Oct. 11, 1966 G. TOOBY 3,277,580

METHOD AND APPARATUS FOR DRYING

Filed July 5, 1963 3 Sheets-Sheet 1

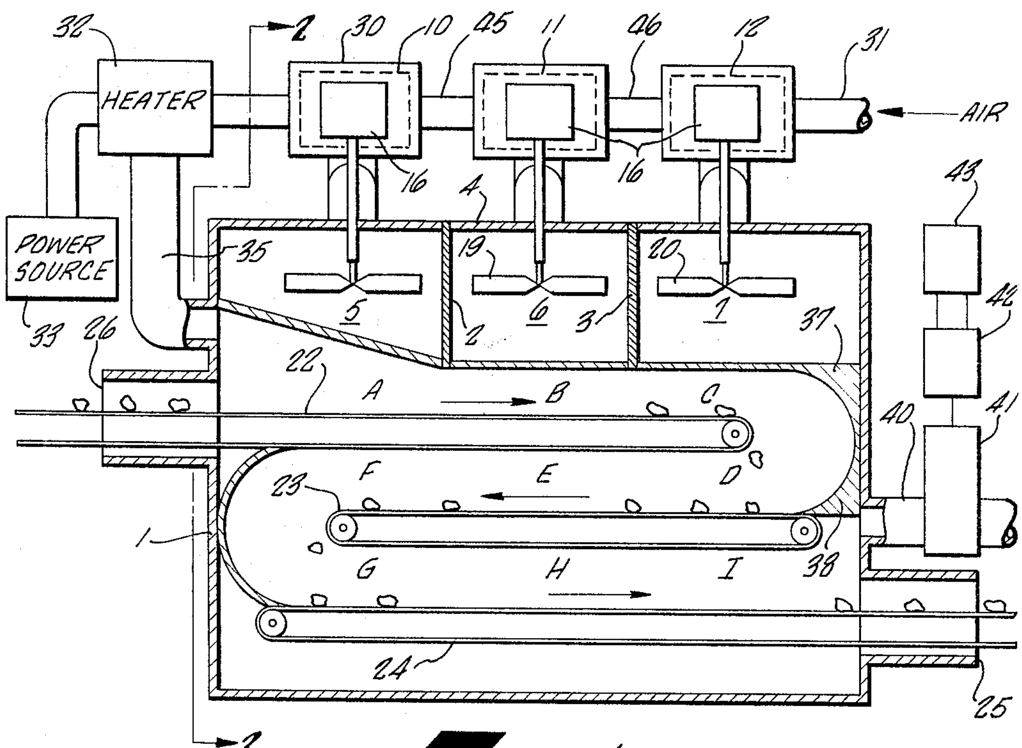

FIG. 1

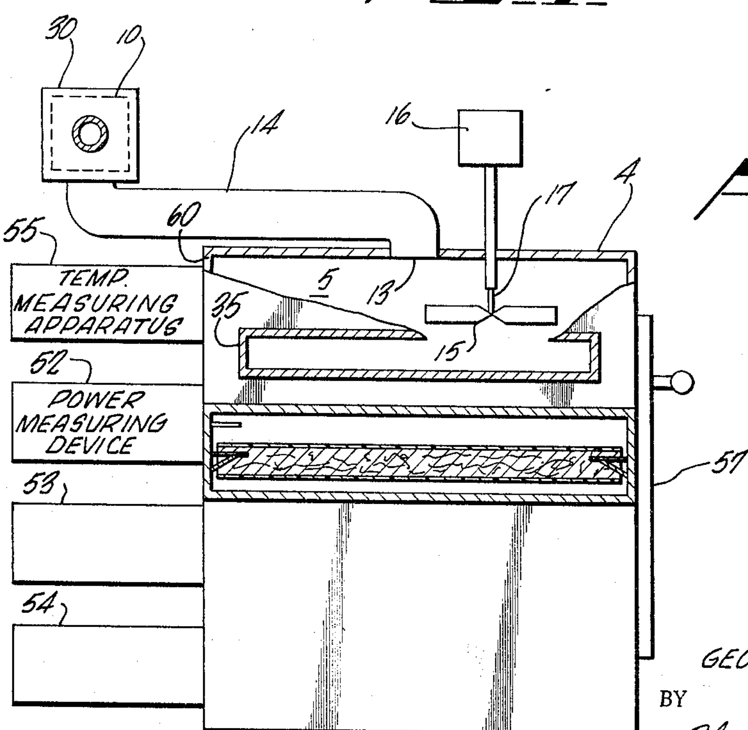

FIG. 2

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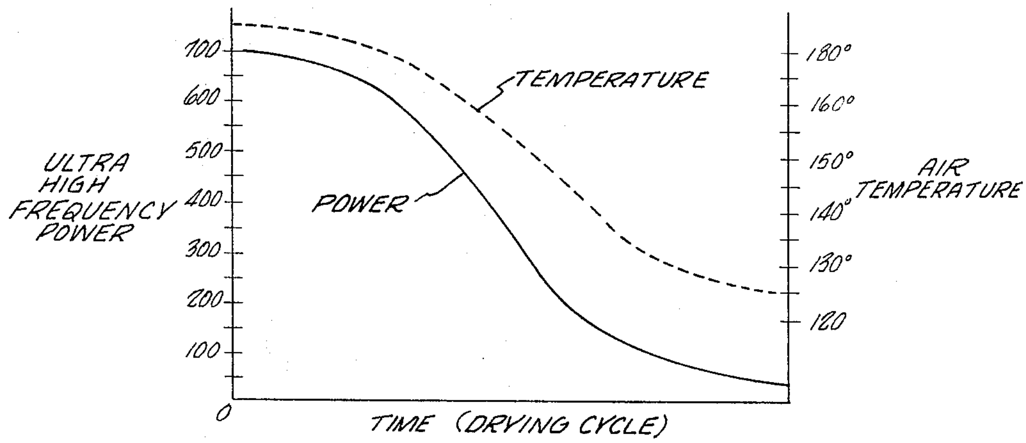

FIG. 3

SOURCE 10 OUTPUT = 1000 WATTS	SOURCE 11 OUTPUT = 750 WATTS	SOURCE 12 OUTPUT = 500 WATTS
ZONE A 700 WATTS (70%)	ZONE B 488 WATTS (65%)	ZONE C 250 WATTS (50%)
ZONE F 150 WATTS (15%)	ZONE E 187 WATTS (25%)	ZONE D 200 WATTS (40%)
ZONE G 150 WATTS (15%)	ZONE H 75 WATTS (10%)	ZONE I 50 WATTS (10%)

FIG. 4

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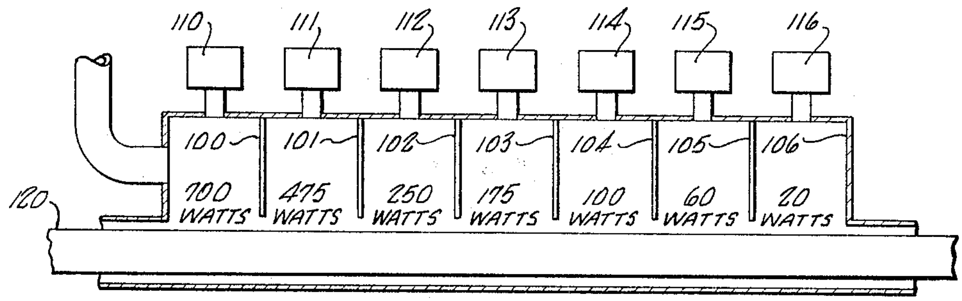

FIG. 5

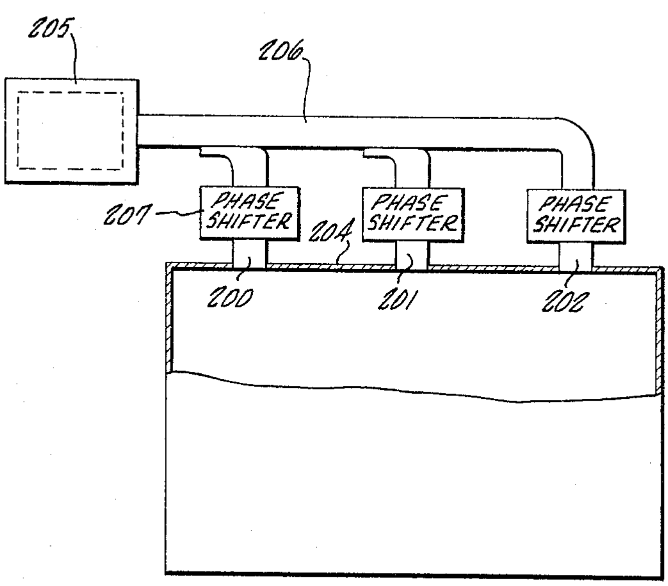

FIG. 6

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METHOD AND APPARATUS FOR DRYING

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9 Claims. (Cl. 34—1)

This invention relates to a method and apparatus for drying at ultrahigh frequencies and, more particularly, to a method and apparatus for drying a continuous supply of products in a short period of time.

Many drying processes are slow and wasteful of space because of the difficulty in supplying the heat of vaporization of the natural fluids or juices within the material. In ordinary oven drying, the drying progresses from the outer surfaces inward and the energy required to evaporate the moisture on the inside must be conducted through the outer portion. It has been found that when discrete pieces or chunks of materials to be dried, such as fruit, vegetables, or meat, are dried by conventional hot air processes, the final dried product has an outer shell which is hardened more than the rest of the product, and the product as a whole is wrinkled, shrunken, and tough. Also, materials and food products dried in this manner rehydrate very slowly and incompletely.

With the advent of radio frequency heating apparatus, a means of generating heat uniformly throughout a nonconducting mass was provided, and its use resulted in the rapid and uniform drying of many materials. Investigations in radio frequency heating included the dehydration of pharmaceutical products, foods, and even the cooking of foods. These investigations indicated that in the preparing of food pieces, bad electrical effects including burning resulted when the process was carried out at the conventional radio frequencies. Accordingly, developmental work was conducted to determine the optimum frequency relationships for transferring the heat energy to the food particles being processed.

One apparatus that is now employed comprises a single cavity or drying chamber similar to the modern ovens found in many homes. Like these ovens, the unitary or singular drying cavity will only dry individual baches of the product. Thus, the unitary apparatus is somewhat limited in the speed of drying or time to camplete a drying cycle and in the amount of product that may be dried at only one time. Additionally, as the product is dried the ultrahigh frequency energy must be decreased as drying proceeds to prevent burns from occuring on or in the product. Therefore, the sources of ultrahigh frequency energy can only be operated at peak efficiency for a small portion of the drying cycle with a resultant decrease in the overall efficiency of the operation.

In addition to the above undesirable characteristics and limitations of present drying apparatus, there is the possibility of non-uniformity of the ultrahigh frequency energy in the area of drying. Thus, some of the product pieces will be drier than others with the possibility of burns occuring.

The present invention provides a drying apparatus and method that overcomes the undesirable shortcomings of the prior art drying apparatus. The drying apparatus and method permits the sources of ultrahigh frequency energy to operate at optimum efficiency at all times. Additionally, the time required to complete a drying cycle is considerably reduced with less chance of ultrahigh frequency burns occurring because of nonuniform fields in the drying area. There is considerable flexibility present so that a large variety of different products may be efficiently dried by employing the same apparatus.

This invention provides a novel and improved method

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and apparatus for drying products in a continuous manner rather than on a batchwise scale. Structurally, the drying appaartus comprises a plurality of zones with each zone being energized by a source of ultrahigh frequency energy. The drying apparatus further comprises means for conveying the product to be dried through each zone in succession. A source of heated fluid is provided with a means for passing the heated fluid over the product as the product is conveyed through the plurality of zones.

The above and other features and advantages of the present invention will be understood more clearly and fully upon consideration of the following specification and drawing, in which:

FIG. 1 is a front elevation view of a drying apparatus, in accordance with the invention;

FIG. 2 is an end elevation view of the drying apparatus shown in FIG. 1;

FIG. 3 is a graphical representation of typical power levels and conveying fluid temperature to which the product is subjected during a drying cycle;

FIG. 4 is a chart of a typical power distribution in the drying zones of the apparatus shown in FIG. 1;

FIG. 5 is an alternative embodiment of the drying apparatus, in accordance with the invention; and

FIG. 6 is an end elevation view of a large drying apparatus, in accordance with the invention.

A preferred embodiment of the drying apparatus, as shown in FIG. 1, comprises a metallic casing **1** which defines a drying cabinet. The drying cabinet is separated into distinct cavities by metallic partitions or dividers **2** and **3**, which are attached to top wall **4** of the metallic casing **1**. The drying apparatus of FIG. 1 thus has 3 distinct cavities **5**, **6** and **7**. It is to be noted that the drying cabinet could be divided into any number of cavities as dictated by the requirements of the particular application. However, for illustrative purposes and for an understanding of the invention, the 3 cavities shown in FIG. 1 are sufficient and will be described in detail.

Each cavity or zone defined by the end walls and the partitions **2** and **3** are energized by separate sources of ultrahigh frequency energy. For example, cavity **5** is energized by a source of ultrahigh frequency energy **10**. Cavities **6** and **7** are energized by sources **11** and **12**, respectively. The ultrahigh frequency energy from source **10** enters cavity **5** through an aperture **13** in the top wall **4** of the metallic casing **1**. The coupling of the energy from source **10** to the cavity **5** may be seen more clearly in the end elevation view of FIG. 2.

The preferred embodiment, shown in FIGS. 1 and 2, provides the ability of mass production which is not possible in the unitary construction that is disclosed and claimed in my copending application Serial No. 262,143, filed March 1, 1963, and now Patent No. 3,235,971.

In FIG. 2, the aperture **13** is shown in the top wall **4**. This aperture is dimensioned in accordance with the frequency of the ultrahigh frequency energy from source **10** to provide the most advantageous coupling. The energy from source **10** is coupled to the cavity through aperture **13** by a wave guide **14**. The wave guide **14** is also dimensioned in accordance with the frequency of the energy from source **10**. Immediately below the aperture **13** in cavity **5** there is a fan or stirrer **15**, which is employed to break up the modes of the energy entering the cavity and to more uniformly distribute this energy over the area of the caivity **5**. The stirrer **15** is coupled to a motor **16** by a shaft **17**. The shaft **17** is comprised of a dielectric material, such as mylar or Teflon, so that it will be transparent to the ultrahigh frequency energy from source **10**. The fan or stirrer **15** is comprised of a metallic material to reflect the energy emitting from the aperture to more effectively break up the modes. The cavities 6 and 7 are similarly energized from sources 11 and 12, respectively. Stirrers 19 and 20 are positioned in these cavities for uniformly distributing the energy within the cavity.

The partitions 2 and 3 extend from the top wall 4 toward the top belt 22. There is only sufficient clearance between the partitions 2 and 3 and the belt 22 to permit the product to pass from one zone or cavity to the next. The product passing under the partitions aids in the prevention of cross coupling or radiation between the cavities, thus, the unabsorbed energy will pass to the next lower level rather than into an adjacent cavity.

The product to be dried is conveyed into the drying apparatus and through the successive cavities or zones by a belt 22. After the product has progressed through the first 3 individual zones, it reaches the termination of the belt 22 and falls down to a belt 23. Belt 23 runs in a direction that is countercurrent to the direction of belt 22 and reconveys the product back through the 3 cavities for further drying. When the product reaches the end of belt 23, it falls down to a belt 24, which carries the product back through the 3 cavities and out of the drying apparatus through an opening 25.

The belts 22, 23 and 24 are made of a material that is transparent to the ultrahigh frequency energy so that the ultrahigh frequency energy may be transmitted through the belts to the lower levels. For example, in cavity 5 the energy from source 10 enters the first zone A, where the majority of the energy is absorbed by the moist product, which enters the drying cabinet through opening 26. The remaining ultrahigh frequency energy passes through the transparent belt 22 into the next zone F. Another portion of the energy is absorbed by the product in zone F and the remaining portion passes through the transparent belt 23 to zone G, where it is absorbed by the product. Similarly, the energy from source 11 passes through zones B and E to zone H, the majority of the energy from source 11 being absorbed by the product in zone B, with the remaining portion being absorbed in zones E and H. Similarly, the energy from source 12 appears in zones C, D and I.

In ultrahigh frequency drying, the initial removal of moisture from the product can be carried out at a very high level of ultrahigh frequency energy. Thereafter, as the product becomes drier, it is required that the energy be reduced to prevent burning or overheating of the product. Thus, the ultrahigh frequency energy in zone A will be greater than the energy appearing in any of the other zones. It is desirable that the ultrahigh frequency energy in the successive zones A through I present a decreasing energy level in accordance with the requirement of less energy needed as the product becomes drier.

A typical power distribution over a drying cycle is shown in FIG. 3. When the product first enters the drying chamber, it is subjected to a large amount of ultrahigh frequency energy. This initial value is shown in FIG. 3 to be 700 watts. As the product becomes drier, the energy required decreases so that the ultrahigh frequency energy is reduced.

The power curve shown in FIG. 3 can be approximated in the drying apparatus of FIG. 1. A chart of typical power levels at the output of the sources 10, 11 and 12 and in the different zones is shown in FIG. 4. By adjusting the speed of the belts 22, 23 and 24 in the apparatus of FIG. 1, the drying cycle can be made to approximate that shown in FIG. 3. Thus, the most advantageous power distribution for each particular product may be attained by controlling the speed of the belts and the level of the ultrahigh frequency energy from the sources.

The amount of energy absorbed in each zone of the apparatus in FIG. 1 is shown for a typical operation in FIG. 4. This power distribution will vary for different products and different moisture contents.

In the prior art devices, which were of a unitary construction and employed a single source of ultrahigh frequency energy for supplying the drying energy for the product over the complete cycle of drying, the energy level had to be continually monitored and reduced as the product became dried. Therefore, the source of ultrahigh frequency energy was operated at peak efficiency for only a small portion of the drying cycle. On the other hand, by employing separate cavities and continually conveying the product through the plurality of zones defined by the cavities and levels of the belts, as shown in FIG. 1, the sources of ultrahigh frequency energy may, at all times, be operated at their point of peak efficiency. Additionally, in accordance with the invention, the deleterious effect of nonuniform distribution of ultrahigh frequency energy, possible in the prior art devices, is substantially reduced in the present drying apparatus. The product is continually changing position within the chamber by the conveying means so that it is not subjected for any extended period of time to any hot spot that might exist in the chamber.

The sources 10, 11 and 12 will generate a large amount of heat while operating in the region of peak efficiency. These sources of ultrahigh frequency energy are represented by blocks in FIG. 1. Each block includes an ultrahigh frequency tube, such as a klystron or a magnetron, and a source of power to activate the tube. The heat generated by both the tube and its power supply is advantageously utilized in accordance with this invention to preheat the fluid which is used for conveying from the drying cabinet the vapor that is produced during the drying process. Each source of energy is enclosed in a fluid duct, of which fluid duct 30 surrounding source 10 is typical.

The fluid employed, which may be the atmospheric or ambient air, enters a duct 31 and is conveyed through and around each source of ultrahigh frequency energy and is thereby preheated. The fluid is conveyed between each source of ultrahigh frequency energy by a duct 45 and a duct 46 provided for this purpose. As the fluid passes through and around each source, it is raised in temperature until it passes through source 10, where it is at a considerably higher temperature than when it first entered the duct 31. The preheated fluid is then conveyed through a heating means 32, wherein it is heated to its final drying cabinet temperature. The heating means 32 may comprise a conventional electric heater, such as an electrical resistance heater connected to a suitable source of power, shown by the block identified by the reference character 33. The fluid received at the heating means 32 is conveyed into the drying cabinet 1 by means of a duct 35 communicating with the heating means 32 and the drying cabinet 1. The fluid passes over the product being dried and through the zones in the same direction as the product is carried by the belts 22, 23 and 24.

The fluid enters the drying cabinet 1 at the left and passes through zones A, B and C and is deflected downwardly into zone B by a fillet 37 and a fillet 38. The fillets are constructed of a material that is transparent to the ultrahigh frequency energy. The fluid then passes from zone D to zone G over the product as it is conveyed by belt 23. The fluid is deflected downwardly from zone F to G and passes through zones G, H and I and is drawn out of the drying cabinet through duct 40 by an exhaust means 41. The exhaust means 41 may be a conventional fan powered by a separate motor 42, also connected to a separate power source 43.

In addition to the fillets for channelling the fluid through the zones, there is provided a covering at the bottom of each cavity 5, 6, and 7. The covering is in the form of a sheet 50 which is comprised of a material that is transparent to the ultrahigh frequency energy in the drying chamber. Additionally, the support for each belt provides a barrier to the fluid so that it will be channelled over the product for carrying away the expelled moisture rather than through the belts.

The described direction of fluid flow is not the only one possible in such a drying apparatus as shown in FIG. 1. For example, the fluid could be brought into the drying chamber at the bottom and exhausted at the top, or vice versa. However, the method shown in FIG. 1 is a preferred embodiment with the fluid being hottest as it enters the drying chamber and being extremely moisture laden as it is exhausted from the drying chamber. A typical curve for the temperature of the fluid is shown in FIG. 3.

Different products require different amounts of ultrahigh frequency energy and different temperatures of fluid for carrying off the evaporated or expelled moisture from the products. For example, fruits like apples and peaches require entirely different energy levels and temperature of fluid than do products like beef, potatoes or carrots or certain other products like wood, porcelain, or ceramic objects. However, all of the products absorb a large amount of energy when they are initially inserted into the drying cabinet because of the large amount of moisture contained therein. The amount of energy absorbed goes down very rapidly as the product becomes drier. This is shown in the graphical representation of the power loss curve in FIG. 3. Additionally, as the product becomes drier it is necessary to reduce the temperature of the air or fluid that is passing over the product and carrying away the vapor expelled from the product. Thus, it is seen in FIG. 3 that the temperature of the fluid also decreases in a manner similar to the decrease in the energy from the ultrahigh frequency sources.

Each product will have an optimum drying cycle. Therefore, the energy levels and temperature of the fluid will be programmed to meet the conditions of the product being dried. The energy level in each zone and the temperature of the fluid in each zone may be monitored by a device inserted into the zone. In FIG. 2 there are shown 3 power absorption measuring devices **52**, **53**, and **54** positioned on the back wall **60** at the 3 levels of zones A, F and G in cavity **5**. Additionally, there is provided a temperature measuring apparatus **55** in zone A for monitoring the temperature of the fluid. Thereafter, the outputs of the power absorption measuring apparatus and the temperature measuring apparatus may be monitored for the automatic programming of the proper conditions in each zone for the drying of the product therein.

The drying apparatus has a door associated with each cavity for the purposes of cleaning and maintenance. For example, in FIG. 2 there is shown a door **57** associated with cavity **5** and zones A, F and G. The door is provided with interlocks (not shown) to protect operating personnel. Additionally, there is an ultrahigh frequency shield surrounding the door to prevent any radiation.

An alternative embodiment of the drying apparatus, in accordance with the invention, is shown in FIG. 5. The drying apparatus in FIG. 5 is contained on one level rather than on a plurality of levels. The apparatus comprises a plurality of cavities defined by metallic partitions **100** through **105**. For illustrative purposes, the apparatus includes 7 cavities, which are separately energized by sources of ultrahigh frequency energy **110** to **116**. The optimum curves or operating conditions for the product to be dried may be attained by singly or in combination varying the energy levels from the sources **110** to **116** or varying the speed of the belt conveying the product through the drying apparatus or varying the size of the cavities to which the ultrahigh frequency energy is supplied. The operation of the drying apparatus of FIG. 5 is the same as the operation of the drying apparatus in FIG. 1. Additionally, in the drying apparatus of FIG. 5, the most advantageous drying conditions may be better approximated by sectioning the belt **120**, with the breaks occurring between zones. Thereafter, there will always be a row of the product positioned between zones until replaced by another row from the preceding zone. The row of product between the zones aids in the blocking of energy from passing from one cavity or zone into an adjacent cavity or zone.

The drying apparatus of the present invention has particular application to large commercial processing plants. When the size of the drying apparatus is greatly increased, it becomes difficult to provide uniform distribution of the ultrahigh frequency energy within a zone when one aperture is employed. Therefore, a plurality of apertures are provided. Such a large drying apparatus is shown in FIG. 6.

Three apertures **200**, **201** and **202** are provided in the top wall **204** of the drying chamber. Energy from a single source **205** of ultrahigh frequency energy is coupled to each aperture by a wave guide **206**. Between the wave guide **206** and each aperture there is positioned a phase shifter of which phase shifter **207** is typical. Upon the application of energy from source **205**, the phase and amplitude of the energy coupled into the cavity through the apertures are adjusted to provide uniform distribution of the energy throughout the drying area. The rest of the apparatus is the same as the drying apparatus of FIG. 1 and operates in the same manner.

What is claimed is:

1. Apparatus for the continuous drying of materials comprising,

a drying cabinet having a plurality of electromagnetic cavities defined therein, the cavities being defined by means of internal walls within the cabinet, individual means coupled to each cavity for producing and propagating ultrahigh frequency electric and magnetic fields within the cavity and the adjacent drying zone in alignment therewith,

said cabinet having a material inlet and outlet, a movable material conveyor mounted in the cabinet and extending outwardly of the inlet and outlet for carrying materials to be dried through the cabinet adjacent each of the cavities to continuously and successively subject materials to be dried carried by the conveyor to the ultrahigh frequency energy of the plurality of cavities, the levels of the ultrahigh frequency energy for each of the cavities being proportioned with respect to the material undergoing drying and with the cavity disposed adjacent the cabinet material inlet provided with the largest amount of drying energy and with the remaining cavity or cavities having preselected amounts of drying energy lower than the said larger amount of energy, the cavity disposed adjacent the cabinet material outlet being provided with the least amount of drying energy, the conveyor being moved through the drying cabinet at a speed correlated to the levels of propagated energy for the plurality of cavities, means for passing a heated, dry gas into the cabinet for carrying away the fluid from the materials being dried in said cabinet, and means for withdrawing the fluid laden gas from said cabinet.

2. Apparatus for the continuous drying of materials as defined in claim **1** wherein the means for passing the heated dry gas is mounted adjacent the cabinet material inlet and the means for withdrawing the fluid-laden gas is mounted adjacent the cabinet material outlet whereby the gas is conveyed between the cabinet inlet and outlet and passes over the material conveyor for contacting the materials undergoing drying.

3. Apparatus for the continuous drying of materials as defined in claim **1** wherein each of the cavities includes an individual ultrahigh frequency stirrer for uniformly distributing the energy therein.

4. Apparatus for the continuous drying of materials as defined in claim **2** wherein the gas admitted to the cabinet has a preselected temperature correlated to the material undergoing drying, the power level of the plurality of cavities, and the air path through the cabinet whereby the exhausted air has a preselected temperature lower than the temperature of the gas admitted to the cabinet.

5. Apparatus for the continuous drying of materials as defined in claim 1 wherein the material conveyor comprises a plurality of individual conveyors, one of the conveyors being arranged to extend through the material inlet for the cabinet and another one of the conveyors being arranged to extend through the material outlet for the cabinet, the conveyors being arranged to move in opposite directions and in different planes in partial overlapping relationship within the cabinet to receive the materials tumbled from the conveyor in the adjacent plane.

6. Apparatus for the continuous drying of materials as defined in claim **5** wherein the gas is conveyed within the cabinet through the different conveyor planes to continuously and successively subject the materials undergoing drying on the different conveyors to the drying gas.

7. Apparatus for the continuous drying of materials as defined in claim 1 wherein the cavities are each provided with a plurality of means for propagating the energy within an individual cavity, the energy being coupled to the cavity at preselected spaced-apart locations to uniformly distribute the drying energy within a single cavity.

8. Apparatus as defined in claim **7** wherein each of said plurality of propagating means includes a phase shifter whereby the phase and amplitude of the energy coupled into the cavity provides uniform distribution of the energy within a cavity.

9. A method for the continuous drying of materials including the steps of:

providing a drying cabinet having a plurality of drying zones wherein a material to be dried is subjected to different levels of ultrahigh frequency energy,

passing a material to be dried through the drying zones at a preselected rate correlated to the characteristics of the material to be dried and the drying energy levels of the different drying zones, the material to be dried being continuously and successivly passed through the drying zones from the zone provided with the highest energy level to the zone with the lowest energy level to thereby continuously subject the material undergoing drying to the ultrahigh frequency energy, and

simultaneously conveying a heated, dry gas through the cabinet to contact the material undergoing drying for carrying away the fluids expelled from the material undergoing drying, the temperature of the gas being preselected and correlated to the material undergoing drying and the drying energy levels, the gas being conveyed through the cabinet with the gas at the preselected temperature being applied at the drying zone with the highest energy level and continuously and successively conveyed through the drying zones along with the material undergoing drying to thereby uniformly dry the material.

References Cited by the Examiner

UNITED STATES PATENTS

2,452,983	11/1948	Birdseye	34—203
2,995,829	8/1961	Allen	34—203
3,027,442	3/1962	Verstraten	219—10.55
3,081,392	3/1963	Warner	219—10.55
3,143,398	8/1963	Swarthout	34—203
3,211,880	10/1965	Johnson	219—19.55

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