been conventional in the art relating to freeze drying of aqueous materials to freeze dry the aqueous material while it lies in a static position. That is, freeze drying apparatus was provided and trays or containers of the product or material to be dried were placed in a housing. At the completion of the freeze drying process the trays or containers were removed and new trays or containers placed in the apparatus. Such apparatus suffers from several disadvantages.

Freeze drying of material in a static position requires excessive handling of material. The apparatus must be intermittently opened for entry in order to remove the trays or containers. This necessitates that the apparatus be completely re-evacuated each time new material is placed therein, with a consequent loss of time and additional expense. A further disadvantage of prior apparatus is the overheating of the portion of the material closest to the heating apparatus, resulting in a "toasting" of the outer surface. Another disadvantage is that in prior methods and apparatus the rate of drying cannot be increased beyond a given point without overheating the material being dried.

The method and apparatus of the present invention overcomes the disadvantages of the prior art by providing a freeze drying method and apparatus which continuously freeze dries aqueous materials in a non-static manner. By the phrase "continuous freeze drying" it is meant that the material to be dried is fed into the apparatus at one position thereon and removed from the apparatus at another position in a continuous manner.

In one embodiment of the present invention the material to be freeze dried is fed into the drying apparatus from a hopper which is concomitant with a supply of the material and a vacuum lock. The hopper feeds the aqueous material onto a tray or holder which is vibrated to cause the material to move from the hopper to an exit position, whereat it is discharged from the drying apparatus. While the material is being transported from its entry to its exit position one or more drying processes may be applied to it.

As is well known to those skilled in the art, freeze drying is the process of subjecting frozen aqueous materials to an evacuated atmosphere and controlled elevated temperatures for a length of time sufficient to sublime the moisture in the frozen material. The method and apparatus disclosed herein may also be applicable for vacuum drying. Vacuum drying is the process of subjecting aqueous material to a reduced pressure and a temperature above room temperature.

The present invention may be used to freeze dry a wide variety of aqueous materials. The present invention may be utilized to freeze dry foodstuff, biologicals, and pharmaceuticals such as coffee, milk, blood, food extracts etc. The advantage in freeze drying is that it permits the products to be stored almost indefinitely without refrigeration. Food products processed in this manner exhibit substantially no impairment or loss of flavor, vitamin content, quality etc.

It is an object of this invention to provide a novel method and apparatus for drying aqueous materials.

It is another object of this invention to provide a novel freeze drying apparatus of the type that operates continuously.

It is another object of this invention to provide a novel method of drying aqueous materials.

It is another object of this invention to provide a novel method of freeze drying which includes more than one type of freeze drying process, and an apparatus therefor.

It is still another object of this invention to provide a novel method for continuous freeze drying that is more efficient and has a higher time rate of drying.

It is yet another object of this invention to provide a novel continuous drying apparatus which controls the rate at which material to be dried is transported through the apparatus according to the moisture content of such material.

It is another object of this invention to provide a novel continuous freeze drying apparatus in which each particle of the material to be dried is uniformly heated.

It is another object of this invention to provide a continuous freeze drying apparatus with a novel means of transporting the material through said apparatus.

Other objects will appear hereinafter.

For the purpose of illustrating the invention, there is shown in the drawings a form which is presently preferred; it being understood, however, that this invention is not limited to the precise arrangements and instrumentalities shown.

FIGURE 1 is a top view of apparatus for performing the freeze drying process of the present invention.

FIGURE 2 is a sectional view of the apparatus shown in FIGURE 1, taken along the line 2-2.

FIGURE 3 is a partial prospective view of a material carrying tray.

FIGURE 4 is a sectional view of the apparatus shown in FIGURE 2, taken along the line 4-4.

FIGURE 5 is a schematic diagram showing the control circuit of the freeze drying apparatus of the present invention.

FIGURE 6 is a graph comparing a part of the freeze drying process of the present invention to prior freeze drying processes.

Referring now to the drawing, wherein like numerals indicate like elements, there is shown in FIGURES 1-3 a continuous freeze drier designated generally as 10.

The freeze drier 10 comprises an L-shaped housing 12 including an end housing 14 and a main housing 16. As shown, end housing 14 and main housing 16 are joined in open communication with each other. End housing 14 is hermetically joined to main housing 16 by means of flanges 18 and 20 held together by fastener means such as bolts 26-32. A seal 24 extends around the periphery of said housings 14 and 16 between flanges 18 and 20 to assure that a hermetic seal has been provided.

A hopper 34 is adjustably supported in end housing 14 above a pair of material carriers 36 and 38. As shown, hopper 34 is provided with a pair of outlets 48 and 50 spaced above material carriers 36 and 38 so as to deposit thereon aqueous materials which may be fed into hopper 34. Rods 40-44 adjustably support hopper 34. As shown, rod 40 is bolted to tab 46 which is attached to the side of hopper 34. Rods 42 and 44 are similarly connected to hopper 34.

Rods 40-44 extend through the bottom wall 52 in end housing 14 and are bolted or otherwise attached to a plate 54. A seal 56 is provided around each rod 40-44 to assure that end housing 14 remains hermetically sealed. A bolt 58 extends through plate 54 and threadably engages

bottom wall 52. An adjustable nut 60 is threaded onto bolt 58 and supports plate 54. By adjusting the position of the nut 60 on bolt 58 plate 54 is moved away from or closer to bottom wall 52. Thus, adjustment of plate 54 results in the adjustment of the vertical position of hopper 34 above material carriers 36 and 38.

A vacuum lock 62 is spaced above end housing 14. The lid 64 with handle 66 thereon is pivotably attached to the top of lock 62 by means of a hinge 68. Latch 70 is provided to hold lid 64 in hermetic sealing relation with lock 62. An outlet 69 connected to a vacuum pump (not shown) is provided in lock 62. By means of a vacuum pump and outlet 69 lock 62 may be evacuated.

A refrigeration chamber 76 is supported within lock 62. The means of supporting refrigeration chamber 76 comprises a pair of supports dependent from the wall of lock 62 and a flange 78, integral with refrigeration chamber 76, resting on support 72 and 74. A low temperature is maintained within chamber 76 by means of a refrigeration coil 80 through which is pumped a coolant. The coolant pumping means is not shown.

The purpose of refrigeration chamber 76 is to retain the material to be dried in a frozen condition prior to its insertion into housing 12. The material to be dried is placed in refrigeration chamber 76 in a frozen condition by opening lid 64 and loading the material through the top of vacuum lock 62. A bottom door 81 is pivotably mounted on chamber 76 by means of hinge 83. When bottom door 81 is open material held in chamber 76 will drop into hopper 34.

Vacuum lock 62 is isolated from end housing 14 by means of a slide valve 82. As shown, slide valve 82 comprises a valve chest defined by a top wall 84, bottom wall 86 and side walls (not shown). A slide mechanism 88 moves in and out of the valve chest in hermetic sealing engagement with top wall 84 and bottom wall 86. When slide mechanism 88 is in its outer position it aligns an aperture 90 with vacuum lock 62 and end housing 14, thus allowing said lock and housing 14 to openly communicate with each other. In its inward position (shown in phantom) slide mechanism 88 sealingly isolates housing 14 from lock 62. Seals 92 and 94 assure that end housing 14 and lock 62 remain hermetically sealed.

In operation, housing 12 would be evacuated by means of a pump (not shown) connect to outlet 96. This is done with slide mechanism 88 in its inward or closed position. Lid 64 is then open and frozen material, preferably in particulate or granular form, is placed into refrigeration chamber 76. Lid 64 is then closed and sealed by means of latch 70. Vacuum lock 62 is exhausted through outlet 69 until it is at a pressure equal to that in housing 12. The pressure in lock 62 can be made exactly equal to that in housing 12 by opening valve 98 in equalizing line 100.

After the pressure in lock 62 has been made equal to the pressure in housing 12, slide mechanism 88 is moved to its outer or open position, bottom door 81 is open and material to be dried is dropped into hopper 34. Bottom door 81 may then be closed, slide mechanism 88 moved to its closed position, lid 64 opened and a new charge of material to be dried placed in refrigeration chamber 76. It should be noted that by using the persent lock system for inserting material to be dried into the housing 12 it is only necessary to evacuate a lock 76 each time a new charge of material is required. Said lock 76 has a much smaller volume than housing 12 and it takes considerably less time to evacuate. It should also be noted that by using the locking means herein described, hopper 34 may be kept filled. It is desirable to maintain the level of the material in hopper 34 above a predetermined point. This may be accomplished by a level switch on hopper 34, which switch can actuate an audible or visual indicator or can automatically control the entire lock feed mechanism. Thus, material will be fed to material carriers 36 and 38 without interruption.

Observation windows 102 and 104 are provided in end housing 14 and main housing 16, respectively. Similarly a large observation window 106 is provided at the end of main housing 16. By means of observation windows 102-106 the drying process may be observed and adjustment made if necessary.

The aqueous material to be dried is deposited by hopper 34 on material carriers 36 and 38. As best shown in FIGURES 2 and 4, material carriers 36 and 38 comprise elongated trays extending from a position with one end under hopper 34 to a position with the opposite end overlying discharge hopper 108. Material carrier 36 is mounted on a pair of vibrators 110 and 112 which are supported by means of supports 111 and 113 depending from a side wall of housing 12. Material carrier 38 is rigidly fixed above material carrier 36 by means of struts 116-120. Thus when vibrators 110 and 112 vibrate material carrier 36, material carrier 38 is also vibrated.

As best shown in FIGURE 3, material carrier 36, which is similar to material carrier 38, comprises a bottom plate 122 upon which are supported a plurality of upright members 124 and a pair of side walls 125. Bottom plate 122 together with an upright member 124 and side walls 125 provide the material carrier with a plurality of channels. As shown in FIGURE 4, upright member 124 did not extend the entire length of the material carriers 36 and 38. Rather, they extend only as far as the outer periphery of the top of the hopper 34. This permits the material to distribute itself evenly across the width of material carriers 36 and 38 before it is vibrated into the channelized section.

The materials carriers 36 and 38 are made of a heat conducting metal such as extruded aluminum. However, if desired an end portion 130 of said carrier adjacent to discharge hopper 108 may be made of an electrically non-conducting material such as Plexiglas. The heating of the metal portion of material carriers 36 and 38 is provided by any one of a number of means. In particular, the bottom plate 122 is heated by means of heater 126 which is an electrically resistive material through which electrical current is passed. Upright members 124 are heated by conduction from bottom plate 122. In this manner aqueous material lying on carriers 36 and 38 is heated by both radiant heat energy emanating from the carrier and by conduction where said material contacts the carrier. Upright members 124 serve to evenly distribute the heat to all surfaces of the material.

An alternative method of heating the material would be to form tubes in bottom plate 122 and circulate hot water therethrough and/or provide a heated surface mounted above carriers 36 and 38 radiating heat downwardly onto the material.

Vibrators 110 and 112 transduce an alternating electrical current from A.C. source 128 into vibratory motion. Vibratory transducers of this type are known. One such device suitable for use with the dryer apparatus of the present invention is the Syntron Vibrator. The Syntron Vibrator is one of the type that moves rapidly in one direction and then withdraws much more slowly in the opposite direction, thus applying a jerking type motion to the body which it vibrates. Vibrators 110 and 112 vibrate material carriers 36 and 38 in a direction parallel to their longitudinal axis. This in turn, agitates material being dried and causes it to move from the position where hopper 34 deposits it on carriers 36 and 38 to the opposite end, where it falls off into discharge hopper 108. It should also be noted that vibrators 110 and 112 may also be of the type which applies a uniform vibratory action to the carriers 36 and 38. If a uniform vibratory action is used then a downward slope, such as shown in FIGURE 2, is one orientation which may be provided for the carriers 36 and 38.

It will be appreciated that other types of vibrators, such as mechanical or pneumatic types, may be used. The motion transmitted by the vibrators to the trays

and product may also impart simultaneously a uniform vibrating action and forward transporting movement by altering the primary direction of axis upon which the vibrator acts wherein a vector of the vibrating force is directed at right angles to the transport direction.

As indicated above, an end portion 130 and 132 each of the material carriers 36 and 38 may be made of an electrically non-conducting material. Spaced on either side of end portions 130 and 132 are radiating plates 134-140 forming the electrodes of a pair of micro wave generators. The microwaves generated thereby have the property of penetrating the material being heated and causing the frozen particles in the center thereof to sublime without heating the portion of the material from which the ice has already sublimed. The use of micro-wave generators are not absolutely necessary to the present invention, but they do result in advantages and utility which will be explained in more detail below.

Adjacent the end of material carriers 36 and 38 are two pairs of capacitance plates 142-148. Said capacitance plates 142-148 form a part of a moisture sensing device. As shown in FIGURE 5, plates 142 and 144 are connected to a source of alternating current 150 through a control device 152. Capacitance plates 142 and 148 together with non-conducting end portion 130 of carrier 36 and the material carried thereon from an electrical capacitor. End portion 130 and the material thereon are a part of the capacitor dielectric.

As is well known, the dielectric constant of a capacitor determines the capacitor's capacitance, and the capacitance in turn determines the capacitive reactance of an alternating current circuit. Using this principle it becomes possible to measure the moisture content of the material. That is, if all other parameters in the circuit are maintained constant and the moisture content of the material varies from a preset amount or zero it will measurably effect the dielectric value of the capacitor. This in turn will be indicated by a change in the capacitive reactance of the circuit which can be measured either as a change in the value of the A.C. current or a change in the voltage drop. Meter 154 in FIGURE 5 is calibrated to indicate the moisture content of the material after it has been dried.

As indicated above, a control device 152 is connected in the measuring circuit. Control device 152 is also connected to a switch 156, which may be a relay or similar device. Control device 152 is adapted to perform two functions. First, it is a timer to periodically actuate switch 156 thus closing the electrical circuit to vibrators 110 and 112. Second, it responds to variations in the moisture content of the material, as measured by changes in the capacitor's reactance.

In operation, when the moisture content of the material passing between capacitor plates 142-148 is within a prescribed range, control device 152 will merely periodically actuate vibrators 110 and 112 to cause material to be transported along carriers 36 and 38 at a rate sufficient to obtain the prescribed moisture content. For example, vibrators 110 and 112 may be turned on for 10 seconds every 30 seconds. However, if the moisture content of the material should rise above or fall below the prescribed range as indicated by changes in the capacitive reactance of the measuring circuit, then control devices 152 will either increase or decrease the periodical rate which vibrators 110 and 112 are turned on and off or change the intensity of vibration.

After the material has been dried it falls off the carriers 36 and 38 into discharge hopper 108. When the hopper is sufficiently filled, as may be observed through window 106, valve 158 is open by sliding slide mechanism 160 from the position shown in phantom in FIGURE 2 to the position shown in solid. Then bottom door 162 in hopper 108 is opened and the material is dropped into a vacuum lock which has previously been exhausted. The valve 158 need not be described in de-

tail, as it is similar to valve 82. The same is true of vacuum lock 164, except it does not have a refrigerated chamber therein.

The dryer apparatus 10 is utilized as follows:

The dryer apparatus may be utilized as a vacuum drying apparatus or as a freeze drying apparatus. For purposes of illustration the description hereinafter will be directed to use of the dryer 10 for freeze drying material. Material to be freeze dried is preferably in powder or granular form and in a frozen state. In this frozen state, the material to be freeze dried is placed in a vacuum lock 62 where it is retained in its frozen condition by refrigeration chamber 76. From there it is inserted onto carriers 36 and 38 by the method already explained. As the freeze drying process commences slide mechanisms 88 and 160 will be in their phantom position, although this is not necessary if the vacuum lock 76 and 164 are at the same pressure as housing 12.

When housing 12 is evacuated to the correct low pressure, a control means is actuated to cause heater 126 to heat carriers 36 and 38. Carriers 36 and 38 will begin to radiate heat into the channel areas. Vibrators 110 and 112 are actuated and the material begins to move from its position beneath hopper 34 toward hopper 108. As indicated above, hoppers 110 and 112 operate periodically rather than continuously. The period of operation is adjusted so as to subject the material to be freeze dried to a reduced pressure in an elevated temperature for a controlled period of time. The actual period of time can be determined by those skilled in the art. The material is vibrated through the channels in carriers 36 and 38, and as a result of the reduced pressure and the elevated temperature, the ice in the frozen material is caused to sublime. The resultant moisture is drawn from the housing 12 through outlet 96 where it is condensed by a condenser (not shown).

The vibration of carriers 36 and 38 performs a function other than that of causing the material to move therealong. The vibration of carriers 36 and 38 also has a stirring action on the material. The advantage of this is that each particle of the material will come into contact with the heated surfaces of the carriers to thus improve heat transfer characteristics. An additional advantage is that each particle will, on the average, come into contact with the same amount of heating surface. Therefore, good uniformity of heating will result and no particle will be subjected to "toasting" which is one of the problems in static freeze drying apparatus.

A further advantage in the use of vibratory action is that it results in a reduction of the time required to dry quantity of material. This is best illustrated by referring to FIGURE 6, wherein a portion of the drying cycle is graphically illustrated. The graph plots percent of residual moisture versus drying time in hours. The solid line 166 represents a freeze drying process using a static tray to retain the material. The dotted line 168 represents the same freeze drying process using a vibratory action on the tray retaining the material. As is clearly illustrated the drying time using the vibratory action on the trays is much faster during the first part of the drying cycle. It should also be noted that the vibratory action permits the use of higher temperatures without burning or "toasting" the outer surfaces of the material.

It has been found that the rate of water removal from the aqueous material being dried is limited by the ability to transfer heat through the dried outer portion of a freeze dried product. Thus, a point is reached where heat must be transferred through a relatively large amount of outer material to reach an inner ice boundary which may be no larger than a few microns. Accordingly, a relatively large amount of heat is required to sublime a small amount of water. This in turn will explain the fact that beyond a certain point the rate of drying using vibration methods is about equal to that using static methods. This phenomenon is best seen by observing

that in the graph in FIGURE 6 the solid line and dotted line have the same slope at the end of about 1 3/4 hours.

It is found that the rate of drawing may be increased if microwave heating is used to sublime the last remnant of moisture. The advantage of microwave heating is that it puts the heat directly into the ice. Thus, heat transfer problems are avoided and the drying time is reduced without overheating the material, as would happen if the temperature of the radiating heat were raised. It has also been found that the use of microwave heat at the beginning of the freeze drying cycle offers no particular advantages over the radiation or contact heating. Radiation or contact heating is just as fast and substantially less expensive and easier to control.

Accordingly, it has been found that microwave heating may be used to its best advantage by applying it at the end of the drying cycle. Thus, when the material being dried reaches the non-metallic end portion 130 of carriers 36 and 38 it passes between electrodes 134-140. The electrodes are connected to a high frequency microwave generator. A high frequency electric field generated between the electrodes and microwave heating is induced in the remaining ice particles in the aqueous material. By using microwave heating at the end of the drying process the final few percent of moisture is taken out of the material in a matter of minutes as opposed to an hour or more if radiation or contact heating is used.

In one example the apparatus was loaded with a quantity of diced carrots and the drying cycle was commenced without activating the microwave heating means. At the end of 3 hours the carrots were removed from the discharge hopper 108. Tests showed a residual moisture content of 2%. The same quantity of diced carrots was freeze dried in a static freeze dryer not using vibration or microwave heating but with all other factors the same. In this case it took 4 hours to produce a freeze dried product with a 2% residual moisture content. Thus there was a 25% increase in the rate at which material can be freeze dried using apparatus and method disclosed herein. Other materials were tested, and equivalent or larger increases in the rate of drying resulted. Thus, a 50% increase was obtained when the product was coffee extract. When microwave heating is used at the terminal part of the cycle, greater increases are attained.

It is not necessary that a moisture sensing means activate only the vibrator as described. It may act as a control mechanism by adjusting the temperature of the heating means if desired. Also, it may control both the vibrator and heating means simultaneously to achieve optimum drying. If desired, the vibrators may operate independently of the moisture control means.

The present invention may be embodied in other specific forms without departing from the spirit or essential attributes thereof and, accordingly, reference should be made to the appended claims, rather than to the foregoing specification as indicating the scope of the invention.

#### I claim:

1. A drying apparatus comprising a housing, selectively operable means disposed adjacent opposite ends of said housing for inserting materials to be dried into said housing adjacent one end thereof and removing said materials adjacent the opposite end, material carrying means within said housing for carrying the material to be dried, said carrying means being disposed with opposite ends thereof in communication with said selectively operable means, means within said housing to heat the material to be dried, means operatively associated with said housing to reduce the pressure within said housing, vibration means for vibrating said material carrying means so that said material is caused to move from said selectively operable material inserting means to said selectively operable material removing means.

2. A drying apparatus in accordance with claim 1 wherein said vibrating means includes means for sensing the moisture content of the material to be dried and

developing an output signal proportional to the amount of the moisture content, and control means for varying the amount of time said carrying means is vibrated in accordance with said output signal.

3. Apparatus in accordance with claim 1 wherein said means within said housing to heat the material to be dried includes a microwave heater adjacent the end of said carrying means closest to said selectively operable material removing means.

4. Apparatus in accordance with claim 1 wherein said carrying means comprises a plurality of elongated trays disposed one above the other, said trays being longitudinally displaced relative to each other so that the ends thereof directly communicate with said selectively operable means, and means for rigidly attaching said trays to each other, whereby vibration of one of said trays causes all of said trays to vibrate.

5. A drying apparatus comprising a housing, a selectively operable means adjacent one end of said housing for providing for the selective introduction of a frozen material into said housing, a selectively operable means adjacent the opposite end of said housing for the discharge of said material from said housing, material carrying means within said housing, said carrying means disposed in open communication with each of said selectively operable means, vibration means for vibrating said material carrying means so that said material is caused to move from said end in communication with said selectively operable frozen material introducing means to the end in communication with said selectively operable means for the discharge of material, means for reducing the pressure within said housing, radiant heating means adjacent said material carrying means for heating said frozen material and microwave heating means juxtaposed the end of said material carrying means in communication with said selectively operable material discharge means for heating said material with microwave heat energy.

6. Apparatus in accordance with claim 5 wherein said material carrying means comprises a plurality of elongated trays disposed one above the other, said trays being longitudinally displaced relative to each other so that the ends thereof directly communicate with said selectively operable means, and means for attaching said trays to each other, whereby vibration of one of said trays causes all of said trays to vibrate.

7. Apparatus in accordance with claim 6 wherein each of said trays comprises a bottom plate and a plurality of upright members forming a plurality of heat radiating channels.

8. Apparatus in accordance with claim 7 wherein the portion of said bottom plate adjacent said radiant heating means is made of metal, and the portion of said bottom plate juxtaposed said microwave heating means is made of an electrically non-conductive material.

9. Apparatus in accordance with claim 5 wherein said vibrating means includes a device for transducing electrical energy into mechanical vibratory energy, said device being mechanically coupled to said material carrying means, a moisture detecting means for detecting moisture content of the frozen material and producing an electrical signal proportional to said moisture content, and control means electrically coupled to said vibrating means and said sensing means, whereby said control means varies the amount of time said vibrating means vibrates said material carrying means in accordance with the moisture content of said frozen material.

10. Apparatus in accordance with claim 5 wherein said selectively operable means for introducing material into said housing comprises a hopper means disposed above said material carrying means, a vacuum lock communicating with said housing above the hopper means, a refrigerated material holding chamber within said lock disposed above said hopper means, a bottom wall means on said refrigerated material holding chamber providing for the selective discharge of frozen material from said

chamber means into said hopper means, and a valve means above said hopper means for hermetically sealing said lock from said housing.

11. Apparatus in accordance with claim 5 wherein said selectively operable means for the discharge of material from said housing comprises a discharging hopper means disposed below the end of said carrying means communicating with said selectively operable means for material discharge, a vacuum lock communicating with said housing juxtaposed below said discharging hopper means, and selectively operable valve means for hermetically-sealing said vacuum lock from said housing.

12. A drying apparatus comprising a housing, a first selectively operable means adjacent an end of said housing for the introduction of a frozen product to be dried into said housing, a second selectively operable means adjacent an end of said housing for the discharge of the product from said housing, material carrying means within said housing for carrying the product to be dried, the ends of said carrying means disposed in communication with said first and second selectively operable means respectively, vibration means for intermittently vibrating said material carrying means so that the product is transported on said carrying means from said first selectively operable means to said second selecting operable means, means for reducing the pressure within said housing, and microwave heating means adjacent the end of said material carrying means in communication with said second selectively operable means for heating the product.

13. A drying apparatus in accordance with claim 12 wherein said carrying means comprises a pair of elongated trays disposed in substantially parallel relation, said trays being longitudinally displaced relative to each other so that the ends thereof directly communicate with said first and second selectively operable means, and means for rigidly attaching said trays to each other whereby vibration of one of said trays causes the other of said trays to vibrate.

14. A method of drying material containing moisture comprising the steps of introducing said material to a zone of sub-atmospheric pressure, supporting the material in narrow elongate channels having heat conductive surfaces, raising the temperature of said material, and vibrating said material to move said material along the channels through said zone, whereby the moisture content of said material is reduced to a small amount of residual moisture.

15. A method of drying aqueous materials in accordance with claim 14 wherein the aqueous material is first frozen and then introduced into the zone.

16. A drying apparatus comprising a housing, selectively operable means disposed adjacent an end of said housing for inserting material to be dried into said housing and selectively operable means adjacent an end of said housing for removing said materials from said housing, elongated tray means within said housing for carrying the material to be dried from said selectively operable material inserting means to said selectively operable ma-

terial moving means, said tray means comprising transversely spaced longitudinally extending upright members, opposite ends of said tray means being disposed in communication with said selectively operable means, heating means within said housing to heat the material to be dried, means operatively associated with said housing to reduce the pressure within said housing, and means in said housing for moving the material to be dried along said tray means so that the material is caused to move from said selectively operable material inserting means to said selectively operable material removing means.

17. Apparatus in accordance with claim 16 wherein said selectively operable means for inserting material to be dried into said housing comprises vacuum lock means communicating with said housing, a selectively operable valve means for hermetically sealing said vacuum lock means from said housing, and a hopper means within said housing disposed above one end of said tray means in open communication with said lock means, and means for adjusting the height of said hopper means above said tray means.

18. A method of drying material containing moisture comprising the steps of

- (a) introducing the material to be dried into a zone of reduced pressure,
- (b) raising the temperature of said material
- (c) vibrating said material,
- (d) removing moisture vapor from said zone,
- (e) heating said material by magnetic wave energy only during the terminal portion of the cycle at which time less than about 25% of the original moisture remains in the material,
- (f) terminating said heating by microwave energy when the residual moisture in the material is about 1-4%, and
- (g) removing the material from the zone.

19. A drying apparatus in accordance with claim 12 wherein said trays include a plurality of channels extending parallel to the longitudinal axis and defined by a plurality of spaced upright members.

20. A method of drying frozen material comprising the steps of introducing the frozen material to be dried to a zone of sub-atmospheric pressure, raising the temperature of said material, vibrating said material, moving the material past a source of microwave heat, and removing the material from the zone.

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