Oct. 4, 1966 K. FRITZ 3,276,138

MICROWAVE DRYING APPARATUS

Filed Sept. 21, 1962 3 Sheets-Sheet 1

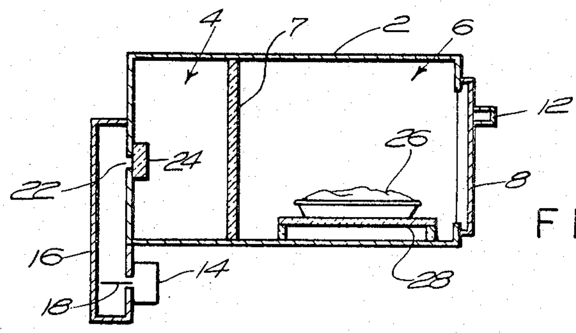

FIG. 1

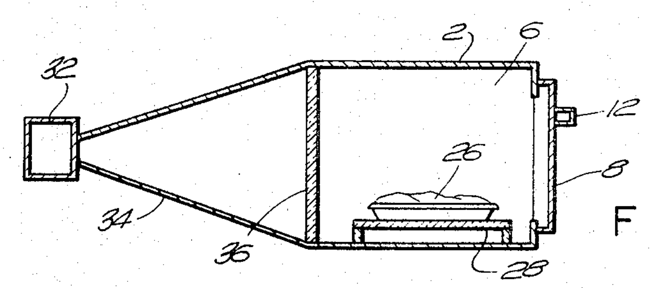

FIG. 2

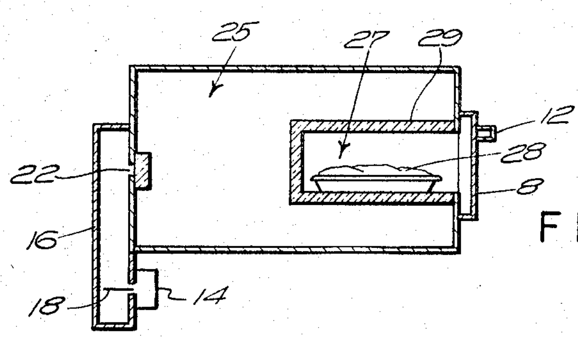

FIG. 3

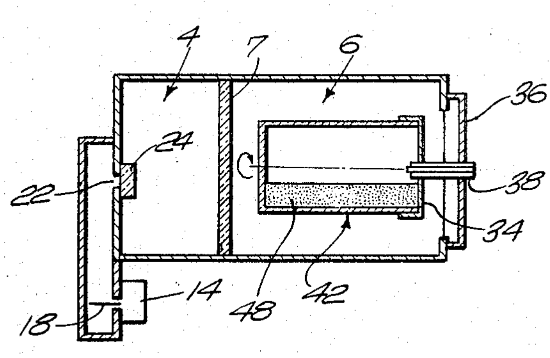

FIG. 4

INVENTOR.
KARL FRITZ

BY

Weingarten, Orenbuch & Pavlecic

ATTORNEYS

Oct. 4, 1966 K. FRITZ 3,276,138

MICROWAVE DRYING APPARATUS

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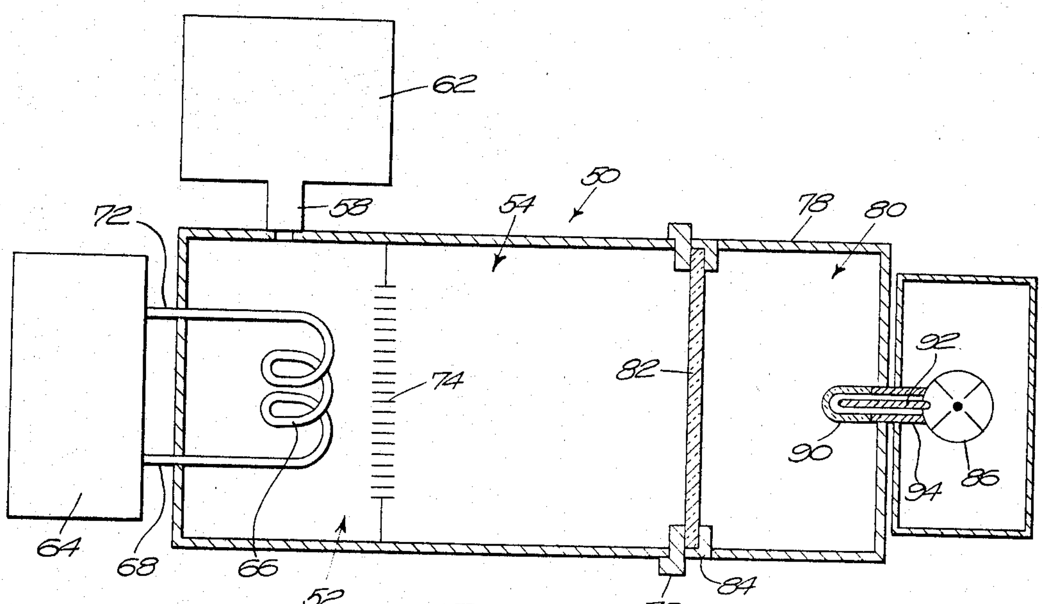

FIG. 5

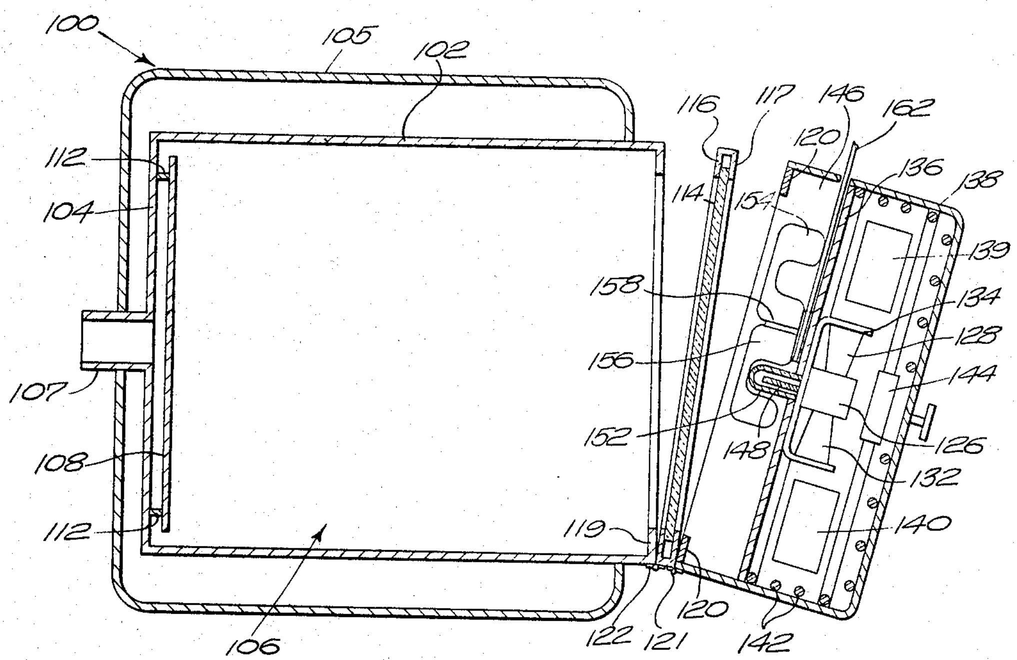

FIG. 6

INVENTOR.
KARL FRITZ

BY *Weingarten, Orenbuch & Pandiscio*

ATTORNEYS

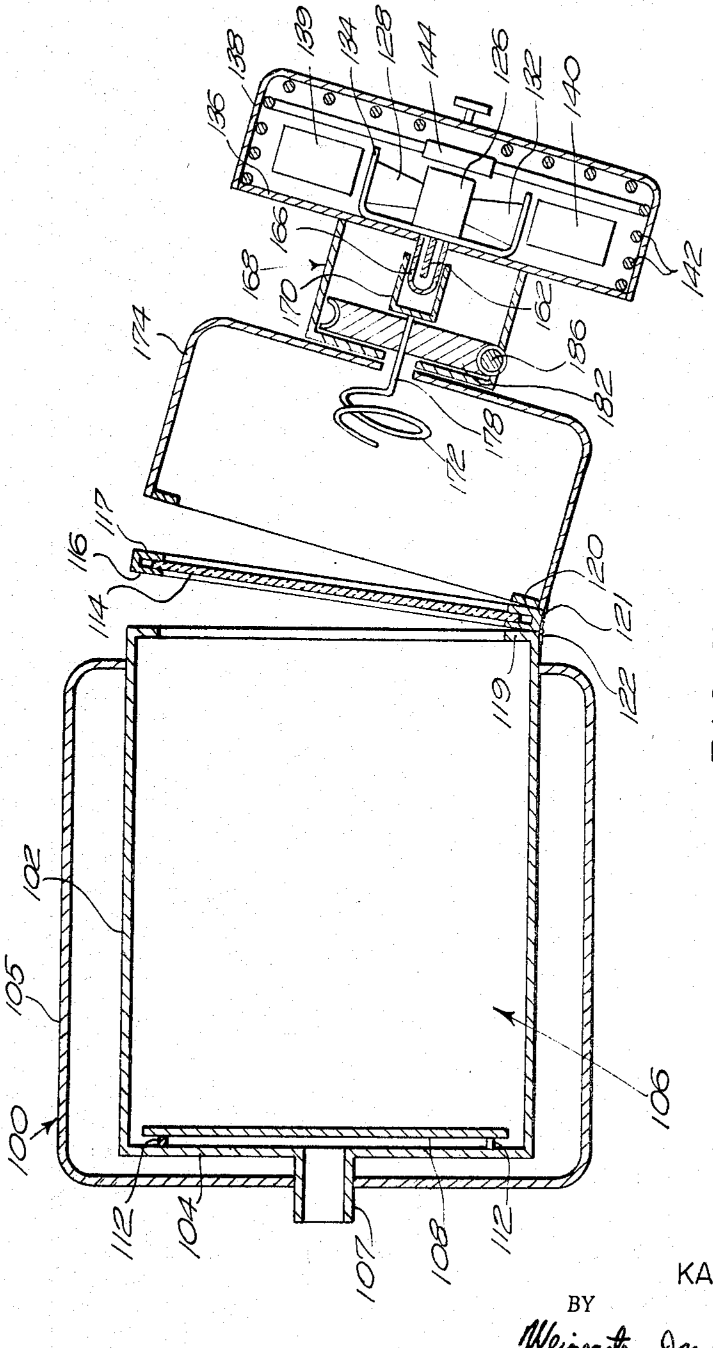

FIG. 7

INVENTOR.
KARL FRITZ
BY
Weingarten, Orenbuch & Pandiscio
ATTORNEYS

United States Patent Office 3,276,138
Patented Oct. 4, 1966

3,276,138

MICROWAVE DRYING APPARATUS

Karl Fritz, Freiburg im Breisgau, Germany, assignor to MIWAG Mikrowellen Aktien Gesellschaft, a corporation of Switzerland

Filed Sept. 21, 1962, Ser. No. 225,218
7 Claims. (Cl. 34—1)

The invention relates in general to drying by electrical energy and more particularly to ovens utilizing microwave energy for drying purposes.

Apparatus for vacuum drying by means of electrical energy allows rapid drying of sensitive objects and substances without impairing essential qualities of food, such of flavor, taste, vitamin content, and color. During the drying process, heat drawn from the object being dried is consumed in evaporating moisture in the object. The resultant effect is to lower the temperature of the object, thus decreasing the rate of drying. Further, the high field strength which is necessary when low frequencies are used for drying results in a gas discharge occurring at low pressure which normally are used in vacuum drying.

From the power efficiency point of view, by making the evacuated drying compartment surrounding the object being dried as small as possible, the amount of energy spent in ionization is reduced. However, reduction of the evacuated space is utilized in exceptional cases only, as the surface of the object being dried would be subjected to strong ion bombardment. In general, ionization should, if possible, be avoided altogether.

In order to compensate for the loss of heat needed to evaporate the object, high-frequency energy such as in the microwave region is utilized to transform a sufficient amount of power into heat at low field intensities.

Further, feeding microwave energy into the evacuated space is a rather difficult problem, as high values of field strength occur near radiating elements entering the drying compartment. These high values of field strength have until now imposed a limit upon the degree of vacuum which could be used in practice.

Another difficulty encountered, even if homogeneous fields are used, arises from the fact that different objects or parts of objects show minor differences of loss factor and dielectric constant, and these differences are accentuated by differences in the rates at which these values change with temperature and residual water content.

The principal object of the invention is to provide apparatus utilizing microwave energy for vacuum drying of materials. Another object of the invention is to allow the degree of vacuum, the temperature, and the amount and distribution of microwave energy in the vacuum drying compartment to be independently adjusted to optimum values. Further, the absence of any interior elements radiating microwave energy at unduly high local values of field strength, or carrying appreciable electrical potentials, enables the entire volume of the evacuated working enclosure to be used for drying purposes. An obvious advantage of the invention is that the material to be dried may be sprayed into the enclosure in liquid form. Moreover, the invention allows microwave equipment to be added to existing vacuum drying installations without important structural modifications and without encroaching on the space used for drying. Further, the microwave apparatus utilized in the drying process can be removed, while the vacuum enclosure remains closed and evacuated.

The invention resides in an apparatus having a metallically confined chamber which is divided into a radiating compartment and a drying compartment. The compartments are separated by a vacuum-tight, low-loss dielectric partition. Microwave energy is fed into the radiating compartment and is uniformly transferred into the drying compartment through the partition. Objects to be dried are placed in the drying compartment which is usually at a near perfect vacuum. In certain embodiments of the invention, means are provided for allowing gases and vapors to escape from the drying compartment, while at the same time preventing microwave energy from escaping from the drying compartment via the same route.

Other objects and many of the attendant advantages of the invention will be readily appreciated as the invention becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings, wherein:

FIG. 1 is a schematic representation of a drying chamber divided into a radiating compartment and a drying compartment;

FIG. 2 schematically depicts an embodiment of the invention in which the radiating compartment is shaped as a radiating horn;

FIG. 3 illustrates an embodiment of the invention in which the drying compartment is restricted to minimum dimensions;

FIG. 4 depicts an embodiment of the invention wherein material to be dried is fed into the drying compartment continuously while the drying compartment is rotated;

FIG. 5 shows an embodiment of the invention wherein gases and vapors may be removed from the drying compartment while microwave energy does not pass out the same route;

FIG. 6 illustrates an embodiment of the invention wherein radiating and drying compartments are easily separable; and

FIG. 7 shows an alternate embodiment of the radiating means of FIG. 6.

Referring to FIG. 1, which schematically depicts an embodiment of the invention, there is shown a vacuum-tight metallic enclosure **2** forming a chamber which is divided into a radiating compartment **4** and a drying compartment **6**. The compartments are separated by a vacuum-tight, low-loss dielectric partition **7**. Access to the drying compartment is provided by a door **8** having a handle **12**.

A microwave generator **14**, e.g., a magnetron tube, feeds energy into a waveguide **16** by means of a probe **18**. The waveguide **16** couples energy into the radiating compartment **4** by means of a coupling slot **22**. Compartment **4** is sealed off from waveguide **16** by a low-loss dielectric window **24** capable of maintaining the vacuum in the compartment. An object, such as food **26**, which is to be dried, is placed on a platform **28** in a drying compartment **6**.

Radiating compartment **4** is maintained at a pressure which is either too high or too low for ionization of the gas to occur even in the presence of strong microwave energy fields, while compartment **6** is evacuated to a pressure better suited to drying purposes. Of course, radiating compartment **4** could contain air at atmospheric pressure which would prevent ionization at any power level likely to be used in vacuum drying applications. A near-perfect vacuum in the compartment **4**, however, serves the same purpose and, at the same time, eases the strain on the dielectric partition due to the different pressures in the compartments. As a practical matter, there is no great difficulty in constructing large dielectric windows which stand up to one atmospheric pressure. Further, while there is no great difficulty in constructing large dielectric windows which stand up to one atmosphere of pressure, the dielectric partition **7** could be made of several small windows (not shown) which would feed energy into compartment 6. Thus, while radiating compartment 4 and drying compartment 6 may be separately evacuated or pressured, the complication and high cost involved would be justified only in exceptional cases. In the embodiment of FIG. 1 and in the other embodiments described herein, the radiating compartment is, therefore, presumed to be at atmospheric pressure.

As can be readily seen, the construction described in FIG. 1 allows microwave energy from the compartment 4 to readily enter drying compartment 6. The absence of any interior elements in compartment 6 radiating microwave energy at unduly high local values of field strength, or carrying appreciable electrical potentials, enables the whole volume of that evacuated compartment to be used for drying purposes.

The apparatus of FIG. 2 is a modification of the embodiment shown in FIG. 1, and similar parts in those two figures bear the same reference numerals. Referring to FIG. 2, there is depicted a different arrangement for transferring energy from the microwave source to the drying compartment. A generator 32 feeds energy into a horn radiating compartment 34. At the end of the compartment 34, the vacuum-tight dielectric partition 36 seals the horn from drying compartment 6. The horn-shaped compartment insures that an even distribution of energy from the generator 32 will impinge upon the drying compartment.

Referring to FIG. 3, there is depicted a modified construction of the drying compartment of FIG. 1. Microwave energy is fed into a radiating compartment 25 in the same manner as that described in FIG. 1. The drying compartment 27, defined by a dielectric member 29 housing an object to be dried 28, is almost entirely contained by the radiating compartment. Provision is made for access to the compartment 27 by means of a door 12. The arrangement of FIG. 3 allows the dimensions of the evacuated drying compartment 27 to be restricted to a minimum, thus saving pumping power and time; that is, a smaller drying compartment requires less power to evacuate the compartment and permits the object to be dried rapidly. However, the size of the radiating compartment cannot be arbitrarily reduced since its configuration is a consideration in obtaining a homogeneous field distribution in the compartment.

FIG. 4 shows another modification of the drying compartment. Microwave energy is fed into radiating compartment 4 in the same manner as in FIG. 1. The vacuum-tight, low-loss, dielectric partition 7 separates the radiating compartment 4 from a working compartment 6. A rotating drum 42, made of dielectric material and having an end cap 34, is housed in compartment 6. Protruding through a door 36 of the working enclosure 6 and the end cap 34 is a nozzle 38. The material to be dried 48 is fed through nozzle 38 into drum 42. As the drum is rotated (by apparatus not shown), the material in the drum is uniformly dried. The drying process is speeded up considerably because the method of feeding the material into the drum, depicted in FIG. 4, ensures that unduly high values of field strength do not occur in the compartment 6. Therefore, for a given degree of vacuum, a higher average field strength can be used as compared with apparatus where the working space is not subdivided in the manner characteristic of the invention.

Referring now to FIG. 5, there is shown an embodiment of the invention in which a metal container 50 is divided into a condensing compartment 52 and a drying compartment 54. Connected to the condensing compartment by a metallic tube 58 is a housing 62 containing a vacuum pump. Refrigerating equipment 64 is connected to a coil 66 in the condensing compartment by a pair of tubes 68, 72. Separating the condensing compartment 52 and the drying compartment 54 is a metallic honeycomb network 74, each cell of the honeycomb being a waveguide beyond cutoff for energy at the lowest frequency to be used in the device. Thus, gases freely pass into the condensing compartment through the cells of the network 74, while microwave energy is reflected thereby.

Container 50 is provided at the end opposite the condensing compartment with a flange 76 to which is attached a removable metal container 78 having a radiating compartment 80. A low-loss dielectric window 82 is seated against the flange by member 84 and provides a vacuum-tight seal for the drying compartment. Radiating compartment 80 transmits microwave energy from a source of microwave energy such as a magnetron 86 into the drying compartment. Energy is coupled from the source 86 into the radiating compartment 78 through a dielectric window 90 which terminates a coaxial line formed by a coupling probe 92 and an outer sheath 94.

The construction of FIG. 5 allows gases and vapors to pass through the network 74 where they are condensed and removed from the oven. However, since the network 74 acts as a waveguide beyond cutoff, microwave energy does not pass into the compartment 52. Therefore, any products of condensation in compartment 52 are not heated by the microwave energy, and no additional power need be supplied for this purpose.

Referring to FIG. 6, there is shown an embodiment of the invention wherein microwave equipment can be easily added to existing vacuum dryers or incorporated in new installations. A drying compartment 100 is formed of a metallic member 102 having an end wall 104. Surrounding the member 102 on three sides is a metallic outer sheath 105. In order to evacuate the working space 106 of the drying compartment, a tube 107 connected to a vacuum pump (not shown) protrudes through sheath 105 into the drying compartment 100. To prevent any microwave energy from leaking out the tube 107, a metal plate 108 is spaced from end wall 104 by supports 112 to form a waveguide beyond cutoff with the end wall.

Drying compartment 100 is sealed on the right end by a low-loss, transparent, dielectric window 114 seated between a pair of flanges 116, 117 and abutting adjoining flanges 119, 120. The flanges 116, 117 are connected together and are pivotally mounted on a shaft 121. Further, a hinge 122 connects the members associated with flanges 119 and 120. Thus, the dielectric window 114 acts like an inner door allowing the contents in the drying compartment to be viewed without disturbing the vacuum.

Microwave energy is radiated into the drying compartment from a generator 126 symbollically indicated as a magnetron having a pair of magnets 128, 132 from creating a magnetic field in a housing 134. The generator structure is mounted on a wall 136 which forms a divider for a housing 138. Also housed within the same compartment as the generator are a power transformer 139 and other associated equipment 140. Cooling of the magnetron is obtained by means of tubing 142 through which liquid is circulated by means of a pump 144. The tubing 142 may be mounted either flat against the housing 138 or can form part of the housing 138.

Energy is coupled from the magnetron 126 into a radiating compartment 146 through a probe 148 enclosed in a pressure-sealed dielectric member 152.

A paddlewheel-type reflector formed of a pair of vanes 154, 156 pass closely over and around the ouput coupling probe 148 of the magnetron. The vanes are connected to a shaft 158 which is driven by a pulley 162 connected to a motor (not shown). Close coupling between the probe 148 and vanes allows the vanes 154, 156 to efficiently "spray" the interior of the working space 100 with the microwave energy radiated axially into it. Further, the use of vanes 154, 156 allows the axial length of the radiating compartment to be greatly reduced.

Referring now to FIG. 7, there is shown a different embodiment of the radiating element of FIG. 6, and similar parts in those two figures bear the same reference numerals. An output coupling rod 162 is coupled to a source of energy **164** such as a magnetron. A dielectric member **166** provides a vacuum seal between the magnetron **164** and a compartment **168**. Energy from the rod **162** is transferred to a rotating coupling element **170** which is directly coupled to a spiral antenna **172**. Energy is uniformly radiated from the antenna **172** into a metal housing **174** forming a radiating compartment. One end of the compartment is formed of a dielectric window **114** which allows energy to be transferred from the radiating compartment into a drying compartment **100**.

Portion **178** of the antenna **172** which is straight is mounted in an insulating body **182** which has the combined function of an insulated support for the rotatable coupling element **170** and the portion **178**. The body **182** has teeth **184** notched thereon, which mate with a worm gear **186** driven by a motor not shown. Rotation of the body **182** rotates the antenna **172** and element **170**, thus allowing energy from the magnetron to be uniformly radiated in the drying space. While a spiral antenna has been shown, it would be obvious that other modifications could be used.

Obviously, many other modifications and variations of the present invention are possible in the light of the foregoing teachings. It is to be understood, therefore, that the invention is not limited in its application to the details of construction and arrangement of parts specifically described or illustrated, and that within the scope of the appended claims, it may be practiced otherwise than as specifically described or illustrated.

I claim:

1. Drying apparatus comprising a conductive enclosure for receiving an confining microwave energy, a substantially vacuum tight dielectric partition within and in contact with said enclosure thereby dividing said enclosure into a conductive radiating enclosure and a conductive drying enclosure each adapted to confine microwave energy, a source of microwave energy, means for coupling energy from the source to the conductive radiating enclosure whereby said microwave energy is uniformly transferred into the conductive drying enclosure through the partition.

2. Apparatus in accordance with claim **1** wherein the conductive radiating enclosure is horn-shaped, the source of microwave energy being coupled to the small end of the horn and the dielectric partition being at the other larger end of the horn.

3. Apparatus in accordance with claim **1** wherein the conductive radiating enclosure substantially surrounds the conductive drying enclosure on three sides.

4. Apparatus in accordance with claim **1** and further including a rotatable dielectric drum in the conductive drying enclosure, and means protruding through the conductive drying enclosure for feeding material to be dried into the drum whereby material in the drum is uniformly dried.

5. Apparatus in accordance with claim **1** and further including a condensing enclosure adjacent the conductive drying enclosure, means forming a waveguide beyond cutoff for microwave energy in the conductive drying enclosure separating the conductive drying enclosure and the condensing enclosure whereby gases may freely pass from the conductive drying enclosure into the condensing enclosure, and means in the condensing enclosure for condensing and removing the gases therefrom.

6. Drying apparatus comprising, a conductive drying enclosure adapted to confine microwave energy, a conductive housing containing a source of microwave power, the conductive housing being removably connected to the conductive drying enclosure, means for coupling said microwave power to a radiating element in said housing, and a dielectric partition separating the conductive housing and the conductive drying enclosure.

7. Apparatus in accordance with claim **6** wherein the coupling means includes a probe for connection to the source, and wherein the radiating element is arranged to rotate and transfer energy from the vicinity of the probe into the conductive drying enclosure.

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JOHN J. CAMBY, *Acting Primary Examiner.*

NORMAN YUDKOFF, WILLIAM F. O'DEA, *Examiners.*