

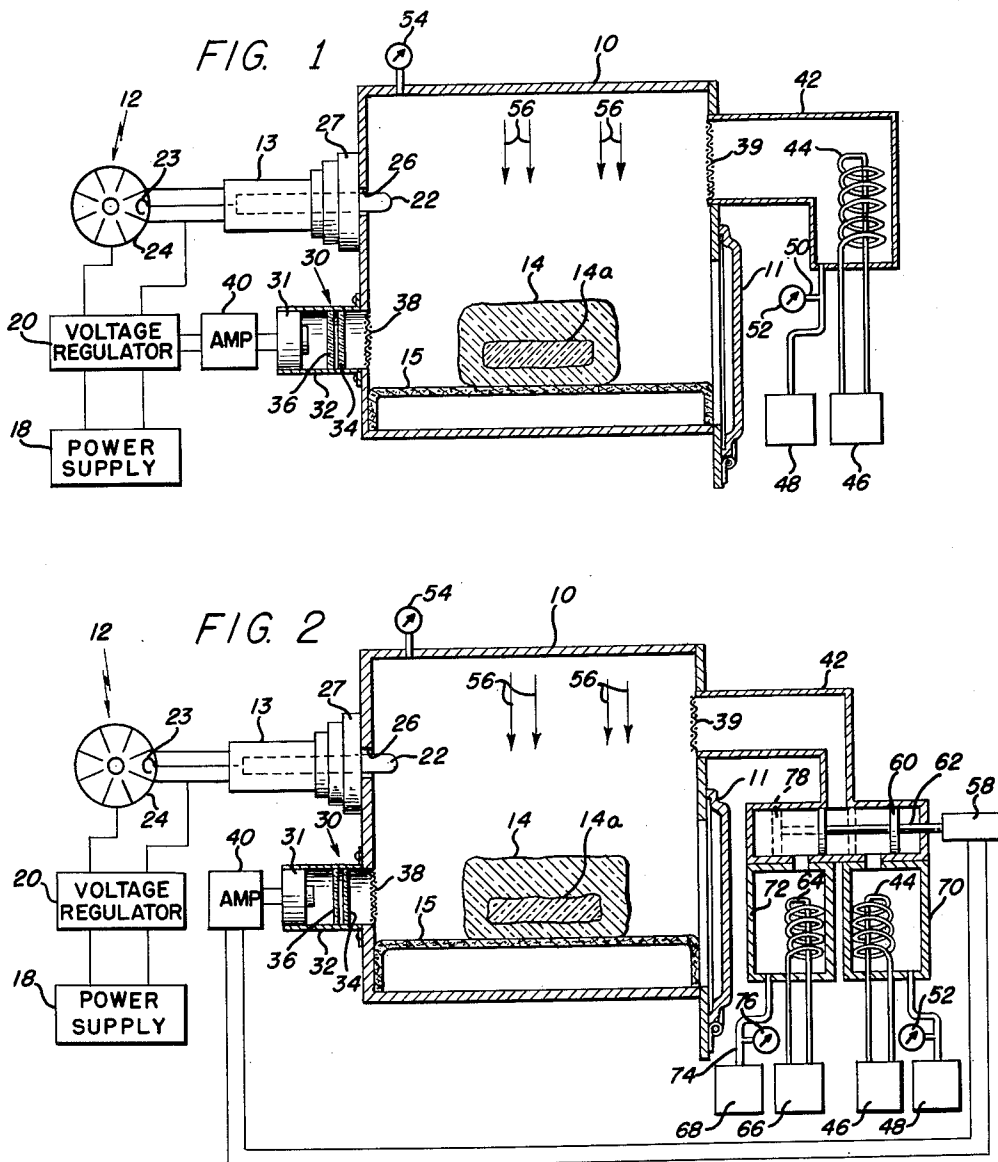
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METHOD AND APPARATUS FOR CONTROL OF FREEZE DRYING

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METHOD AND APPARATUS FOR CONTROL OF FREEZE DRYING

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This invention relates to the use of microwave energy for the freeze-drying of materials such as foods, and more particularly, to a means for controlling the freeze-drying process to prevent heat damage to the materials being processed.

Drying by sublimation of such materials as foods, tissues and cultures of organisms that have first been frozen has proven to be a useful preservation process, particularly for heat sensitive materials. The use of radio frequency energy for freeze-drying of such material, which is usually placed in a hermetically sealed dielectric container with means for drawing off and condensing the sublimated material, is described in detail in Patent No. 2,859,534, issued November 11, 1958, to David A. Copson. However, in a process of this type, it is important to keep the rate of application of energy below the point at which the moist frozen material reaches the melting point of the included liquid. If this precaution is not taken and some of the included material condenses on the substance being dried, this liquid will absorb radio frequency energy and be heated, together with the surrounding region of dry material which may be burned or otherwise damaged. This is particularly true when the freeze-drying process has reduced the moisture content to a relatively low value and the applied radio-frequency or microwave energy is relatively great in proportion to the remaining moisture content in the material being processed. At this portion of the freeze-drying cycle, the microwave energy density and the molecular vapor concentration surrounding the material or food being processed approaches critical values and glow discharge or the development of an intensely blue colored atmosphere occurs in the evacuated container. This discharge is undesirable because, when foods are being processed, it contributes a characteristic spark discharge type of flavor to the foods whenever they are exposed to an appreciable amount of discharge. The occurrence of glowing is, therefore, a process limit which is associated with the microwave energy density being in excess of that desired in the system. It is, therefore, desirable to provide a means for sensing the occurrence of glow discharge in order to control the molecular vapor concentration and the microwave energy density in the container to provide a relatively rapid rate of sublimation without the danger of damaging the material or foods being processed.

In accordance with the invention, a photoelectric cell is provided with a filter which renders the photoelectric cell sensitive only to blue light. The photoelectric cell is mounted on an evacuated microwave oven or food container in a manner adapted to sense for the presence of the development of glow discharge whenever the microwave energy density in said container exceeds the density required to obtain a desirable rate of sublimation. When glow discharge is sensed, the photoelectric cell provides a responsive signal which is amplified and used as a control signal to reduce the microwave energy input to a power level below that required to melt moist frozen material within the container. In a further embodiment of the invention the control signal is used to increase the pumping capacity of the evacuating means to draw off the vaporized component of the sublimation process at a faster rate so as to reduce the molecular vapor concentration in said container. In this manner, the freeze-drying process is permitted to continue at a rate which does not

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elevate the temperature of any portion of the moist frozen material within the container above the melting point of the vaporizable portion of the material. It should be understood that when other materials are processed, the glow discharge may take on other colors which can be suitably filtered before being sensed.

Other and further features and advantages of the invention will become apparent from the following description taken in connection with the accompanying drawing illustrating the invention wherein:

FIG. 1 is a schematic diagram of one embodiment of the invention; and

FIG. 2 is another embodiment of the invention shown in schematic form.

Referring to FIG. 1, the reference numeral 10 designates a conductive cavity or metallic oven having a door 11 to permit the insertion of food material into said oven, and a source of microwave energy, shown here by way of example as a magnetron 12, coupled to said oven through a coaxial transmission line 13 of the waveguide type, such as shown, for example, in Patent No. 2,526,226, issued October 17, 1950, to F. A. Gross. Frequencies which are particularly significant for this purpose are those in the microwave range, which may be considered as those lying between 300 megacycles per second and 30,000 megacycles per second. Material 14 in the frozen state to be dried is inserted into and hermetically supported on the nonconductive tray 15. Cavity 10 together with transmission line 13 may be referred to as a propagated electromagnetic wave guiding structure since this structure is used for guiding and directing the propagated electromagnetic microwave energy to the material 14.

Magnetron 12 is energized from a suitable power supply source 18 in series with a well-known voltage regulator 20 and, when so energized, delivers microwave energy having a predetermined wavelength to coaxial transmission line 13. The inner conductor of the transmission line is coupled to oscillator 12 by a loop 23 and the outer conductor is connected to the magnetron conductive envelope 24. The inner conductor 22 of transmission line 13 extends into the interior of the container 10 through a suitable aperture 26 provided in the rear wall thereof, while the outer conductor of said transmission line is connected to the rear wall of the container by a suitable fastening means 27.

In order to sense the development of glow discharge in container 10 a photoelectric sensing mechanism 30 comprises a photoelectric cell 31 hermetically sealed in a metallic tube 32 which, in turn, is hermetically sealed to the wall of container 10. A red and yellow color filter 34 and 36, respectively, is mounted in tube 32, in front of the face of the photoelectric cell. In this manner, only the light having a characteristic blue glow will pass the light filter and become sensed by the photoelectric cell. The wall of the container 10 is provided with a screen 38 formed with openings of a diameter small with respect to the wavelength of the microwave energy, to prevent the propagation of microwave energy into the photoelectric cell 31 while permitting the passage of light into the filters. When glow discharge is sensed by the photoelectric cell 31, a control signal is fed to a conventional amplifier 40. The output of amplifier 40 is the amplified control signal which is fed to the voltage regulator 20 to reduce the input power to magnetron 12 and, thereby, to reduce the microwave energy input into container 10.

On the opposite side of container 10 is a metal conductor 42 hermetically sealed to the wall of the container and provided with a cooling coil 44 for removing the sublimated vapor from the container 10. Cooling coil 44 is connected to a conventional compressor 46 adapted to pump cooling fluid through the coil 44. The container

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10 is connected through the manifold 42 to a vacuum pump 43 through a pipe 50 fitted with a pressure gauge 52. An additional vacuum gauge 54 is connected to the container 10 to read operating pressure, which, preferably is below 4.5 millimeters.

In operation, the material 14, such as meat, is supported by the tray of dielectric material 15, such as glass, affording a minimum of impedance to the passage of microwave energy. As microwave energy, represented by the arrows 56, penetrates the frozen material 14, the ice or other component to be vaporized, evaporates without first becoming a liquid, that is, it sublimates due to the absorption of microwave energy-producing heat. This sublimation produces a region of dry material, represented by the section 14 and leaves a core of frozen undried material represented by the dotted section 14a. The dried material 14 offers no appreciable impedance to the microwave energy, thus permitting the sublimation of the moist material to continue at a substantially uniform rate. However, as the freeze-drying cycle progresses, the load placed upon the source of microwave energy by the decreasing volume of the moist material becomes smaller, and the microwave energy density and molecular vapor concentration surrounding the dried material approach critical values. When this condition occurs, the development of glow discharge occurs throughout the atmosphere in the evacuated container. The occurrence of glowing is sensed by the photoelectric cell 30, which produces a control signal to decrease the microwave energy density and to prevent the aforementioned spark discharge type of flavor. In this manner, the microwave energy can be applied at a considerably more rapid rate without danger of damaging the dried region 14. By preventing the development of glow discharge the microwave energy is also prevented from being applied fast enough to raise the temperature of any portion of the material above the melting point of the vaporizable portion of the material. Should this be permitted to happen, the liquid, particularly if water, would offer considerably greater impedance to the microwave energy and hot spots might develop, which, in the case of food, would cause changes affecting the flavor and texture. However, the above method of maintaining the voltage supplied to the oscillator at a predetermined process limit achieves this objective.

Referring to FIG. 2, a modification of FIG. 1 is shown in which the control signal from photoelectric cell 30 and amplifier 40 is fed to a solenoid relay 58 to actuate transfer valve 60 and to move plunger 62 to a position in which an additional cooling coil 64 is adapted to withdraw the sublimated vapor from the container 10. The additional cooling coil 64 is provided with a compressor 66 and vacuum pump 68. Each cooling coil 64 and 44 is provided with a separate cooling chamber 70 and 72. Vacuum pump 68 is connected to the cooling chamber 72 through a pipe 74 fitted with a pressure gauge 76. In operation, as the freeze-drying cycle progresses, the molecular vapor concentration surrounding the dry material is removed by compressor 46 and deposited upon cooling coil 44. However, as the frozen vapor is deposited on coil 44 in the form of ice, the efficiency of the coil decreases and the molecular vapor concentration in container 10 tends to increase. As the vapor concentration approaches a critical value, the development of glow discharge is sensed by the photoelectric cell 30 and actuates the transfer valve 60 to the position shown at 78. This permits cooling coil 64 to communicate with manifold 42 and to draw off the molecular vapor at an increased rate. This, in turn, decreases the molecular vapor concentration in container 10 and prevents the development of glow discharge therein. In this manner, the sublimation process proceeds without the development of glow discharge and the cooling coil 44 no longer accumulates frozen vapor and can be defrosted in a well-known manner. Screen 39 prevents radiation from magnetron 12 from entering the manifold 42. It should be understood that the correction for the

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occurrence of glow discharge is also provided by increasing the product in the container 10, such as, for example, by increasing the speed of a conveyor, not shown, which can be used to carry material through the evacuated container 10.

For the foregoing reasons, it is to be understood that the above-described arrangements are illustrative of the application of the principles of the invention. Numerous other arrangements may be devised by those skilled in the art without departing from the spirit and scope of the invention. Accordingly, it is desired that the invention not be limited to the particular details of the embodiments disclosed herein except as defined in the appended claims.

What is claimed is:

1. Apparatus for controlling the removal of a vaporizable component by a sublimation from material including a solid and said vaporizable component in the solid state comprising container means for holding the material to be treated, means for drawing off from said container vapors to hold said container at a pressure substantially lower than atmospheric pressure, an electrical energy generator communicating with said container and adapted to apply propagated electromagnetic energy to said material to supply the heat of sublimation to sublimate a substantial portion of said component, photoelectric means for producing a control signal in response to the presence of glow discharge in said container when said electromagnetic energy approaches a predetermined concentration, thereby to initiate said glow discharge, and control means responsive to said control signal to reduce the presence of glow discharge in said container.

2. A method for controlling the removal of a solid and vaporizable component from a mixture in the solid state by evaporation without liquification comprising the steps of subjecting the mixture to an atmosphere of reduced pressure, applying propagated electromagnetic energy to said mixture while said mixture is subjected to said atmosphere of reduced pressure, sensing for the detection of glow discharge in said atmosphere, and increasing the rate of withdrawal of said vaporizable component in response to the detection of said glow discharge.

3. A method for controlling the removal of a vaporizable component substantially by sublimation from material comprising a solid and said vaporizable component comprising the steps of applying propagated electromagnetic microwave energy to said material through an electromagnetic microwave transmission line coupled to a generator of said energy and communicating with the space occupied by said material to concentrate said energy in said space while subjecting said material to a pressure substantially lower than the atmospheric pressure to vaporize said vaporizable component, sensing for the presence of glow discharge in said space and increasing the rate of withdrawal of said vaporized component from said space in response to the presence of said glow discharge.

4. Apparatus for controlling the removal of a component from a mixture in the solid state by evaporation without liquification comprising a hermetically sealed container for the material to be treated, pump means for maintaining the atmosphere in said container at a reduced pressure, a microwave energy generator, a waveguide structure coupled to said microwave energy generator and communicating with said container for applying the microwave output of said generator to said container thereby to vaporize said component, means for drawing off said vaporized component, means for sensing for the presence of glow discharge in said container, and means actuated by said sensing means for reducing said microwave energy output in response to the presence of said glow discharge.

5. A method for controlling the removal of a vaporizable component substantially by sublimation from material comprising of solid and said vaporizable component com-

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prising the steps of applying propagated electromagnetic microwave energy to said material through a propagated electromagnetic microwave transmission line coupled to a generator of said energy and communicating with the space occupied by said material to concentrate said energy in said space while subjecting said material to a pressure substantially lower than the atmospheric pressure to vaporize said vaporizable component, withdrawing the vaporized component from said space to maintain said lower pressure in said space, sensing for the presence of glow discharge in said space, and increasing the rate of withdrawal of said vaporized component from said space in response to the detected presence of glow discharge in said space.

6. A method for controlling the removal of a vaporizable component substantially by sublimation from frozen aqueous material comprising a solid and said vaporizable component comprising the steps of applying propagated electromagnetic microwave energy to said material through a propagated electromagnetic microwave transmission line coupled to a generator of said energy in circuit with a voltage regulator and communicating with the space occupied by said material to concentrate said energy in said space while subjecting said material to a pressure substantially lower than atmospheric pressure to vaporize said vaporizable component, withdrawing said vaporizable component from said space to maintain said lower pressure in said space, sensing for the development of glow discharge in said space, and controlling said voltage regulator to decrease the concentration of energy in said space in response to the detection of said glow discharge.

7. A method for controlling the removal of a vaporizable component substantially by sublimation from frozen aqueous material comprising a solid and said vaporizable component comprising the steps of applying propagated electromagnetic energy to said material through a propagated electromagnetic transmission line coupled to a generator of said energy in circuit with a voltage regulator and communicating with the space occupied by said material to concentrate said energy in said space while subjecting said material to a pressure substantially lower than atmospheric pressure to vaporize said vaporizable component, withdrawing said vaporized component from said space to maintain said lower pressure in said space, sensing for the development of glow discharge in said space, and feeding a control signal in response to said glow discharge to said voltage regulator to decrease the concentration of said energy in said space.

8. A method for controlling the removal of water substantially by sublimation from frozen aqueous material comprising the steps of applying propagated electromagnetic microwave energy substantially uniformly to said material through an electromagnetic wave transmission line coupled to a generator of said energy and communicating with the space occupied by said material to concentrate said energy in said space while subjecting said material to a pressure substantially lower than atmospheric pressure to sublimate ice from said material, withdrawing said sublimated ice from said space to maintain said substantially lower pressure in said space while preventing withdrawal of said propagated electromagnetic microwave energy with said sublimated ice, sensing for the presence of glow discharge in said space, and increasing the rate of withdrawal of said sublimated ice from said space in response to the presence of glow discharge in said space.

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9. Apparatus for controlling the removal of a vaporizable component by sublimation from material including a solid and said vaporizable component in the solid state comprising container means for holding the material to be treated in an atmosphere at a pressure substantially lower than atmospheric pressure, a microwave electrical energy generator communicating with said container means and adapted to apply propagated electromagnetic microwave energy to said material to supply the heat of sublimation to sublimate a substantial portion of said component, photoelectric means for producing a control signal in response to the presence of glow discharge in said container when said electromagnetic microwave energy approaches a predetermined concentration, thereby to initiate said glow discharge, control means responsive to said control signal to reduce the concentration of electromagnetic microwave energy in said container, and pump means communicating with said container means for drawing off said vaporizable component to maintain the pressure in said container substantially below atmospheric pressure.

10. Apparatus for controlling the removal of water substantially by sublimation from a frozen aqueous material in response to molecular vapor concentration surrounding said material comprising container means for holding the material to be treated in an atmosphere at a pressure substantially lower than atmospheric pressure, a microwave electrical energy generator communicating with said container means for applying propagated electromagnetic energy to said material to supply the heat of sublimation to sublimate a substantial portion of said water in said material, photoelectric means for sensing the presence of glow discharge in said container when said electromagnetic energy approaches a predetermined concentration, control means responsive to said photoelectric means for reducing the output of said microwave electric generator when said photoelectric means senses the presence of said glow discharge, and pump means communicating with said container means for maintaining said lower pressure.

11. Apparatus for controlling the removal of a vaporizable component by sublimation from material including a solid and said vaporizable component in the solid state comprising container means for holding the material to be treated in an atmosphere at a pressure substantially lower than atmospheric pressure, a microwave electrical energy generator, a propagated electromagnetic wave guiding structure coupled to said generator and communicating with said container, means for applying propagated electromagnetic wave energy to said material to supply the heat of sublimation to sublimate a substantial portion of said component, photoelectric means for producing a control signal in response to the presence of glow discharge according to the molecular vapor concentration in said container means, a plurality of pump means communicating with said container means for drawing off said vaporizable component to maintain the pressure in said container substantially below atmospheric pressure, and control means fed by said control signal to replace one of said pump means by another of said pump means adapted to draw off said vaporized component at an increased rate, thereby to reduce the molecular vapor concentration in said container.

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