United States Patent

Johnson

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[54] CONTINUOUS MICROWAVE HEATING OR COOKING SYSTEM AND METHOD

[72] Inventor: **Ray M. Johnson,** 118 Verde Mesa, Danville, Calif. 94526

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[52] **U.S. Cl.** **219/10.55**

[51] **Int. Cl.** **H05b 9/06**

[58] **Field of Search** 219/10.55

[56] **References Cited**

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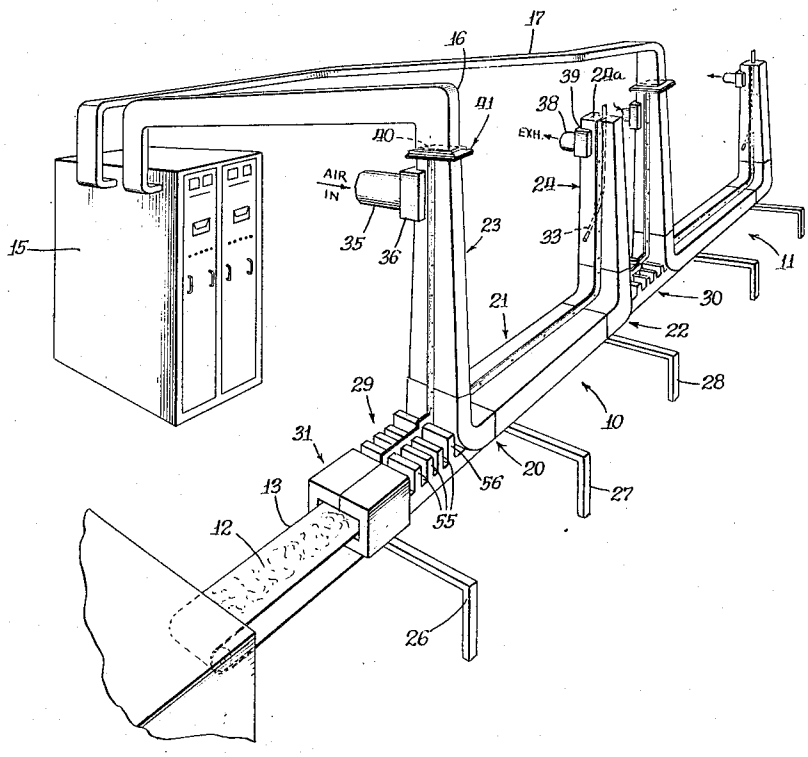
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Primary Examiner—J. V. Truhe
Assistant Examiner—Hugh D. Jaeger
Attorney—Carl C. Batz

[57] **ABSTRACT**

A rectangular type wave guide applicator having a pair of opposing broadwalls separated by a distance b, is excited in principally the TE_{10} mode; and material being treated is conveyed through the applicator along the direction of power flow. The distance *b*, is maintained throughout the applicator to be less than half a wavelength of the excitation frequency so that only TE_{mo} modes will propagate. Rejection filters are provided at the input and exit apertures through which the material is passed to prevent the escape of microwave energy without absorbing it. Air is circulated through the heating chamber for removing moisture and gases. A termination is provided downstream of the heating chamber in the form of a water load to absorb all microwave energy not absorbed in the material being treated to insure that the source sees a load which is substantially independent of variations in the amount of material being treated.

11 Claims, 4 Drawing Figures



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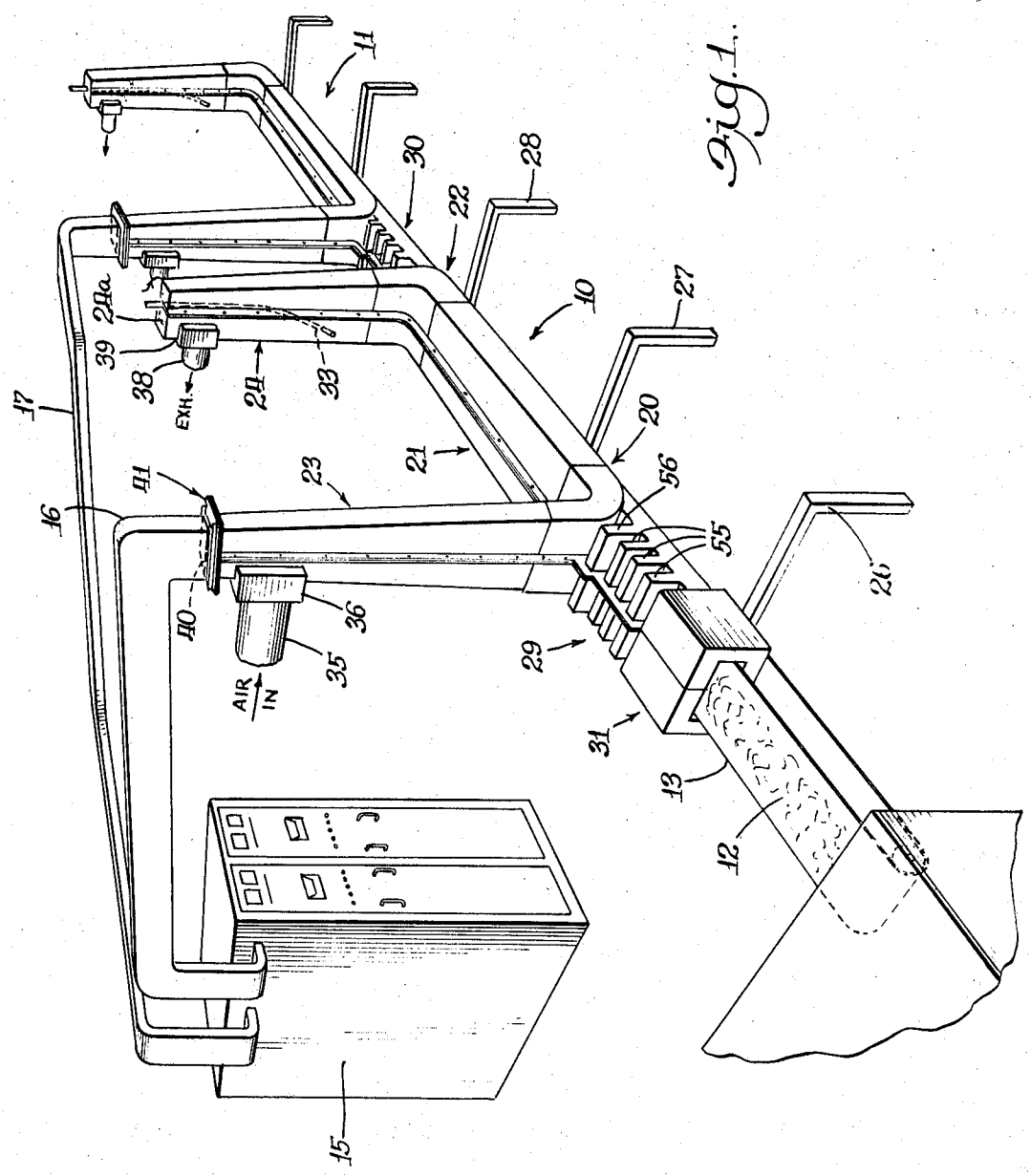
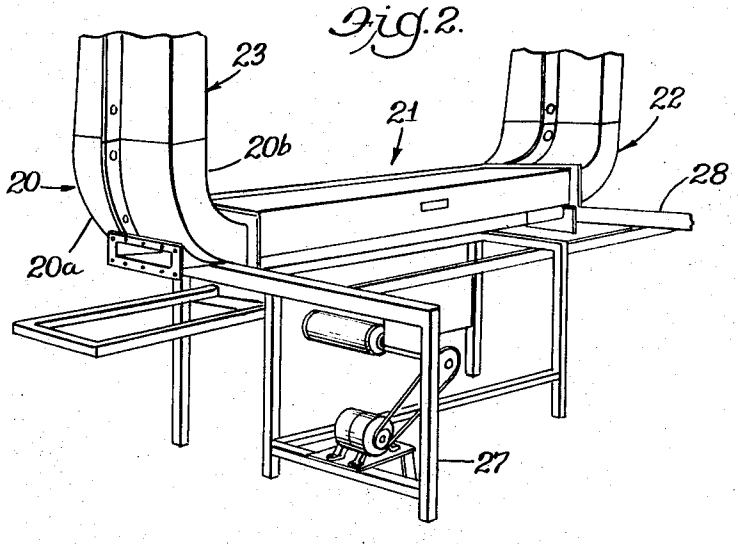


Fig. 1.

Inventor:
Ray M. Johnson

By: Carl C. Batz
Atty.

Fig. 2.



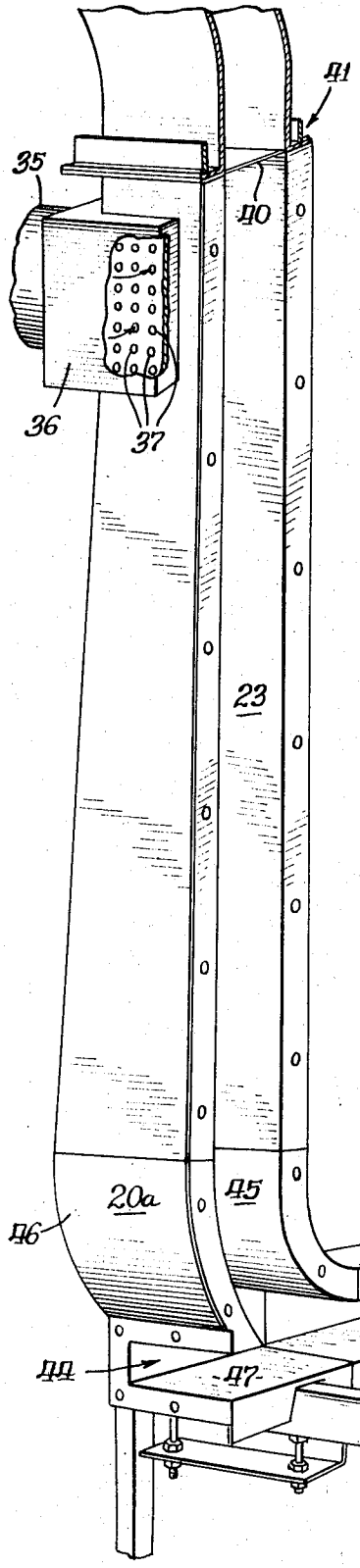


Fig. 3.

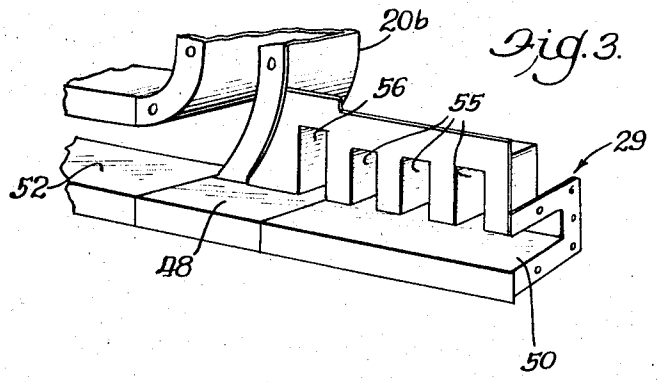
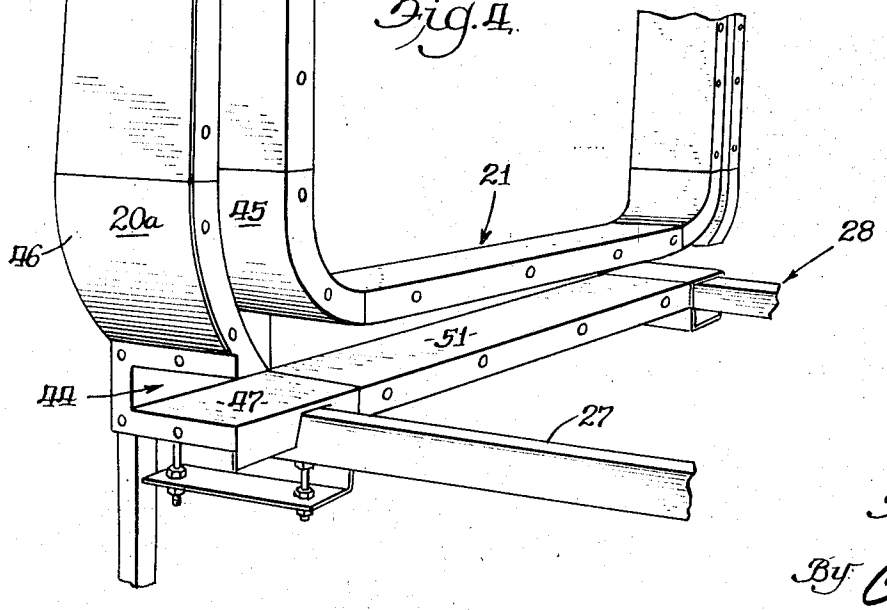


Fig. 4.



Inventor:
Ray M. Johnson
By Carl C. Batz
Atty.

CONTINUOUS MICROWAVE HEATING OR COOKING SYSTEM AND METHOD

This is a continuation of application Ser. No. 816,722, filed Apr. 16, 1969.

BACKGROUND AND SUMMARY

The present invention relates to a system for heating or cooking with microwave energy. In particular, the invention relates to a system for heating or cooking with microwave energy wherein the applicator in which the material is treated is a wave guide, as distinguished from a multimode cavity.

An early development in the field of microwave or electronic cooking was the construction of a box providing a cavity of generally rectangular shape and designed for heating food. The relative dimensions of wavelength and cavity at a given frequency are such that the cavity is several wavelengths on a side. Food material is placed in the cavity, the door closed, and the oven turned on. The oven is designed, by means of mode stirrers and reflectors, such that the heat generated in the oven is generally independent of the position of the material being heated. This type of oven is sometimes referred to as a "batch" type oven since the material is heated or cooked in a batch; and the oven must be shut down for putting food into and taking food from the oven. Sometimes these ovens are referred to as multimode cavities since they are designed to excite many different modes of the microwave energy within the cavity; and reflectors and stirrers are usually provided in an effort to evenly distribute the multimode microwave energy.

A continuous-type microwave oven was developed which feeds microwave power into an elongated tunnel through a series of slit openings spaced longitudinally of the tunnel. These tunnels served the same function as multimode cavities since a number of different modes were excited as the microwave energy entered the tunnel. A continuous belt conveyed the material being heated through the tunnel; and energy-absorbing devices (in the form of traps cooled by circulating liquid) were provided at each end of the tunnel adjacent the entrance and exit openings for preventing the escape of excess radiation and for absorbing excess microwave to prevent damaging the microwave system.

Another development included the use of a wave guide folded into a serpentine arrangement (sometimes referred to as a meander system) and arranged so that the product passes through a slot in the broadwall of the wave guide arranged in a number of such folds. Energy is piped into one end of the wave guide; and the energy level decreases along the length of the wave guide finally terminating in a water load.

A wave guide refers to a hollow pipe or conduit of generally closed cross section for propagating and channeling electromagnetic energy in the microwave region. The term wave guide is generic, as used herein, since it includes both the conduit which couples power from the source to the applicator as well as the applicator itself which provides the "heating chamber" or "treating zone," as it is sometimes referred to. The direction in which the energy propagates is referred to as the "z" direction. A "rectangular" wave guide is a wave guide of generally rectangular cross section, although it need not necessarily be a true rectangle.

The lowest order mode (i.e. TE_{10} mode) of propagation of microwave energy through a wave guide is characterized in that the electric field lines (or vectors) extend between two opposing wall surfaces (sometimes called the "broadwalls"), and that these field vectors are generally parallel to each other and perpendicular to the flow of microwave energy (or power). The "y" coordinate is taken to be the direction along which these field lines extend; and the "x" coordinate extends perpendicular to the y direction and to the flow of power. Hence, the x and y coordinates are orthogonal to each other and define a plane perpendicular to the flow of power through a wave guide.

In a wave guide of the rectangular type, the distance separating the broadwalls (i.e. taken along the y coordinate) is "b;" and the distance separating the other side walls (i.e. the width of the broadwalls and taken along the x coordinate) is "a."

The modes of operation refer to Transverse Electric field vectors; and TM modes refer to Transverse Magnetic field vectors.

The TE_{mn} mode of operation describes the electric field within the wave guide wherein: (a) there is no component of the electric field which extends in the z direction; (b) there are "m" nodes (minima or maxima) in the electric field intensity profile along the x direction; and (c) there are "n" nodes in the electric field intensity profile along the y direction.

Thus, the TE_{10} mode of operation in a wave guide refers to a condition wherein the electric field vector extends perpendicularly between the broadwalls (in the y direction), and there is substantially no electric field in the z or x directions. It will be appreciated that the foregoing explanations, which have been for purposes of illustration, are theoretical. In practice, these concepts are useful design tools only; and they are not to be taken as rigorous definitions of structure, operation or result. The free-space wavelength of the excitation frequency, λ_o, is the length of a period of the excitation frequency as it would exist if the wave were propagated through free space. The b dimension may be held at a value less than one-half the free-space wavelength of the excitation frequency to suppress the propagation of all TM modes and all TE_{mn} modes where n is an integer greater than zero. Further, the a dimension may be maintained to be greater than one-half of the free-space wavelength and less than one free-space wavelength to suppress TE_{mn} modes where m is greater than one.

In the TE_{10} mode, the intensity profile of the electric field varies according to a sinusoidal function from a minimum at one side of the treating zone through a maximum at the transverse center of the broadwall (i.e. $x=a/2$), and back to a minimum at the opposite side of the treating zone. Thus, for a given input power, the electric field intensity at the transverse center of the treating zone is at a maximum.

In the present system, wave guide means couples power from a source to a wave guide applicator of generally rectangular cross section having a pair of opposing broadwalls and a second pair of opposing side walls. The width of the broadwalls (which defines the separation of the opposing side walls) is a distance, a, and the width of the side walls (which defines the separation of the broadwalls) is a distance, b. The wave

guide applicator is excited by the source in the TE_{10} mode; and the *b* dimension is maintained to be less than one-half the free-space wavelength of the excitation frequency to inhibit propagation in modes other than TE_{mo} where m is an integer. Further design restrictions prevent excitation of modes where *m* is greater than one.

The advantages in using a wave guide as an applicator in heating or cooking material are manyfold in both efficiency and design. In a wave guide applicator in which a traveling wave is excited and power flows through the applicator, the modes of excitation and propagation are more controllable in the sense that a system can be designed to propagate only those modes which are desired. This leads to the ability to predetermine the dissipation of energy in the material being treated.

Further, as a practical matter, most sources of microwave power include a magnetron tube which is designed to generate microwave energy over a very narrow frequency band; and although the frequency of the magnetron may vary slightly (depending on the phase and magnitude of reflected power) its output power may drop markedly for such frequency variations. There is a complex interrelationship between the frequency of oscillation of a magnetron and the load which it feeds. Thus, if the load varies even slightly, the frequency of oscillation of a magnetron may shift and its output power may vary appreciably. If one is able to use a wave guide applicator then the load seen by the magnetron should be kept substantially constant even though the amount of material being treated may vary appreciably. Q is the ratio of reactive energy to dissipative energy. The maintenance of a constant load as seen by the magnetron keeps the operation of the magnetron within a very narrow frequency band at a low value of reflected power — thus preserving its operating life and insuring operation at a higher efficiency.

In the present invention, the material being heated or cooked is conveyed through the applicator along (i.e. in or against) the direction of power flow. Rejection filters may be provided at the input and exit apertures through which the material is passed to prevent the escape of microwave energy. Some systems wherein the applicator was of the multimode type, employ water traps at such openings in order to absorb any energy seeking to exit to these openings. The water traps, of course, absorb escaping energy. In the instant invention, I prefer to use reject filters to prevent the escape of the energy without absorbing it.

A termination may be provided downstream of the heating chamber in the form of a water load to absorb all microwave energy not absorbed in the material being treated. Thus, the source sees the material load and the water load in series; and energy not dissipated first in the material load is dissipated in the water load. This provides an advantage in that the source sees a constant load independent of the amount of material being treated; and this, in turn, permits the magnetron in the source to operate at a single frequency and thus extend its life and operate at a more efficient level. A distinction is made between the water load described here and a water trap used in certain multimode cavities. As already mentioned, such water traps are used primarily to absorb energy seeking to escape; and any such energy cannot be put into useful heating. The water load, on the other hand, only absorbs energy which has not been dissipated in the material being treated; and the above-mentioned reject filters perform the function of the water traps in preventing the radiation of energy from the input and exit apertures.

If desired, the present invention may be adapted so that air is circulated through the heating or cooking chamber; and it may be assembled to be easily dismantled for cleaning purposes. Further, the applicator of the present invention may be provided in modules which may be arranged in tandem for applications requiring greater amounts of energy.

Other features and advantages of the present invention will be apparent to persons skilled in the art from the following detailed description of a preferred embodiment wherein identical reference numerals will refer to like parts in the various views.

THE DRAWING

FIG. **1** is a perspective view of a continuous microwave heating or cooking system according to the present invention with two applicators in tandem;

FIG. **2** is a perspective view of the heating chamber and input and output elbows of an applicator according to the present invention;

FIG. **3** is a side perspective view of a half section of a reject filter as seen from the inside; and

FIG. **4** is a side perspective view of a separated half section of one of the applicators illustrated in FIG. **1**.

DETAILED DESCRIPTION

Referring first to FIG. **1**, there are shown two separate applicator sections, generally designated **10** and **11** respectively, which are arranged in tandem — that is, the material being treated is passed through the applicator sections **10** and **11** sequentially and in that order. The material being treated is schematically designated **12**; and it is supported by means of a continuously moving conveyor belt **13**. It will be appreciated that the present invention is not limited in application to the types of material being treated, and it may, for example, be chips of food or individual lots of food arranged in convenience sizes. Further, in applications for heating or drying, the conveyor belt need not necessarily be provided as in the case of drying continuous strips of wallboard, etc.

The applicator sections **10** and **11** are energized by means of a modular source of microwave energy generally designated **15** via wave guides **16** and **17** respectively. It will be appreciated that in a typical application, usually requiring fairly large amounts of energy, separate magnetrons or groups of magnetrons (or other microwave power tubes) will be feeding each applicator section. The power source **15**, for example may be capable of delivering a total of 50 kilowatts of power; so that 25 kilowatts of power are coupled to each of the applicator sections **10** and **11**.

Each of the individual applicator sections **10** and **11** may be identical in structure and operation (although the wave guides coupling power to the applicator section will, of course, be of slightly different configuration), so that only one applicator section need be explained in further detail for a complete understanding of the invention.

Turning our attention, then, to applicator section **10**, it includes an input elbow generally designated **20**, a heating chamber generally designated **21** and an output elbow generally designated **22**. The heating chamber **21** provides the treating zone. A tapered input coupling section **23** extending in a generally vertical direction couples power from the wave guide **16** to the input elbow **20**. A termination section **24** is connected to the output elbow **22**; and as can be seen from the drawing, the termination section **24** also extends in a generally vertical direction.

Since the input tapered section, the input elbow **20**, the heating chamber **21**, the output elbow **22** and the termination section **24** are themselves wave guides, a traveling wave flows through each of these sections in the order named; and power flows in a similar direction — that is, from the input tapered section **23** through the heating chamber **21** and to the termination section **24** via the elbows. Hence, when the terms "upstream" and "downstream" are used hereinafter, they refer to the direction of flow of power.

Each of the sections of the applicator just mentioned are formed of a conductive metal such as aluminum; and they are fabricated in symmetrical half sections with inner flanges extending in a vertical plane for suppressing radiation leakage or, if desired, for holding the halves together. The entire applicator may be separated along a vertical plane extending longitudinally of the heating chamber **21** for cleaning the interior of the applicator section. This is particularly advantageous when the system is used for cooking.

The applicator rests on horizontal cross bars of three metal horses designated **26**, **27** and **28** respectively.

An input rejection filter **29** is provided at the location in the input elbow **20** through which the material being heated enters the applicator, as will be described in more detail in connection with FIG. **3**. Further, an output rejection filter **30** is provided at the location through which the material being treated exits from the applicator. A pre-entry chamber of low power absorbing material **31** may be coupled to the input of the rejection filter **29**; and the chamber **31** and filter **29** are supported by the metal horse **26**. The input and output filters **29** and **30** are flanged similar to the individual sections of the applicator to facilitate fabrication and to permit convenient access to their interior for cleaning.

A liquid conduit **33** of electrically non-conducting material enters through the inner broadwall of the termination section **24**, extends through it, and exits through a top or end plate **24***a* of the termination section and thereby provide a water load for the applicator. An input air conduit **35** is coupled to the input tapered section **23** by means of a coupling box **36**; and, as can be seen more clearly in FIG. **4**, a plurality of apertures **37** are formed in one side wall and both broadwalls of the input taper section **23** to one side of its central flange to permit air to flow from the input air conduit **35** into the applicator. The air, forced by means not shown, then travels down through the input taper section **25** and enters the heating chamber **21** via input elbow **20**. The forced air exits through an output air conduit **38** which is coupled to the termination section **24** by means of a second coupling box **39**. Apertures similar to the previously-described aperture **37** are provided in the termination section **24** through which the exhaust air may pass. These air apertures are small enough to prevent the radiation of the microwave energy for the particular excitation frequency.

A thin dielectric membrane **40** (see FIG. **4**) is provided at the interface between the feed wave guide **16** and the input taper section **23** to prevent the flow of the circulating air back to the power source. An ON/OFF switch generally designated **41** is provided at the same interface; and it includes a metallic tongue capable of sliding through an aperture in the broadwall of the wave guide **16** for terminating the same in a first position. A second or ON position of the switch **41** permits the unattenuated flow of power to the taper section **23**. The switch **41** provides a safety device for preventing the flow of power to the applicator when it is dismantled for cleaning, etc. In the alternative, the switch **41** may be replaced with a choke joint with the advantage that it will permit the separation of the applicator halves without having to unbolt the flanges of the guide **16** and the input taper section **23**.

Referring now to FIGS. **2–4**, the input elbow **20** includes left and right (when viewed in the direction of power flow) side sections, denoted **20***a* and **20***b* respectively. The left sections **20***a* of the input elbow is seen in FIG. **4**; and the right sections **20***b* in FIG. **3**. The input elbow **20** changes the direction of power flow by 90°, receiving power from the generally vertical input taper section **23** and delivering it to the generally horizontal heating chamber **21**. An input aperture **44** is formed in the input elbow **20** through which the material being treated is admitted.

Referring now to FIG. **4**, the left section **20***a* of the input elbow includes first and second opposing broadwall sections **45** and **46** which are curved to define the direction of power flow. The input aperture **44** is, of course, formed only in the broadwall **46**; and a bottom plate **47** is formed as a horizontal tangent to a continuation of the broadwall **46**. Similarly, the right section **20***b* of the input elbow is provided with a bottom plate **48** which lies co-planar with the bottom plate **47** when the system is assembled. The left section of the applicator is secured to the iron horses **27** and **28**; and the right-half section of the applicator is movable along these supports.

It is important, for reasons explained in my co-pending, co-owned application WAVE GUIDE APPLICATOR SYSTEM AND METHOD, Ser. No. 817,097, filed Apr. 17, 1969, now U.S. Pat. No. 3,597,565, to introduce the material being treated at a location as nearly as possible to the bottom plates **47** and **48** in the input elbow so that the electric field intensity vector, excited in the TE_{10} mode, is normal to the surface of the material being treated at introduction. This orientation between material and electric field intensity vector is desirable in order to prevent excessive dissipation of energy at the entrance location.

Turning now to FIG. **3**, the lower broadwall of the right section of the input rejection filter **29** is denoted **50**; and the broadwall **50** lies co-planar with the bottom plate **48** of the input elbow **29**. The other half of the lower broadwall of the input rejection filter forms a similar planar surface with the bottom plate **47** of the left-hand section of the input elbow. Similarly, the lower broadwall of the heating chamber **21** is divided into planar sections **51** (FIG. **4**) and **52** (FIG. **3**)

respectively so that the material being treated will be conveyed along and may rest upon a flat supporting surface, if desired.

Referring to FIGS. 1 and 3, the input rejection filter 29 includes three stubs designated by reference numeral 55 (FIGS. 1) and having a length equal to a quarter wavelength of the wave guide, and an impedance-matching stub 56. The stubs 55 are tuned to the frequency of excitation of the applicator; and they are designed to reject the transmission of that frequency through the rejection filter. The section 56 is an impedance-matching section designed to match the impedance of the resonant stubs 55 to that of the wave guide applicator without excess reflection and without creating modes capable of being propagated through the guide.

As seen in FIG. 3, each of the stubs 55 as well as the impedance matching section 26 are rectangular shells (only the right-half being illustrated in FIG. 3) having a lower open side coextensive with an opening in the upper broadwall of the input rejection filter 29.

The adjacent stubs 55 of the rejection filter can be seen to be periodic in space with the wavelength of the period equal to one-half the wavelength of the input/output wave guide. The height of the stubs 55 (that is, the direction extending transversely vertical of the broadwall) is a quarter wavelength of the filter wave guide; and the length of the stubs (that is, the direction extending transverse of the direction of product movement through the rejection filter) is less than 1.5 times the free-space wavelength of the excitation frequency. The direction extending parallel to the direction of product movement is less than one-half the free-space wavelength of the excitation frequency and this length of the impedance matching section is the same as the length of the resonant stubs; however, the height of the impedance matching section and the distance from the intersection between the flow of power and the location at which the product is introduced into the input elbow 20 is best determined empirically in order to minimize the reflections seen at the source.

Having thus described in detail a preferred embodiment of the present invention, certain theoretical aspects of the electrical characteristics of the system will now be detailed. It is desirable that the only modes which propagate in the applicator be the TE modes — that is, the electric field intensity vector extends only transversely of the direction of power flow, and there is no electric field in the direction of power flow. Further, it is desirable that only the TE_{10} mode excite the wave guide applicator, and that the wave guide applicator be designed so that only such modes will propagate. In order that only the TE_{mo} modes will propagate (that is, there will be no modes or variations in electric field intensity in a plane transverse of the direction of power flow and in the direction in which the side walls extend — the vertical direction in the illustrated embodiment) the height of the side walls (which will hereinafter be referred to as the dimension) is less than one-half of the free-space wavelength of the excitation frequency.

The dimension, a, (that is, the direction transverse of the power flow and parallel to the broadwall) is greater than one-half of the free-space wavelength of the excitation frequency and less than a full wavelength in order to propagate energy and to prevent modes higher than $m = 1$ mode from propagating. However, as disclosed in my co-pending, co-owned application entitled SYSTEM AND METHOD FOR HEATING MATERIAL EMPLOYING OVERSIZE WAVE GUIDE APPLICATOR, Ser. No. 816,500, filed Apr. 16, 1969, now U.S. Pat. No. 3,632,945, this restriction need not necessarily always be met as long as design provisions are made to limit the propagation of higher modes as taught in this last-identified, co-pending application. Further, if the wave guide is oversize as I have taught, it may be of advantage to terminate the applicator wave guide in an oversize wave guide water load as distinguished from the termination section 23. An oversize termination under these conditions prevents the storage of reactive energy in the TE_{mo} modes when the applicator is excited without any material in the heating cavity.

Since the electric field intensity varies transversely of the wave guide applicator, it is preferred that the transverse dimension of the material being heated be less than about one-third of the dimension a in order to avoid non-uniform heat dissipation in the material.

Another important design consideration is that the entire applicator illustrated in the drawing (including heating chamber, input and output feed sections and rejection filters) as well as the placement of material within the applicator are symmetrical about a vertical plane extending along the direction of power flow and passing through the transverse center of the applicator. That is to say, if one looks at a cross section of the applicator along the direction of power flow, all elements of one side of the applicator as well as the material form a mirror image of corresponding elements on the other side about a center line parallel to the direction of the electric field lines. This symmetry about the plane of separation of the illustrated embodiment is maintained in order to minimize the excitation of the TE_{mo} modes where m is an even integer. If these modes are not excited, continuous metal-to-metal contact at the center flanges (extending in a vertical plane in FIG. 4) is not necessary since the transverse current vector is zero here and there will be no radiation even if there is a slot. Hence, the need of finger stock or bolting at these flanges, which otherwise might be necessary is obviated.

Further, with the provision of symmetry mentioned above, the length of the stubs in the reject filter in a direction transverse of the direction of power flow may be up to one and one-half the free-space wavelength of the excitation frequency; whereas, if the symmetry is not maintained in the application design, the transverse length of the rejection filter stubs must be restricted to less than the free-space wavelength of the excitation frequency.

Having thus described in detail and illustrated a preferred embodiment of the present invention, it will be apparent to persons skilled in the art that certain modifications may be made to and equivalents substituted for those elements which have been disclosed; and it is, therefore, intended that all such modifications and equivalents be covered as they are embraced within the spirit and scope of the invention.

I claim:

1. In a system for applying microwave energy to material having upper and lower extended surfaces, the

combination comprising: a waveguide applicator providing a heating chamber having upper and lower opposing broadwalls lying in parallel planes extending in a generally horizontal direction and spaced to prevent the propagation of TE_{mn} and TM_{mn} modes where n is greater than zero, said waveguide applicator being symmetrical about a vertical plane extending along the direction of power flow to minimize excitation of TE_{mo} modes where m is an even integer, support means supporting said material for carrying the same in a generally horizontal disposition through said heating chamber between said broadwalls with said upper and lower surfaces of said material extending substantially parallel to said broadwalls, and source means for energizing said applicator substantially entirely in the TE_{10} mode whereby the electric field vector impinging on the upper and lower extended surfaces of said material is not parallel thereto.

2. The system of claim 1 wherein said applicator further comprises input elbow means of rectangular cross section receiving power from said source for coupling said power to said waveguide heating chamber, said input elbow receiving said power in a generally vertical direction and transmitting the same in a generally horizontal direction to said heating chamber, one broadwall thereof defining an aperture for admitting passage of said material to said chamber.

3. The system of claim 2 further comprising rejection filter means adjacent said admitting aperture for preventing the passage of microwave energy therethrough.

4. The system of claim 3 further comprising means for circulating air through said heating chamber.

5. The system of claim 4 wherein the half sections of said heating chamber are separateable to permit access to the interior thereof for cleaning.

6. The system of claim 4 further comprising an output waveguide elbow of rectangular cross section receiving power from said heating chamber for transmitting the same in a generally vertical direction, one broadwall of said output elbow defining an aperture for admitting the egress of said material, and termination means receiving power from said output elbow and including a load for absorbing said power without substantial reflection.

7. The system of claim 6 further comprising output rejection filter means coupled to said output waveguide elbow adjacent said aperture for inhibiting the passage of said microwave energy therethrough.

8. A system for applying microwave energy to a food product which has a generally uniform thickness along one direction comprising a rectangular waveguide having upper and lower broadwalls extending in a second direction; excitation means including a source of microwave energy coupled to said waveguide for energizing the same substantially entirely in the TE_{10} mode, said waveguide being symmetrical about a vertical plane extending in a direction of elongation of said broadwalls to inhibit the generation of electrical modes other than the TE_{10} mode; conveyor means supporting said product for moving the same within said broadwalls wherein extended surfaces of said product are generally parallel to said broadwalls, said conveyor means moving said product in the direction of power flow within said waveguide while holding the direction of uniform thickness of said product substantially perpendicular to the direction of power flow of said waveguide.

9. The system of claim 8 wherein the broadwalls of said waveguide are spaced at a distance less than one-half of the free-space wave length of the excitation frequency to inhibit propagation of TE_{mn} where n is greater than zero modes.

10. The system of claim 8 wherein said waveguide is in general U-shape form when viewed from the side, said waveguide defining a first input aperture in its lower broadwall receiving said product and a second output aperture in its lower broadwall through which the product is discharged from said waveguide, said system further including a rejection filter at said input and output apertures to reject the passage of microwave energy while permitting the passage of said product, and termination means downstream of the direction of power flow from said output aperture for absorbing remnant power.

11. In a process for treating with microwave energy a material having upper and lower surfaces, the steps of propagating microwave energy in the TE_{10} mode between upper and lower opposing broadwalls lying in parallel planes extending in a horizontal direction and spaced to prevent the propagation of TE_{mn} and TM_{mn} modes where n is greater than zero while avoiding excitation of TE_{mo} modes where m is an even integer, and passing said material between said broadwalls with its said upper and lower surfaces extending substantially parallel to said broadwalls in the direction of said propagation of energy and substantially perpendicular to the electric field vector impinging on said upper and lower extended surfaces of said material.

* * * * *