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J. E. CURRAN  
HEATING OF SUBSTANCES BY ELECTRICAL ENERGY AT  
MICROWAVE FREQUENCIES

3,397,296

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3 Sheets-Sheet 1

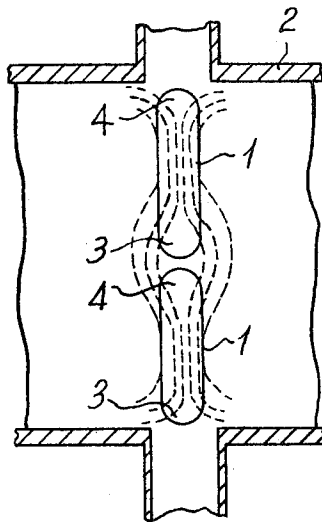


Fig. 1.

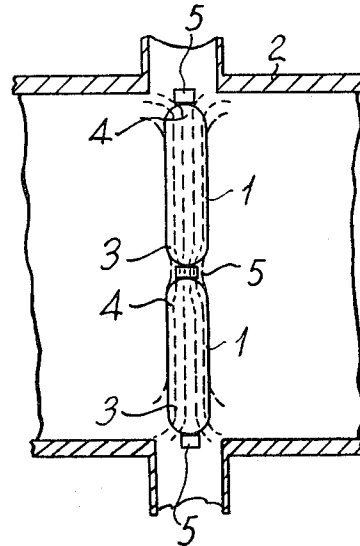


Fig. 2.

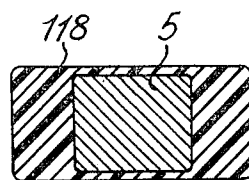


Fig. 3.

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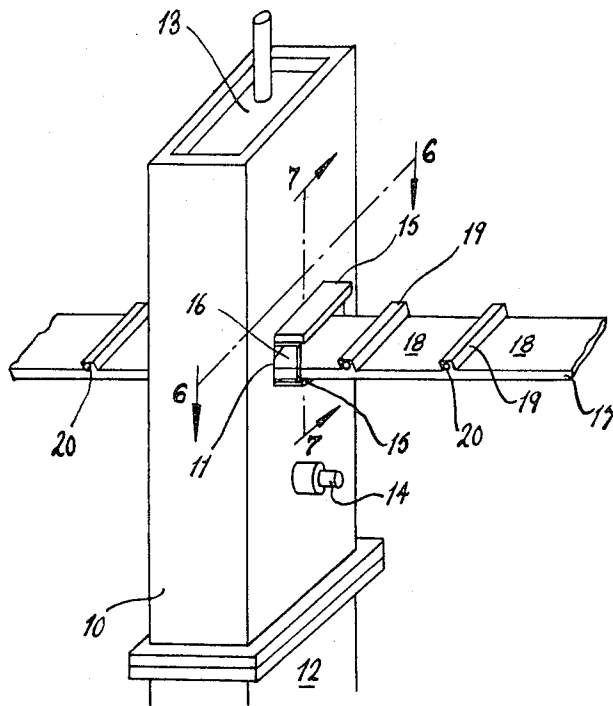
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*Fig. 4.*



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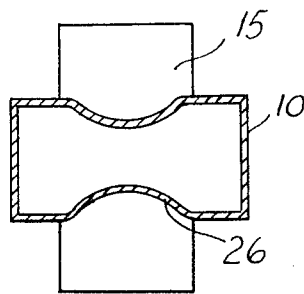
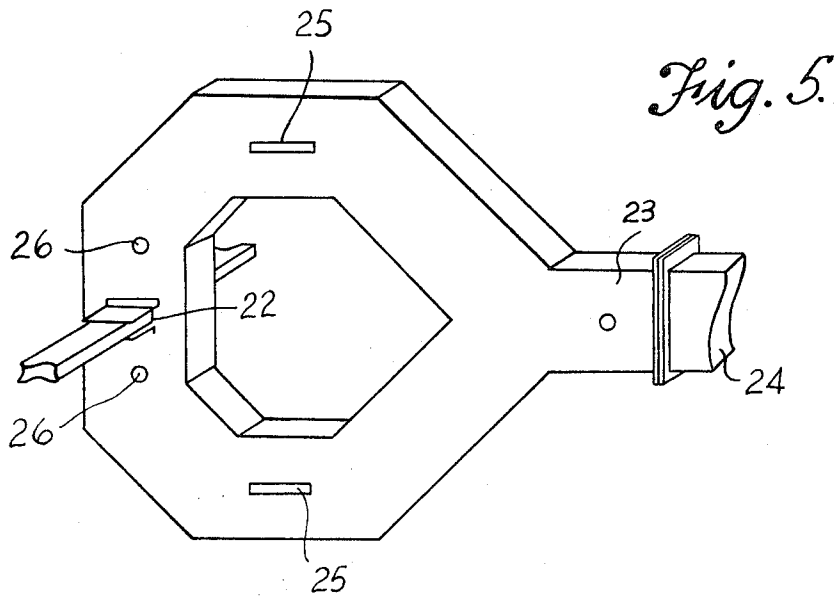


*Fig. 6.*

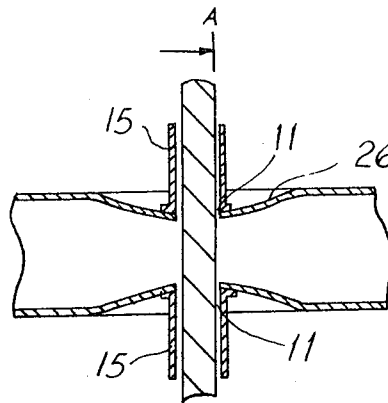


*Fig. 7*

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3,397,296

## HEATING OF SUBSTANCES BY ELECTRICAL ENERGY AT MICROWAVE FREQUENCIES

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17 Claims. (Cl. 219—10.55)

### ABSTRACT OF THE DISCLOSURE

A method of heating an elongate body such as a sausage, a group of sausages, or a steak by placing the body together with two electrically conductive members located respectively adjacent the opposite ends of the body within a waveguide so that the length of the body is generally parallel to the electric field of the waveguide. The electrically conductive members insure uniform heating of the body.

The apparatus includes a waveguide and a source of microwave arranged to transmit energy in the fundamental ( $H_{10}$ ) mode only. The waveguide is provided with openings in opposite faces and support means extending therethrough.

This invention relates to the heating of organic substances by electrical energy at microwave frequency and relates in particular to a method of, and apparatus for, heating an elongate body or heating in succession (in a production-line manner) a number of substantially identical elongate bodies, the body or bodies being made of organic substances such as meat or meat products, and having a relatively high dielectric constant or a high electrical loss factor at the frequency of the microwave energy.

Each elongated body may be a single body, such as for example sausage meat made up into a sausage of substantially circular cross-section and of between  $\frac{1}{2}$ " to 1" in diameter, with a length of between about 3" and 5" and with each end of generally hemispherical form. However, the term "elongate body" as used in this specification (and, in particular, as used in the claims of this specification) also includes a body or a group of bodies having a length greater than its breadth, such as a group of two or three or four sausages arranged side-by-side to present a body of rectangular plan form and having a thickness less than either the length or the breadth of the body. The term "elongate body" as used herein, also includes a body, for example of steak or of offal, which is of generally rectangular plan form and has a thickness less than either the length or the breadth of the body.

By using microwave electrical energy to heat or cook a body of an organic substance the treatment of the body is more rapid than is possible with conventional means since with conventional means where heat is only applied to the surface of the body the quantity of heat which can be supplied is limited by the onset of excessive surface temperature and possible burning, but with microwave heating heat is liberated within the body and the surface temperature is not a limiting factor in the quantity of heat which can be achieved. In the course of such rapid heating as is envisaged by the use of microwave electrical energy, conduction processes have only limited ability to bring about temperature equalisation within the body, temperature equalisation being generally desirable, and it is thus important in order to achieve uniform heating of the body to distribute the liberated heat throughout the substance. It is therefore essential to so dispose the

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body in an electromagnetic enclosure that the electrical fields everywhere within the body are approximately of the same magnitude. Account has to be taken of the fact that the shape of the body of organic substance can seriously modify pre-existing fields in the enclosure and also the need to provide openings for the body to enter into, and leave the enclosure, but which permit only a relatively small amount of electromagnetic energy to escape therefrom.

In general the high frequency heating field is arranged parallel to the length of the or each body of organic substance, and it is preferred for the electric field to be directed along the line which the body takes as it passes through the electromagnetic enclosure. The desired arrangement can be achieved by employing a conventional rectangular waveguide having energy propagated there-through in the fundamental ( $H_{10}$ ) mode only and passing the body at right angles to the longitudinal axis of and parallel to the narrow faces of the waveguide through openings cut centrally in the opposite parallel broad faces of the waveguide.

It is known to heat and cook elongated bodies of an organic substance by passing these bodies transversely through a waveguide along which is propagated VHF electrical energy. It is found that as each body is passed through the waveguide, or is stationary in the waveguide, the geometry of the ends of the body causes the electrical field to diverge with the result that the ends of the body are not heated to the same extent as the remainder of the body.

An object of the present invention is to provide an improved method of and apparatus for heating one or more elongate bodies of an organic substance which brings about more even heating of the body(ies).

According to one feature of the present invention, in a method of heating at least one elongate body of an organic substance of the kind set forth, the body is positioned in a waveguide with electrically conductive members located adjacent respective opposite ends of the body and electrical energy at microwave frequency is applied to the waveguide such that the electrical field component of the energy extends through the body and the members in a direction generally parallel to the longitudinal axis of the body for sufficient time to raise the temperature of the body to the required value.

According to a second feature of the invention apparatus for heating at least one elongate body of an organic substance of the kind set forth comprises a waveguide, means for propagating microwave energy through said waveguide, means for positioning the body in the waveguide with the longitudinal axis of the body arranged to be within and generally parallel to the electric field component produced in the waveguide when microwave energy is propagated there through and electrically conductive members for location one adjacent each of the respective opposite ends of the body.

The members of electrical conductive material restore field uniformity in the end regions of the body by producing a concentration of the field lines sufficient to counteract the previously described tendency to undertreatment at the ends of the body. The members may be of copper or other suitable material and the size and shape is not critical, the best shape for a particular application being easily found. For elongate bodies such as a single sausage, the members may be in the form of discs or spheres positioned one adjacent each end of the body and substantially on the longitudinal axis thereof. When the breadth of the body is similar to but less than the length of the body, as for a group of sausages, or a piece of steak, or a piece of offal, the member is preferably in the form of a rod of a length slightly less than the breadth of the body, and the rod is positioned normal to the length of the body.

If the electrically conductive material is actually allowed to touch the body it is found that local burning can occur, but this can be avoided by covering the metal with a thin layer of electrically low-loss dielectric material. Polyethylene or PTFE are suitable dielectric materials and they may be wrapped around or moulded on to the metal and a thickness of the order of .02" is sufficient to prevent burning.

The provision of electrically conductive material adjacent to each end of the body serves to make the field along the length of the body substantially uniform in a direction parallel to the longitudinal axis of the body. To provide also a substantially uniform field across the breadth of the body, the profile of the waveguide in the region through which the bodies pass can be modified. This is brought about by reducing or increasing the height of the waveguide in this region. This modification has two effects—of altering the local electric field and also the time spent in the field by adjacent parts of the body as it passes through the waveguide.

To obtain uniformity of heat treatment through the thickness of the body it is preferable that the energy is applied equally to both opposite faces of the body. This may be partially effected by placing an effective short-circuit in the waveguide on the side of the body remote from the source of energy, or more completely by feeding the electromagnetic chamber equally from two directions.

In order that the invention may be more readily understood, it will now be described with reference to the accompanying drawings in which:

FIG. 1 is a diagram illustrating a sausage being heated by microwave electrical energy by a known method;

FIG. 2 is a diagram illustrating a sausage being heated by microwave electrical energy by a method embodying the present invention;

FIG. 3 is a view on a larger scale of part of the apparatus shown in FIG. 2;

FIG. 4 is a perspective view of apparatus in accordance with one embodiment of the invention;

FIG. 5 is a perspective view of apparatus in accordance with a further embodiment of the invention;

FIG. 6 is a sectional view of the invention taken along line 6—6 of FIG. 4 with a slight modification; and

FIG. 7 is a sectional view of the invention taken along line 7—7 of FIG. 4 with the modification as indicated in FIG. 6.

Referring to FIGURE 1, if a sausage 1 is passed through a waveguide 2 with the length of the sausage extending transversely across the waveguide, the microwave frequency electrical energy is propagated along the waveguide, the sausage will be heated by the electrical energy, but the electric field will diverge away from the ends of the sausage. If two sausages are passed through in end to end relation as illustrated in FIG. 1, the electric field is distorted at the adjacent ends 3, 4 of the sausages and as a result, the sausage will not be heated uniformly, and it will not be possible to cook the sausage evenly throughout by this method.

In accordance with the invention, this known method is modified by locating members 5 of electrically conductive material one adjacent to each end of each sausage and extending across the axis of the sausage as illustrated in FIG. 2. The presence of the member 5 tends to prevent the electric field from diverging away from the ends of the sausage and thereby ensures that the sausage is heated evenly by the electrical energy. By utilising this method, the sausage can be cooked evenly throughout by passing it through the waveguide. It is found that any surface of the sausage which is in contact with the member 5 tends to char, but this effect can be prevented by locating a piece of dielectric material of sufficient thickness between the sausage and member 5. FIG. 3 shows a cylindrical or rectangular member 5 of conductive material covered with a layer of polythene 118 at least 0.01" thick and extending over at least the parts of the member which are adjacent to the surfaces of the sausages. It is preferable

for the conductive member to be completely covered with polythene.

Referring to FIG. 4, a microwave frequency oven comprises essentially a section of rectangular waveguide 10 having a rectangular opening 11 formed in each of its opposite broad faces. The openings are aligned and positioned centrally of the broad faces, and the longer sides of the openings are normal to the longitudinal axis of the waveguide. The openings are of sufficient size to permit a generally rectangular body of an organic substance to pass through the waveguide substantially normal to its longitudinal axis.

Microwave energy at a frequency of the order of 1,000M/c.p.s. is propagated, in the  $H_{10}$  mode only along the waveguide from a source shown generally at 12. On the side of the openings remote from the source a short-circuit in the form of a conductive plate 13 is provided across the waveguide and a matching obstacle in the form of a simple capacitive post 14 projecting into the waveguide is provided on the other side of the openings between the openings and the source. The length of the waveguide between the obstacle and the short-circuit can be regarded as a resonant electromagnetic cavity through which the bodies to be heated are passed. The capacitive post may be replaced by other matching arrangements known in the art, or alternatively a number of such posts may be provided and suitably spaced apart to control the magnitude of the cancelling reflections within the waveguide. Any tendency for energy to leave the waveguide through the openings can be reduced by providing metal plates 15 along the longer edges of each slot at right angles to the broad faces of the waveguide. The plates provide additional attenuation for uniform fields developed across the openings and if the plates are effectively  $\frac{1}{4}$ " wavelength long, any leakage, due to an nonuniform fields arising from incidental asymmetry, is reduced.

A rectangular duct 16 of dielectric material extends through the openings transverse to the waveguide and a continuous conveyor belt 17, also of dielectric material, conveniently polytetrafluoroethylene, extends through the duct and is moved by a suitable electric motor (not shown). The conveyor belt is divided into sections 18 of approximately 6" in length by a plurality of transverse hollow walls 19, and each section is capable of containing one of a number of the substantially identical elongate bodies referred to above, which are passed in succession through the waveguide 10 in a production-line manner. Thus, there may be a succession of similar single sausages, or a succession of similar groups of sausages, or a succession of similar piece of steak, etc. In each transverse wall between adjacent sections a member of conductive material in the form of a rod 20 is provided which extends substantially the whole width of the conveyor belt. The members ensure that the electric field in the waveguide does not diverge away from the ends of the bodies being heated as they pass through the waveguide.

FIG. 5 shows apparatus in accordance with an embodiment of the invention which is arranged to provide improved uniformity of heat treatment across the thickness of the body of organic substance as it passes through the waveguide. The waveguide extensions on each side of the openings 22 are bent round and joined to a common waveguide 23 leading to a single microwave power source 24, and at least the bends nearest the openings are preferably in the plane of the broad faces of the waveguide to avoid interference with the conveyor or belt. With this apparatus it is important to ensure that the effective distances from the junction of the waveguides to each face of the body as it passes through the waveguide are substantially the same. To bring this about phase-shifting elements 25 may have to be provided in one or both of the extensions, and it may also be necessary to provide matching elements 26 in order to cancel re-

flections arising from the body being treated and also from the waveguide junction.

In order to secure uniformity of heat treatment in the plane of the rectangular body to be heated across its breadth parallel to the broad faces of the waveguide, the central portion of the waveguide in the vicinity of the openings may be deformed to vary the electric field in this neighbourhood. In FIGS. 6 and 7 an arrangement is shown where the waveguide height in the neighbourhood of the openings 11 is reduced by having the walls of the broad faces of the waveguide deformed inwardly, as shown at 26. As an alternative to this arrangement, obstacles may be affixed to the upper or lower broad faces of the waveguide on both sides of the openings.

It is thus possible in accordance with this invention to heat an elongate body as defined above, uniformly over its length as it passes through the waveguide, and in accordance with modifications which can be made to the waveguide, the heating of the body can be made substantially uniform in each of the three dimensions of the body.

What I claim is:

1. A method of heating an elongate body, as hereinbefore defined, or organic substances, in which said body and two electrically conductive members located respectively adjacent the opposite ends of said body are located within a waveguide through which microwave energy is transmitted only in the fundamental mode whereby the electric field within said waveguide extends only in directions transverse of the waveguide, said body being so positioned that its length is generally parallel to said electric field, and said members being chosen in relation to said body to ensure that said electric field is substantially uniform lengthwise within said body, whereby substantially uniform heating lengthwise within said body is obtained.

2. A method as claimed in claim 1, wherein said body is passed across the interior of said waveguide at a substantially constant speed and in a direction parallel to the said length of said body.

3. A method of heating an elongate body, as hereinbefore defined, of organic substances, in which said body and two electrically conductive members located respectively adjacent the opposite ends of said body are located within a rectangular-section waveguide through which microwave energy is transmitted in the fundamental ( $H_{10}$ ) mode only, said body being so positioned that its length is generally parallel to the electric field within said waveguide, and said members being chosen in relation to said body to ensure that said electric field is substantially uniform lengthwise within said body, whereby substantially uniform heating lengthwise within said body is obtained.

4. A method as claimed in claim 3 wherein said body is passed across the interior of said waveguide at a substantially constant speed and in a direction parallel to the said length of said body.

5. A method of heating in succession a number of substantially identical elongate bodies, as hereinbefore defined, of organic substances, in which said bodies arranged end-to-end in said succession and a separate corresponding electrically conductive member located between the adjacent ends of each successive pair of said bodies are passed in said succession across the interior of a waveguide through which microwave energy is transmitted only in the fundamental mode whereby the electric field within said waveguide extends only in directions transverse of the waveguide, said bodies being so positioned that their lengths are generally parallel to said electric field within said waveguide, and said members being chosen in relation to said bodies to ensure that said electric field is substantially uniform lengthwise within each said body within said waveguide, whereby substantially uniform heating lengthwise within each said body is obtained.

6. A method as claimed in claim 5, wherein said bodies are passed through said waveguide at a substantially constant speed and in a direction parallel to the said lengths of said bodies.

7. A method of heating in succession a number of substantially identical elongate bodies, as hereinbefore defined, of organic substances in which said bodies arranged end-to-end in said succession and a separate corresponding electrically conductive member located between the adjacent ends of each successive pair of said bodies are passed in said succession across the interior of a rectangular-section waveguide through which microwave energy is transmitted in the fundamental ( $H_{10}$ ) mode only, said bodies being so positioned that their lengths are generally parallel to the electric field within said waveguide, and said members being chosen in relation to said bodies to ensure that said electric field is substantially uniform lengthwise within each said body within said waveguide, whereby substantially uniform heating lengthwise within each said body is obtained.

8. A method as claimed in claim 7 wherein said bodies are passed through said waveguide at a substantially constant speed and in a direction parallel to the said lengths of said bodies.

9. A method as claimed in claim 7, wherein said microwave energy is transmitted through said waveguide in each of the two opposite directions.

10. Apparatus for heating an elongate body, as hereinbefore defined, of organic substances, said apparatus comprising a source of microwave energy, a rectangular-section waveguide supplied from said source and arranged to transmit said energy in the fundamental ( $H_{10}$ ) mode only, at least one opening extending across one of the broader faces of said waveguide in the direction perpendicular to the length of said waveguide, a support of dielectric material arranged to receive said elongate body for insertion into said waveguide through said opening whereby the length of said elongate body is generally parallel to the electric field within said waveguide, and two electrically conductive members spaced apart on said support so as to lie respectively adjacent the opposite ends of said elongate body within said waveguide, said members being chosen in relation to said body to ensure that said electric field is substantially uniform lengthwise within said body within said waveguide, whereby substantially uniform heating lengthwise within said body is obtained.

11. Apparatus for heating in succession a number of substantially identical elongate bodies, as hereinbefore defined, of organic substances, said apparatus comprising a source of microwave energy a rectangular-section waveguide supplied from said source and arranged to transmit said energy in the fundamental ( $H_{10}$ ) mode only, two corresponding openings extending respectively across the two broader faces of waveguide in the direction perpendicular to the length of said waveguide, an elongate support of dielectric material extending across said waveguide through said openings, a succession of similar electrically conductive members similarly spaced along the length of said support to define a succession of sections each for the receipt of a separate corresponding one of said elongate bodies, and means for moving the support in the direction of its length, whereby each said elongate body is passed in turn across the interior of said waveguide with its length parallel to the electric field within said waveguide and with one of said members located against each of the opposite ends of each said elongate body, the said members being chosen in relation to said bodies to ensure that said electric field is substantially uniform lengthwise within each said body, whereby substantially uniform heating lengthwise within each said body is obtained.

12. Apparatus as claimed in claim 11, wherein said support is an endless belt.

13. Apparatus as claimed in claim 11, in which said

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support extends through said waveguide in a duct made of dielectric material.

14. Apparatus as claimed in claim 11, wherein at least those portions of said electrically conductive members which can come into contact with said elongate bodies are covered with dielectric material. 5

15. Apparatus as claimed in claim 11, wherein said support is provided with a succession of transversely extending hollow walls of which the hollow interiors respectively receive said electrically conductive members. 10

16. Apparatus according to claim 11, wherein said waveguide is connected at its one end to said source and is terminated at its other end with a device arranged to reflect back microwave energy towards the source.

17. Apparatus according to claim 11, wherein said waveguide is connected at each of its opposite ends to 15

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said source, whereby said microwave energy is transmitted through said waveguide in each of the two opposite directions.

References Cited

UNITED STATES PATENTS

|           |         |              |             |
|-----------|---------|--------------|-------------|
| 2,540,036 | 1/1951  | Spencer      | 219—10.55   |
| 3,102,181 | 8/1963  | Verstraten   | 219—10.55   |
| 3,110,794 | 11/1963 | Sale         | 219—10.55   |
| 3,210,511 | 10/1965 | Smith        | 219—10.55   |
| 3,219,460 | 11/1965 | Brown        | 219—10.55 X |
| 3,271,169 | 9/1966  | Baker et al. | 219—10.55 X |
| 3,271,552 | 9/1966  | Krajewski    | 219—10.55   |

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