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Boucher

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[54] **METHOD AND APPARATUS FOR SURFACE STERILIZATION**

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[52] **U.S. Cl.** ..... **21/54 R,** 21/58, 21/83, 21/85, 21/86, 21/102 R, 21/DIG. 4, 219/10.55

[51] **Int. Cl.** **A61l 1/00,** A61l 3/00

[58] **Field of Search** ..... 21/54, 102, 91, 92, 21/93, DIG. 4; 99/217, 219, 221, 253; 219/10.55

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[57] **ABSTRACT**

A method and apparatus for the rapid sterilization of a contaminated surface which involves the use of microwave energy fields combined with a humid atmosphere having a relative humidity of at least 50 percent. The material to be sterilized is placed into a self-sealed container at least partially transparent to microwaves. Said container is then introduced into an oven cavity. The moist atmosphere is confined inside the container walls. Through both thermal and non-thermal effects, surface decontamination by electromagnetic radiation takes place in a matter of minutes. The apparatus of the invention eliminates potential oven walls contamination and is entirely safe from the radiation view point. It can be operated by unskilled personnel.

16 Claims, 3 Drawing Figures

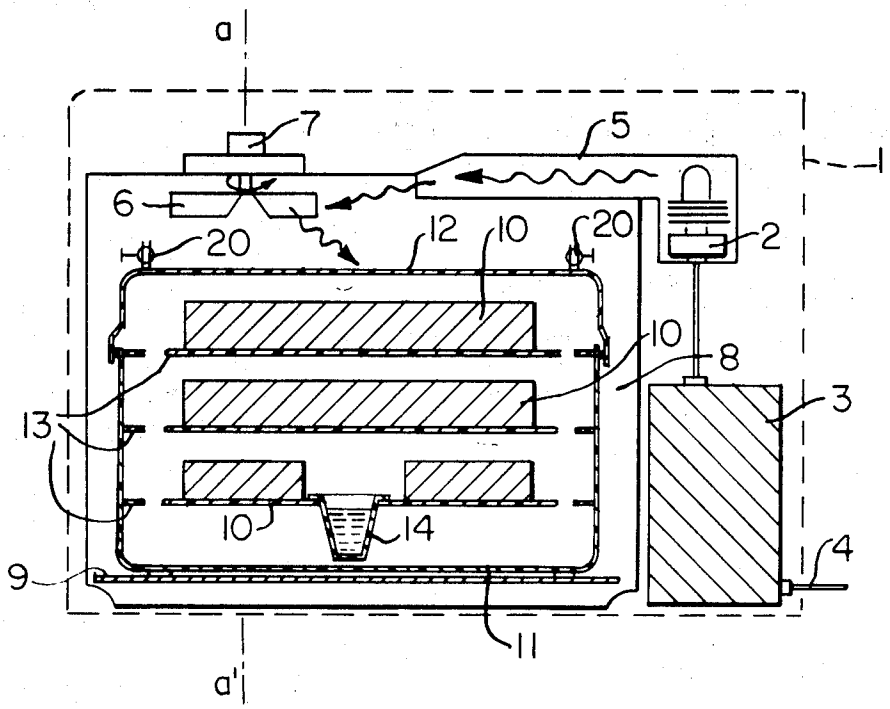


FIG. 1.

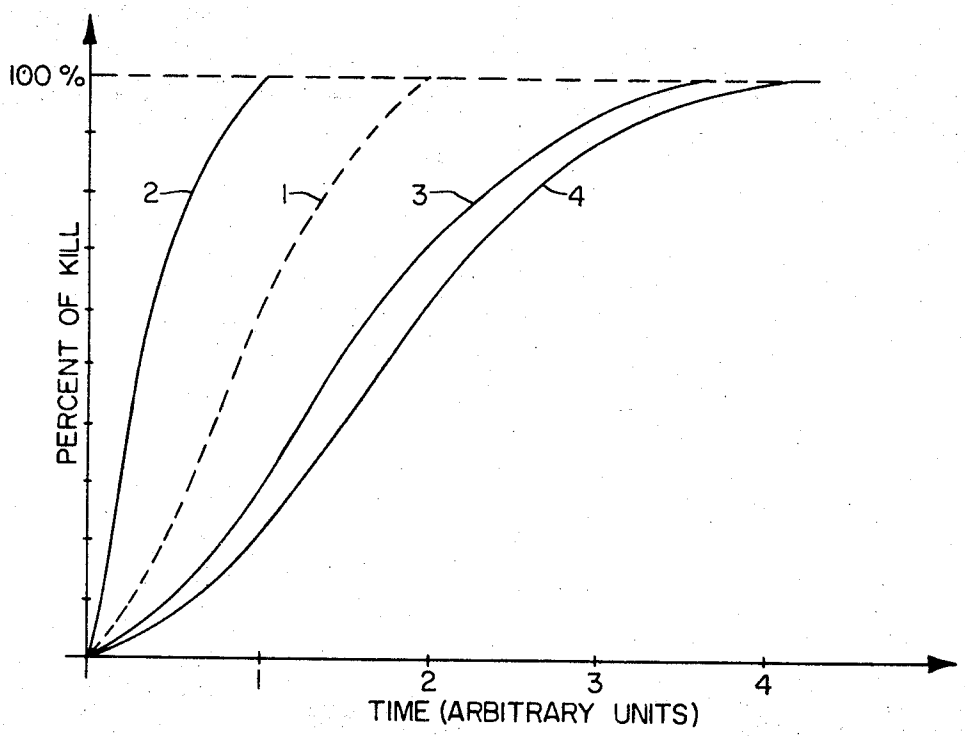


FIG. 2.

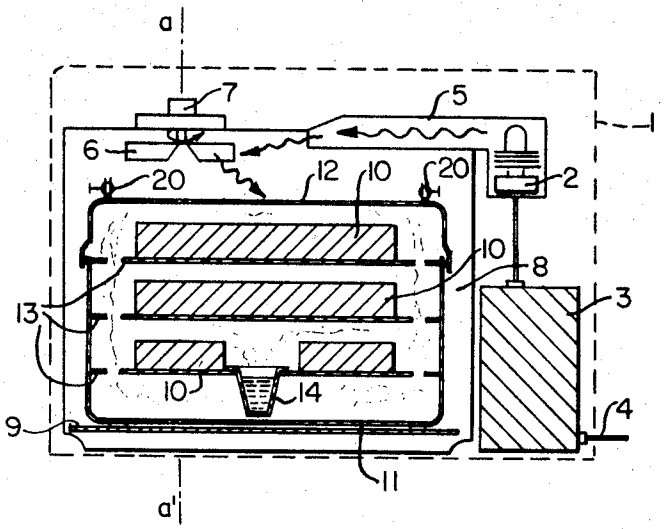
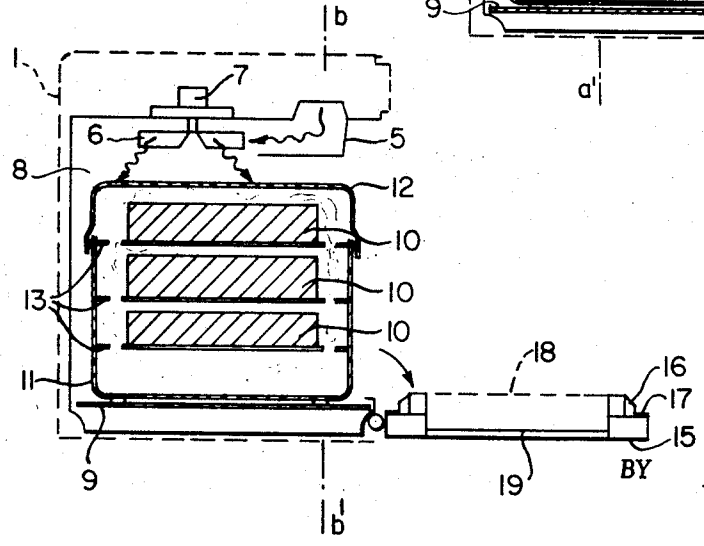


FIG. 3.



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METHOD AND APPARATUS FOR SURFACE STERILIZATION

This invention relates to a method and apparatus for surface sterilization of laboratory, medical and dental instruments in a moist atmosphere at lower temperature than those presently used and in a shorter period of time by means of electromagnetic radiation in the microwaves range.

In the past, several attempts have been made to use microwaves for the destruction of microorganisms. We shall recall for instance the experiments conducted for pasteurization of raw milk (M.A.K. Hamid and col., Journal of Microwave Power, 4-4, 1969), pasteurization of baked goods (R.B. Decareau and col., Journal of Microwave Power, 3-3,1968), irradiation of potato waste water (M.A.K. Hamid and col., Journal of Microwave Power, 5-1, 1970) and the destruction of larvae and insects in grain (M.A.K. Hamid and col., Journal of Microwave Power, 4-1, 1969). Unfortunately serious limitations (short exposure time) were always placed on these methods which dealt with the continuous processing of a dynamic stream of liquids pr products. The efficiency of microwaves sterilization is essentially a function of both the density of electromagnetic energy and exposure time. It depends also on a large extent upon the physical characteristics of the irradiated material (moisture content, dielectric loss factor, etc.) Therefore, to successfully develop an economical method for the destruction of microorganisms one must be able to use a reasonable exposure time (at least several minutes) which will in turn enable to operate with relatively inexpensive power sources commercially available in the kilowatt range.

A laboratory type sterilizer would fulfill such requirements since it will be a safe and relatively uncomplicated instrument which will easily compete with other systems such as dry heat or steam sterilizers; which both require longer exposure time (at least an hour) to destroy thermal resistant spores (B. *Subtilis* var. niger., B. *Stearothermophilus*, C. *Botulinum*, etc.) It is, however, to be understood that the object of the present invention deals exclusively with surface sterilization. In other words, we speak of the destruction of bacteria, spores, viruses, etc. deposited at the interface of solids. "In depth" sterilization of certain solids by microwave (thermal effect) may also be successful in some particular instances, but the present invention does not intend to cover such special cases.

Although scattered information found in the scientific literature mentioned examples of fast microwave sterilization of various contaminated surfaces, no commercial system has yet been developed or built for this purpose. During our experimentation, we discovered that the main reason for this failure was due to the fact that few scientists maintained the right humidity at the level of the irradiated microorganisms. It is only through a combination of proper humidifcation with the thermal and non-thermal effects of microwaves irradiation that reproducible and satisfactory results can be obtained with a wide variety of species including thermoresistant spores.

It is, therefore, an object of this invention to provide a method to surface-sterilize, in a matter of minutes, laboratory, medical, dental tools, instruments and other goods.

It is also an object of the present invention to surface-sterilize at a far lower temperature than those encountered today in dry heat and steam sterilizers, thus allowing the decontamination of numerous laboratory instruments or components made of plastic or low melting point materials.

It is a further object of this invention to surface-sterilize heat sensitive laboratory equipment, products and components which otherwise would be damaged by dry heat or steam processing.

It is a further object of this invention to quickly surface-sterilize all types of surfaces without any need to later decontaminate part or totality of the sterilizer between runs.

It is a further object of this invention to provide an apparatus which will be automatic, completely safe and would allow fast surface-sterilization in batches by non-skilled personnel.

It is a further object of this invention to provide a microwave apparatus for surface-sterilization which will eliminate any risk of arcing or metal instruments piting during processing.

It is a further object of this invention to provide a microwave apparatus with a cavity into which interchangeable loaded containers, transparent to wave energy, will be inserted. Said containers being filled with both the material to be sterilized and the liquid to be evaporated to achieve a faster destruction of the microbiological contaminants.

Other objects, advantages, features and uses will be apparent during the course of the following discussion. To aid in the understanding of the present invention, we shall briefly discuss the mechanisms by which microwave energy destroys microorganisms at gas/solid interfaces.

As is well known, microwave energy is coherent electromagnetic energy. By this we mean that it is ordered. In other words, we can readily identify its characteristics and can control it with precision. Thermal energy, on the other hand, has random, disordered, characteristics which are not so easily controlled. Although the term microwave, in general, may cover a rather wide range of frequencies (from 100 MHz up to several hundred thousands MHz) the present invention mainly contemplates the use of frequencies between 100 and 23,000 MHz.

Any biological material irradiated by microwaves is submitted to two different effects: the first of a thermal and the second of a non-thermal nature. Let us start with the purely thermal effect which is in general more widely known (often referred to as "microwave heating").

The mechanism through which microwave heating occurs at the above-mentioned frequencies is based upon the dipole moment, or "polarization" of the molecules of the irradiated substance. When the polar molecules (absorbed water in cellular organisms for instance) are subjected to a strong alternating field, their rapid reorientations within the field create some kind of internal friction resulting in heat. In a more precise sense, one could say that heat is produced through the conversion of the potential energy of polarization into random energy. It is important to note that with microwave heating, no contact with the substance itself is required. In other words, the transfer of energy takes place directly without the necessity of an intermediate medium such as a hot surface or a high temperature air

stream. Energy transfer occurs wherever the field penetrates. By a proper choice of the materials used in the construction of the components of our instruments-sterilizer it is then possible to produce heat exclusively inside the irradiated microorganisms while keeping the walls and all the other components and interfaces of the processing chamber cool.

The advantages of this approach over conventional, dry heat sterilizers based mainly on heat conduction and convection phenomena are numerous. Microwave heating eliminates the inherent inefficiency of transferring heat from an external source to the processed load. Since microwave energy can be switched on to full power levels and off again by simply flipping a switch, the time lags associated with thermal processes are not present either. As an example, we shall recall that an efficient dry heat sterilizer (Dri-Clave Bulletin, Westbury, L. I. 1956) will require a warm up time of 15 minutes to reach the operational temperature of 320°F.

Also of great importance is the fact that all the risks associated with the presence of high temperature radiating elements (dry heat sterilizers) in contact with potentially explosive gas mixtures, are eliminated. This is indeed a tremendous advantage in operating rooms or clinical laboratories where various exotic gases (anesthesic, oxygen, etc.) are often in use.

In first approximation, the amount of power that can be delivered to a standard unit of volume of water containing microorganisms is proportional to the product e tan Sf E^2 where e is the permittivity (the amount of electric field that is produced by the molecules for a given applied field), tan S is the loss tangent of the material (proportional to the conductivity), *f* is the frequency and E is the electrical field strength. Since the product e tan S will vary for each microorganisms species, different irradiation times will be needed for sterilization through a purely thermal effect when using a fixed output power at a fixed frequency.

Let us now review the present knowledge of the mechanisms of heat sterilization since it may shed light on some peculiar aspects of microwave sterilization phenomena.

It has long been known (Chick, 1908–1910) that thermal death of bacterial cells and spores is logarithmic. There are, however, numerous exceptions (Reynolds and LIchtenstein, 1952) which exhibit sigmoidal curves. This led to the adoption of a theory (Charm, 1958) called "The Distribution of Resistance" which among other things pointed out the existence of non-uniform heat resistant spores.

When applying heat to a microorganisms population (spores for instance) it seems to be well understood that deviation from the linear logarithmic nature of the survival curve is generally due to two basic factors: (1) The presence of a hump or "lag" in the initial portion of the survival curve is due to heat "activation;" (2) The presence of a tailing of the final portion is due to the presence of thermoresistant variants in the population.

An energy of "activation" is generally necessary to initiate a chemical or biological process, in the case of spores, it is the energy necessary to release spores from their dormant state to begin their germination process. There is also an activation energy requirement to inactivate (lethal effect) microorganisms. Heat activation and inactivation both obey first order kinetics (Busta and Ordal, 1963), in combination and in that order. The moment a spore becomes activated, it is subjected to the inactivation law. A mathematical approach to this complex problem has been attempted recently (Shull, Cargo and Ernst, 1963) and seems to have given satisfactory results with Bacillus *Stearothermophilus* spores.

The effect of heat on microorganisms is in general regarded as the result of enzyme inactivation, proteins denaturation, or both. This is, in other words, the integer of several complex phenomena. Among the various factors to consider during heat sterilization, one must mention the widely different thermal resistance of spores. A species of bacterial spore highly resistant to moist heat is not necessarily highly resistant to dry heat and vice versa. For instance, to inactivate 100,000 spores of B. Stearothermophilus in saturated steam at 121°C requires 12 minutes but 1,000,000 spores of B. Subtilis var. niger are inactivated in less than one minute at the same temperature. However, B. *Subtilis* var. niger is much more resistant to dry heat than B. *Stearothermophilus* under identical experimental conditions.

The type of heat flux (dry or moist), the manner into which the heat is generated or penetrates through the microorganisms (convection, conduction, radiation, etc.) are therefore extremely important. This could explain the fast killing rates observed with microwave energy which acts at once at molecular level and creates a coherent state of molecular turbulence throughout the entire irradiated mass.

In short, for an equivalent amount of thermal energy released through the same spore species various death rates will be observed according to the nature of the heating process. It is also true that the same heating process applied to different species may give different survival curves.

Another reason which could explain the efficiency of microwaves heating in spores destruction is the influence of molecular controlled agitation on ions. In 1957, Amahada and Ordal indicated that differences in degree and rate of thermal destruction might be associated with the loss of cations which enhance the thermal resistance of spores. DPA (pyridine-2, 6 dicarboxylic acid) which has been found in all bacterial endospores (Wooley and Collier, 1965) has been recognized with calcium as one of the main agents in thermoresistance. Both calcium and DPA may respond more effectively to friction heat caused by microwave energy and thus explain the faster killing rate observed with this kind of heat source.

Hereabove we have stressed the modifications produced in microorganisms by heat and the special role played by microwave induced heat. It is also important to consider the non-thermal effects of microwaves during sterilization.

Although very difficult to study separately, the non-thermal effects of microwaves (and electro-magnetic radiation in general) have been established beyond doubt and thoroughly investigated by several authors (See C.M. Olsen, Journal Micro. Power, 1-2 , 45–56, 1966). For instance, microspores of Fusarium solani f. phaseoli in water suspension (Baker and Fuller, 1965) were irradiated at 2450 MHz and compared with a treatment in water at a slightly higher temperature. Spores germination data showed that thermal treatment curves were guite conventional in shape but microwave treatment spores germinated on an "all or

nothing" basis. These data suggested that microwaves may affect a metabolic system distinct from that of thermal energy.

In another experiment C. M. Olsen irradiated at 2450 MHz three bread mold fungi during 2 minutes with a maximum end temperature of 65°C. When Penicillium sp. spores on the microwave treated bread were recovered and plated, counts showed there were only 0.1 colonies per plate while samples of unirradiated bread (same final temperature achieved by thermal means) yielded 1486 colonies per plate.

During studies in soil sterilization at 915, 2450 and 5800 MHz several fungi were irradiated and the maximum sterilization temperature was compared to the thermal death point. The latter, by definition, is the lowest temperature at which a suspension of bacteria is killed in 10 minutes. It was found, for instance, that a relatively large soil fungus, Rhizoctonia solani, was killed at a temperature about 10°C below that of its normal thermal death point. Verticillium albo-atrum, another soil fungus with extremely small spores, was killed at about 3°C below its lethal temperature. Non-spore forming bacteria, were in general killed by microwave energy at points as much as 10°C below thermal death point.

The non-thermal effects of microwaves on microorganisms can be due to several overlapping phenomena such as: high speed molecular oscillations which produce chemical bonds breaking, accelerated diffusion of ions through membranes, electrical charges modification at interfaces or P_h modification. Regarding chemical bond cleavage (C.M. Olsen, 1965) it has been shown that a few seconds irradiation at 2450 MHz of 0.1 N solutions of NaOH will produce hydrogen peroxide. The first 5 second exposure yielded about 0.01% H_2O_2 and each subsequent exposure yielded an additional amount. The temperature at the end of three 10 second (i.e. 30 seconds) exposures was about 100°C. When similar samples wree treated in a water bath to the same temperature, no hydrogen peroxide was detected with the UV absorption technique.

This, among other things, shows that the result of checmical bonds breakage can also be the production of new chameicals with sporicidal or bactericidal characteristics.

All the above described phenomena (dehydration and non-thermal effects) play a role in microwave surface sterilization and according to the type of irradiated microorganism and substrate, their contribution varies in importance. We, however, discovered that in all cases the sterilization rate was greatly improved when the original water content of the micrroorganisms was increased. This had already been noticed by other for the industrial processing of fungal spores. C.M. Olsen, for instance, mentioned that when Penicillium sp. spores were exposed to 40 percent relative humidity for 15 minutes prior to a 30 second microwave treatment (1350 watt output cavity), a 90 percent greater kill was recorded over that of microwave treated dry spores. This indeed makes sense from the theoretical view point (Alderton and Snell, 1963) since as previously stated ion enchange phenomena in liquid phase are one of the keys to thermoresistance.

It is also important to recall that microwave sterilization is a function of both the electrical energy density of the field and the exposure time. Most of the attempts made in the past to assess microwave sterilization economics were geared to the use of continuous irradiation processes (irradiated tunnel with conveyor belt system) at industrial scale. This indeed limited rather sharply the practical exposure time.

The method object of our invention does not have such limitations since it will compete with other established techniques (dry heat and steam sterilizers) which necessitate at least thirty minutes of residence time. In FIG. 1 we show the trend of three typical spores kill curves as a function of time. The curve No. 1 (dotted line) represents the microwave kill curve without prehumidifying of the microorganisms. Curve No. 2 shows under the same experimental condition the percent of kills with humidifying. Sigmoidal curves No. 3 and No. 4 correspond to dry heat and steam sterilization.

The method of surface sterilization, object of the present invention, consists of a combination of microwaves irradiation in an oven type cavity within an atmosphere partially saturated (at least 50 percent R.H.) or super saturated with water or a saline solution. The water or saline solution can be present as a vapor or as an aerosol dispersion (i.e., liquid droplets smaller than 10 microns). Slightly saline solutions (0.1 to 0.5 molal NaCl solution) are particularly suited since their high dielectric loss factor (between 200,000 and $400{,}000.10^4$) enables a quick evaporation in the microwave field. The water or saline solution to be evaporated is placed inside a plastic or paper container transparent to microwave energy. The instruments, tools or material to be sterilized are also placed inside the container and are therefore in direct contact with the moist atmosphere. The container is self-sealing with a lid and retains the vapor or aerosol phase during the sterilization. It therefore avoids any contact between moist air and cavity oven walls. This new method provides a solution to the problem of the contamination of the microwaves cavity walls. The use of an open container with water, or any other suitable liquid, placed directly with the instruments inside the microwave oven cavity would obviously create a severe contamination problem since some of the liquid in contact with living microorganisms during the irradiation could be reentrained or projected against the cool cavity walls where they would survive due to an insufficient dose of radiation. This would necessitate a tedious and lengthy decontamination of the cavity after each sterilizing run.

To the contrary the method object of the present invention does not necessitate such decontamination of the cavity walls since the container is introduced inside the microwave oven as a sealed gas-tight unit. The container can be made of disposable hard paper or plastic transparent to microwave energy. The shape of the container is such that it provides room for both the material to be processed and the humidifying solution. The volume of the humidifying solution is calculated to correspond after evaporation to partial (at least 50 percent RH) or complete saturation of the container volume without its load. When the microwaves cavity is turned "on" the electro-magnetic energy penetrates through the container walls, it then evaporates the water which "conditions" the microorganisms. At the same time, electro-magnetic waves proceed with their thermal and non thermal effects. The whole operation results in a considerable gain of time (often a matter of minutes) when compared to the dry heat or steam sterilizing methods. If using a molded container made of

reusable plastic, the container can indeed be sterilized separately at the end of each operation.

Another advantage of the method hereabove described lies in the fact that intense microwave fields in the presence of metal objects (instruments, etc.) can produce localized arcing which will pit the metal surface. In the presence of a moist atmosphere this important drawback is practically eliminated. The invention, contemplates the use of either a continuous wave emission or a pulsed wave emission in an oven type cavity. In the latter case, the average power requirements will be decreased while the lethal effects on microorganisms will be enhanced due to sharp variations in the electrical field gradient (A. P. Wehner, Int. Journ. Biometer, Vol. 7 No. 3, 277–82, 1964).

Having described our microwave sterilization technique in a moist atmosphere, we shall now describe, by way of a non-limiting example, one embodiment of the apparatus of the present invention, as shown in the accompanying drawings.

FIG. 2 is a simplified cross-sectional front view of a preferred form of apparatus of the invention taken along line *b—b'* as seen in FIG. 3.

FIG. 3 is a simplified cross-sectional view of the apparatus of FIG. 2 taken along the line *a—a'* in FIG. 2 with the front door in an open position. (Position used to insert or remove the container before and after sterilization).

As can be seen from FIG. 2, the apparatus consists of a metal housing 1 quite similar to those used today in microwave ovens. Located within the housing are the main components of the microwave system. They comprise the magnetron 2 which, with the help of the transformer, rectifier and magnetic field circuit (all contained in the power pack 3), converts the 60 cycle AC current from the line 4 into microwave energy. The high power beam of microwave energy is contained in a wave guide 5 and directed against the blades 6 of a fan 7 which rotates at a slow RPM. The fan, often called stirrer, reflects the power beam bouncing it off the walls, ceiling, back and bottom of the oven cavity 8. At the bottom of the oven cavity 8 one can see a Pyrex glass plate 9 transparent to microwaves, which is suspended approximately one inch above the metal bottom of the processing cavity. The instruments or materials to be surface-sterilized 10 are placed inside a gas-tight sealed container 11 which is positioned in the oven cavity 8 and rests upon the glass plate 9. The container 11 can be made of any material transparent to microwave energy: plastic polypropylene, polyethylene, polystyrene, teflon, etc.), paper or special glass composition. The container 11 shown in FIG. 2 is of parallelepipedic shape with an upper lid 12 also made of microwave transparent material. The container can be designed in any form and shape as long as the microwave energy will penetrate through it from all directions when placed inside the oven cavity 8. As can be seen, the container 11 of FIG. 2 contains three trays 13 which support the workload (instruments placed in a perforated basket for instance). The trays are perforated to let the moisture penetrate throughout the entire processing area. The water or solution to be evaporated or aerosolized is placed in a plastic or disposable paper cup 14 inside the container.

FIG. 3 is a cross-sectional side view of the apparatus at the plane of the stirrer. We show in FIG. 3 the drop-down door 15 in an open position. To decrease radiation leaks the door is equipped with a quarter wave choke seal 16 in addition to an absorber seal 17. The choke cavity is filled with polypropylene for instance while the secondary seal is made of vinyl loaded with carbon black. The door is equipped with a viewing screen 18 made of perforated stainless steel (diameter holes 0.0265 inch). Transmission through this viewing screen is approximately −70 db. In some cases added protection is given to the door by the addition of a glass or optically transparent plastic plate 19. This means that when the door is closed the maximum of radiation leakage in the immediate vicinity of the door is well below the 1 mW/cm^2 specified by the US Public Law, 90-602. Of course, a unit as shown in FIG. 2 and 3 has other standard safety features such as door interlock switches which are not shown for the sake of clarity since they are the kind of standard feature well known to the man of the art. Also not shown for the same reason are other common features such as timer, oven and dial lights, start switches, stirrer shield and blower used to cool the magnetron tube.

It is obvious that within the scope of our invention any gas can be used to fill the gas-tight container. This means that according to the type of microorganisms one can also take advantage of the chemical effects of gas sterilants, vapors or aerosols, such as ethylene oxide, propylene oxide, formaldehyde, methylbromide, chloropicrin, epichlorohydrin, ethyleneimine, glycidaldehyde, peracetic acid, glutaraldehyde solution or any other chemical with known bactericidal or sporicidal characteristics.

In the case of using such chemicals, precautions must be taken to operate during a period of time short enough to avoid any irradiated part to reach a temperature close to the ignition or explosive point. Mixtures of gases which decrease the flammability or explosive point are recommended. As an example, we can refer to the use of carbon dioxide or fluorinated hydrocarbons mixed with ethylene oxide.

There are indeed several ways to introduce sterilant gases into a container such as represented in FIG. 2. As an example, we show in FIG. 2 two stopcocks or valves 20 which when open would enable introducing the sterilant gas with or without the help of vacuum.

Without departing from the framework of the present invention it must be well understood that, according to the results derived, the present invention can be applied to variable volumes of different gases at different temperatures or at multiple pressures, and that, still without departing from the scope of the invention, the structural details of the described apparatus, the dimensions and the shapes of their members (such as the shape of the container) and their arrangement (position of trays inside the container) may be modified, and that certain members may be replaced by other equivalent means (Magnetron replaced by klystron or amplitron tubes.)

In order to illustrate the possibilities of the invention more concretely by a precise example, but without limiting the scope of the invention, following is an example of a sterilizing operation.

The tests were conducted with a Magnetron type apparatus whose cavity had the following dimensions: height 8 ½ inch, width 15 ½ inch, depth 13 inch. The Magnetron emitted at a nominal frequency of 2540 MHz (±25 MHz). The electrical energy input to the

TABLE 1

50 Spordex strips (*B. Subtilis*) and 25 control strips are used in each experiment. Microwave Frequency: 2540MHz; Energy Density: 0.023 watt/cm³

Experimental Conditions	Incubation time in hours	Number of Irradiated Test Tubes With Growth	Number of Control Test Tubes with Growth
Microwave with moist air 10 minutes irradiation	24	0	25
	48	0	25
	72	0	25
	168	0	25
Microwaves without moist air 10 minutes irradiation	24	4	25
	168	5	25
Dry-heat at 160°C 15 minutes	24	9	25
	168	10	25
Dry-heat at 160°C 30 minutes	24	0	25
	168	0	25

Magnetron tube was approximately 1200 watts. Under loading conditions the average amount of microwave energy radiated in the cavity was 650 watts. (Minumum 605 watts — Maximum 675 watts)

Inside the cavity we placed a teflon container whose volume was approximately half a cubic foot. In the container was also placed a cup filled with 25 cm³ of water. The container had two perforated trays on which the samples were placed among a load of instruments and gauze. The samples consisted of fifty SPORDEX Bacterial spore strips from the American Sterilizer Co. The Bacillus Subtilis population of each strip was said to average 100,000. Since each package of SPORDEX contained three strips, two were used for our test and the third one was always kept as a reference.

The microwave surface-sterilizer was turned on and kept running for ten minutes. The spore strips were then removed and under sterile conditions were individually placed in labelled test tubes, each containing 25 cm³ of sterile fluid thioglycollate medium. The control strips left unsterilized, were also placed into test tubes containing the same medium.

Table 1 gives the results of our tests for various incubation times. A second series of tests was then conducted under identical conditions without any humidification (no water in the cup inside the teflon container). Results of such tests are also given in Table 1. A third series of tests was also conducted, for comparison purposes, with the same load and number of spores strips inside a DRI-CLAVE (model 75) dry heat sterilizer. The dry heat sterilizer was run at 320°F (160°C) for 15 and 30 minutes.

Data from Table 1 clearly show the advantage of the object of our invention. They also show the tremendous reduction in processing time when comparing our method with dry heat sterilization.

The teachings of the invention may be practiced within the following parameters:

a. Microwave Energy —

Nominal frequency: 100 MHz to 300,000 MHz

Average radiated energy level inside the cavity (i.e. total power output divided by cavity volume): Higher than 0.01 watt/cm³.

Type of wave: Continuous pr pulsed emission at a repetition rate between one per nanosecond and one per minute.

b. Humidity in processing chamber: Higher than 50 percent relative humidity at the gas temperature during processing.

c. Any gas in the container at a temperature safely below its ignition or explosive point.

While the invention has been described by means of specific examples and in a sepcific embodiment, it is not limited thereto, for obvious modifications will occur to those skilled in the art without departing from the spirit or scope of the invention.

We claim:

1. The method of destroying surface deposited micro-organisms including bacteria pathogens, viruses and spores like organisms which comprises:

providing a gas-tight container made of a material at least partially transparent to microwave energy;

placing a contaminated material into said container and sealing said container;

placing said container and the material confined therewithin into a microwave oven having top, bottom and opposite side walls defining a processing cavity therein;

creating a microwave energy field inside said cavity;

irradiating said container and contaminated material with said microwave energy so that the contaminated material remains at a temperature lower than saturated steam at atmospheric pressure;

and using a source of moisture separate from said contaminated material to create at least 50 percent relative humidity inside said container during irradiation, said microwave energy in conjunction with said at least 50 percent relative humidity destroying said microorganisms in a shorter time and at a lower temperature than heretofore obtained and without contaminating said oven walls.

2. The invention of claim **1**, wherein the microwave energy field has a frequency of from about 100 MHz to about 300,000 MHz, and an average electromagnetic density greater than about .01 watt/cm³.

3. The invention of claim **1** wherein the processing time is greater than 2 seconds.

4. The invention of claim **3** wherein the electromagnetic field is a continuous wave emission.

5. The invention of claim **3** wherein the electromagnetic field is a pulsed wave emission having a repetition rate of the order of between one per nanosecond and one per minute.

6. The invention of claim **1**, including the step of introducing a chemical having bactericidal or sporicidal effects into said sealed container.

7. The invention of claim **6**, including the step of introducing a gas sterilant into said sealed container.

8. The invention of claim **6**, including the step of introducing a sterilant vapor or aerosol into said sealed container.

9. The invention of claim **6**, wherein said chemical is a liquid and including the step of utilizing said microwave energy to evaporate said cehmical and thus produce said at least **50%** relative humidity inside said sealed container.

10. The invention of claim **6**, wherein the chemical sterilant is an organic compound selected from the group consisting of ethylene oxide, propylene oxide, methylbromide, chloropicrin, epichlorohydrin, ethyl-

ene immine, glutaraldehyde, formaldehyde, glycidaldehyde, and peracetic acid.

11. Apparatus for surface decontamination of contaminated articles comprising:

a microwave oven having top, bottom and opposite side walls defining a processing cavity therein;

means connected with said microwave oven for generating a microwave electromagnetic energy field inside said processing cavity;

a reusable gas-tight container for said articles and made of a material impermeable to moisture and at least partially transparent to microwave energy, said container having a readily removable top and a bottom and means for sealing said top to said bottom with said articles sealed inside said container, a receptacle for said separate source of moisture located within said container;

access means in said microwave oven for introducing into and removing said container from said processing cavity, and means in said container other than said articles for producing at least 50 percent relative humidity inside said container during irradiation of said articles with said microwave energy;

said at least 50% relative humidity and said microwave energy decontaminating said articles in a shorter time and at a lower temperature than heretofore obtained and without contaminating said oven walls.

12. The invention of claim 11, wherein the means for generating microwave energy includes a source of microwave energy, a wave guide connected between said source and said cavity, a means in said cavity in the path of the microwave energy entering said cavity from said wave guide to spread said microwave energy throughout said cavity, said oven walls made of metallic material to reflect microwave energy, and said access means comprising a door in one oven wall constructed to seal the processing cavity and keep radiation through said door to less than one milliwatt per square centimeter at a distance of two inches from said door.

13. The invention of claim 12, wherein said generating means comprises a source of continuous waves.

14. The invention of claim 12, wherein said generating means comprises a source of pulse waves.

15. Apparatus for surface decontamination of instruments or other materials comprising a housing, a cavity within said housing, a container in said cavity for said articles or other materials and made of a material at least partially transparent to microwave energy, means for sealing said container with said articles or other material therein, means connected with said cavity for generating a microwave electromagnetic energy field inside said cavity and said container, means in said container for producing at least 50 percent relative humidity inside said container during irradiation, said container having means associated therewith for selectively establishing communication between the interior of the container and the exterior of the container for introducing a chemical having bactericidal, or sporicidal characteristics into said container, means in said cavity for spreading the microwave energy field in all directions throughout the entire cavity and container, access door means in said housing for introducing and removing said container into and from said cavity, means to automatically expose the contaminated instruments or other materials to microwave energy for a period at least longer than two seconds and means to maintain the level of radiation through said housing to outside thereof during the radiation of said articles and other materials below 1 milliwatt per square centimeter at a distance of 2 inches from said housing.

16. The invention of claim 15, wherein the chemical sterilant is an organic compound selected from the group consisting of ethylene oxide, propylene oxide, methylbromide, chloropicrin, epichlorohydrin, ethylene immine, glutaraldehyde, formaldehyde, glycidaldehyde, and peracetic acid.

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