

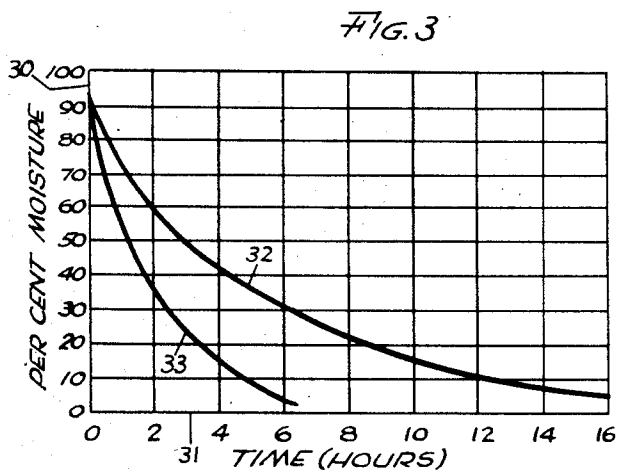
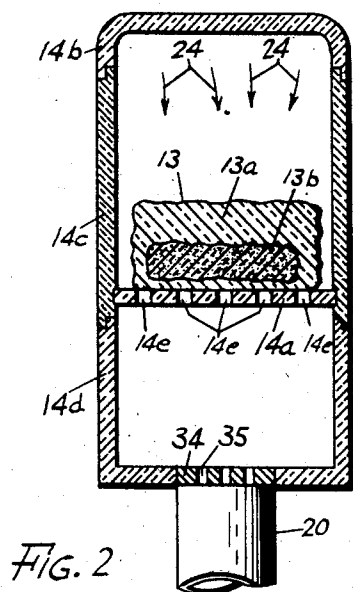
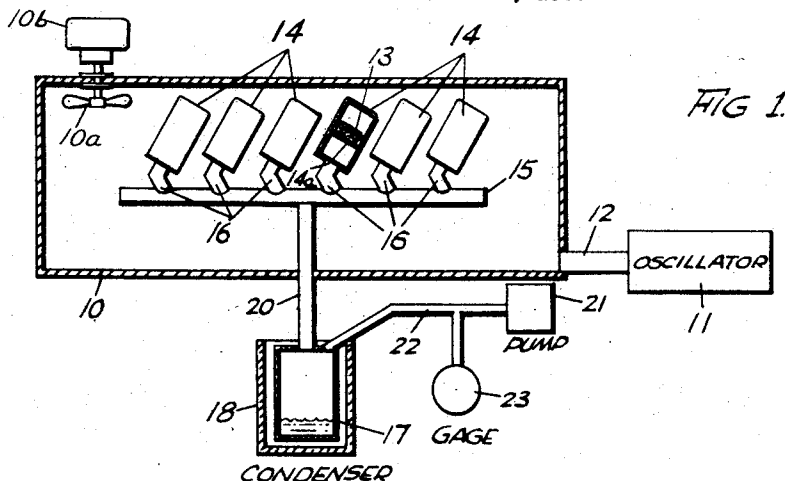
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D. A. COPSON

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METHODS AND APPARATUS FOR RADIO FREQUENCY FREEZE-DRYING

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INVENTOR
DAVID A. COPSON
BY *Charles J. Gorn*
ATTORNEY

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METHODS AND APPARATUS FOR RADIO FREQUENCY FREEZE-DRYING

David A. Copson, Waltham, Mass., assignor to Raytheon Manufacturing Company, Waltham, Mass., a corporation of Delaware

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This invention relates to the use of radio frequency energy for the freeze-drying of materials such as foods.

Drying by sublimation of such materials as foods, tissues, and cultures of organisms that have first been frozen has proved to be a useful preservation process particularly for heat labile substances. However, many materials are not amenable to this treatment because of their dimensions or structure. For example, as beefsteak or bone tissue is freeze-dried, the highest surface at which sublimation occurs steadily recedes behind a dried portion of the substance that acts as a poor conductor for heat. As the process goes on, more and more heat is dissipated in the dried portion of the material before reaching the vaporizing surface to cause sublimation. If the heat is applied at a slow enough rate to avoid damage to the dried material, the process is slowed up to a point where it will take as much as twenty-four hours to dry an average sized beefsteak. A piece of bone, 2 cm. x 4 cm. x 8 to 10 cm., may require as much as eight days to be completely dried. The bulkier the piece of material to be dried, the greater this difficulty.

By the present method, advantage is taken of the fact that many materials in the dry state absorb little electromagnetic energy at radio frequencies compared to the energy absorbed by the same material in a moist frozen state. The result is that radio frequency energy applied to moist frozen material is absorbed almost entirely by the moist frozen portion of the material. By this process, little or no energy is lost in transmission through the dried material, making the drying process far more efficient. In fact, a given sized piece of beefsteak can be dried by radio frequency energy in about one-third of the time required to dry it by other forms of heating under the same conditions. The process is made more efficient by being carried on in a very low pressure atmosphere where sublimation will take place at low temperatures requiring a minimum of heat to be applied. As radio frequency energy is absorbed more by a liquid, such as water, than by the same substance in its solid state, such as ice in the case of water, it is important to keep the rate of application of energy below the point at which the moist frozen material will reach the melting point of the included liquid, such as water. 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 material which may be burned, or otherwise damaged. As voltage-regulated power supplies are usually required for the generator of radio frequency energy used for heating, this requirement raises no problem.

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 apparatus utilized in carrying out the process of the invention;

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Fig. 2 is a diagram of a piece of material being freeze-dried by the process of the invention; and

Fig. 3 is a graph of the extent of drying plotted against time for the process of the invention as compared to the conventional method of freeze-drying.

In Fig. 1 the reference numeral 10 designates a conductive cavity to which the propagated electromagnetic radio frequency energy is applied from an oscillator 11 through a transmission line of the wave guide type as shown at 12, such as shown for example in Patent No. 2,540,036 issued January 30, 1951 to P. L. Spencer. Frequencies which are specially 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. The two most practical frequencies in this range are in the region of 2450 megacycles per second and 915 megacycles per second. Material 13 in the frozen state to be dried is inserted into and hermetically sealed in one or more non-conductive containers 14, each connected to a manifold 15 of the conductive material by means of pipes 16, also of conductive material. Cavity 10 together with wave guide 12 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 for application to the material 13. The fan 10A and the motor 10B driving fan 10A act as a mode stirrer for uniformly applying the electromagnetic microwave energy to the material 13 as for example shown in Patent No. 2,648,760 issued August 11, 1953 to W. M. Hall et al. The manifold 15 is connected to the inner container 17 of a condenser 18 through a pipe 20. Container 17 is connected to a vacuum pump 21 through a pipe 22 fitted with a pressure gauge 23.

The operation of the invention is best understood by reference to Fig. 2 as well as to Fig. 1. Fig. 2, a single piece 13 of material, such as meat, is shown supported on a platform of dielectric material 14a in a container 14, also of dielectric material, such as glass, affording a minimum of impedance to the passage of radio frequency energy. This container can be most conveniently formed of three parts, a cap 14b, the main body 14c, and the base 14d for easy demounting and accessibility to the material to be dried. The joints between the parts must, of course, be capable of being hermetically sealed. The platform is formed with openings 14e to permit the free passage of the vapor. As radio frequency energy, as represented by the arrows 24, penetrates the frozen material 13, the ice or other component to be vaporized evaporates without first becoming a liquid, that is it sublimates due to the absorption of radio frequency energy-producing heat. This sublimation produces a region of dried material, represented by the undotted section 13a, and leaves a core of frozen undried material, represented by the dotted section 13b. The dried material 13a offers no appreciable impedance to the radio frequency energy, thus permitting the sublimation of the moist material to continue at a substantially uniform rate. This is quite different from what happens when heat is applied by any of the conventional means, as from electric or gas heating elements. With the conventional means applying heat, once the surface region 13a is dried, it presents considerable resistance to the passage of the applied heat so that much of this heat is lost before reaching the still moist region 13b. This means that heat must be supplied at a very slow rate to prevent burning or other heat damage to the dried material. With this invention the radio frequency energy may be applied at a considerably more rapid rate without danger of damaging the dried region 13a. The only precaution that need be taken is to keep the radio frequency energy 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 radio frequency energy and hot spots might develop, which, in the case of food, would cause changes affecting the flavor. However, known methods for maintaining the voltage supplied to the oscillator at a predetermined value will accomplish this objective.

The graphs in Fig. 3 bring out the advantages of the invention over other methods of freeze-drying. In these graphs the percentage of moisture remaining is plotted vertically along the line 30 with reference to the time in hours that drying has progressed plotted horizontally along the line 31. It will be noted that the curve 32 for the conventional freeze-drying method requires 16 hours to reduce the moisture content of a given quantity of beefsteak to 5 percent. moisture content, while the process of the invention only requires 6 hours for this much drying for the same quantity of beef under comparable conditions. This represents a saving in time of a factor of 2 $\frac{2}{3}$:1. The saving for other materials is comparable.

The process of the invention may be used to evaporate out from any material any component that may be evaporated from the solid state. The evacuation serves to reduce the partial pressure of the component to be evaporated in the atmosphere of the heating chamber, thus setting up the conditions necessary for sublimation. The pump serves to maintain the desired pressure.

The radio frequency energy can be introduced directly into the chamber 14. In this case the chamber 14 would be so formed as to provide a reflecting surface for the radio frequency energy and so serve as the cavity as well as the evacuation chamber. In the interests of efficient operation, precautions must be taken to prevent the escape of radio frequency energy through the pipes 16 and the manifold 15 or the absorption of this energy by these pipes and manifolds. This may most conveniently be done by the insertion of a disc 34 formed with openings 35 of a diameter small with respect to the wavelength of the radio frequency energy. This serves to prevent the propagation of the radio frequency energy into the pipes and manifold while permitting the exhausted vapors to flow through these pipes and manifold. Forming the pipe 16 and manifold of conductive material also serves to reflect back any energy propagated towards the pipes. The portion of the container 14 below the platform 14a can be cooled and the platform 14a can be formed with openings similar to the choke 34 to serve as a choke as well, permitting the lower portion of the container 14 to be provided with cooling means and used as the condenser of the system.

This invention is not limited to the particular details of construction, materials and processes described, as many equivalents will suggest themselves to those skilled in the art. It is accordingly desired that the appended claims be given a broad interpretation commensurate with the scope of the invention within the art.

What is claimed is:

1. Apparatus for removing 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 microwave energy to said material to supply the heat of sublimation to sublimate a substantial portion of said component, and pump means communicating with said container means for drawing off said vaporized component to maintain the pressure in said container substantially below atmospheric pressure.

2. Apparatus for removing water substantially by

sublimation from a frozen aqueous 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, a propagated electromagnetic wave guiding structure coupled to said generator and 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, and pump means communicating with said container means for maintaining said lower pressure.

3. Apparatus for removing water substantially by sublimation from a frozen aqueous 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, a propagated electromagnetic wave guiding structure coupled to said generator and 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, and pump means communicating with said container means for maintaining said lower pressure, said pump means having means for preventing said energy from entering said pump means.

4. Apparatus for removing water substantially by sublimation from a frozen aqueous material comprising container means for holding the material to be treated in an atmosphere at a pressure substantially lower than atmospheric pressure, said container means comprising dielectric material affording a minimum impedance to the passage of said energy therethrough, 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 energy to said material to supply the heat of sublimation to sublimate a substantial portion of said water in said material, and pump means communicating with said container means for maintaining said lower pressure, said pump means having means for preventing said energy from entering said pump means.

5. A method for removing 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 a propagated electromagnetic wave guiding structure 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 vaporize said vaporizable component, and withdrawing said vaporized component from said space to maintain said lower pressure in said space.

6. A method for removing water substantially by sublimation from frozen aqueous material comprising the steps of applying propagated electromagnetic microwave energy substantially uniformly to said material through a propagated electromagnetic wave guiding structure 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 said water from said material, and withdrawing said sublimated water from said space to maintain said substantially lower pressure in said space while preventing withdrawal of said propagated electromagnetic microwave energy with said sublimated water.

7. A method for removing 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 in a dielectric container, through

a propagated electromagnetic wave guiding structure coupled to a generator of said energy and communicating with the space occupied by said container to concentrate said energy in said space while subjecting said material to a pressure substantially lower than atmospheric pressure to vaporize said vaporizable component, and with-

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drawing said vaporized component from said space to maintain said lower pressure in said region.

References Cited in the file of this patent

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