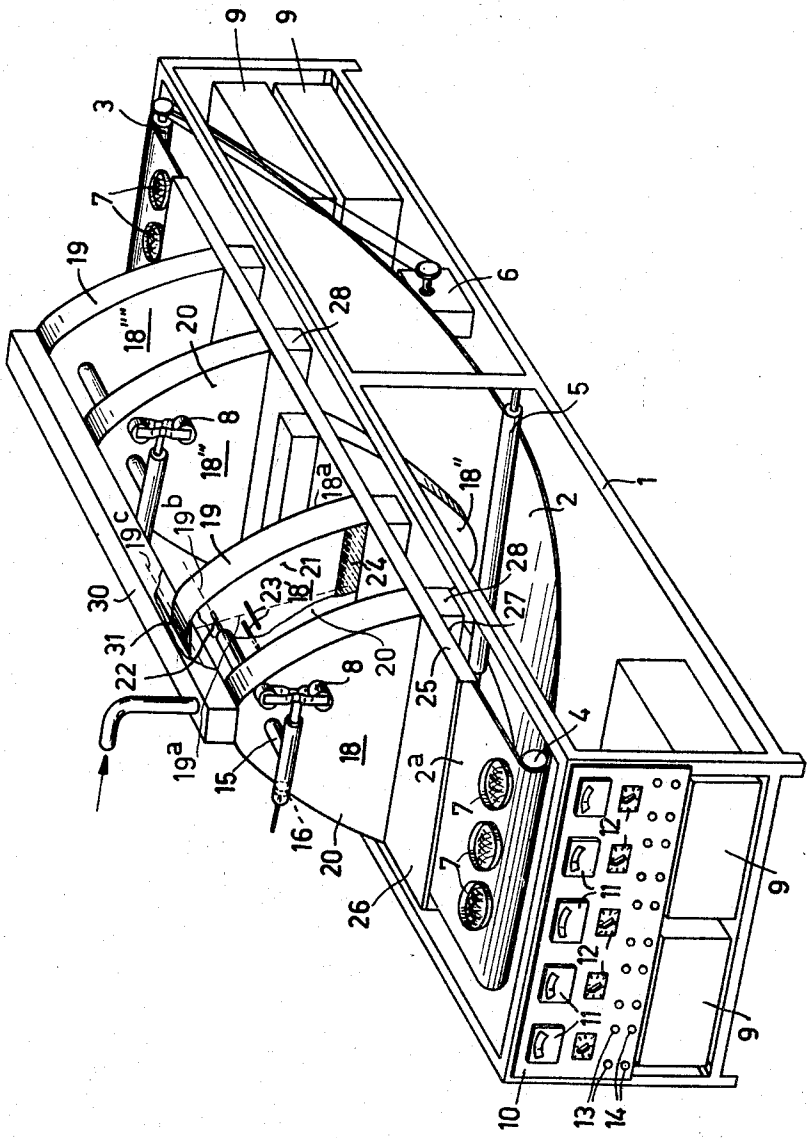
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HIGH-FREQUENCY FURNACES

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HIGH-FREQUENCY FURNACES

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The invention relates to high frequency heating furnaces and more particularly to high frequency furnaces operating in the microwave region.

This application is a continuation-in-part of my co-pending application, Serial No. 26,235 filed May 2, 1960, and entitled "High Frequency Heating Furnaces Operating With Very High Frequencies." The heat furnace described therein comprises a heating unit having a high frequency generator and compatible waveguide system. The waveguide system comprises a parabolic planar reflecting surface bounded by a pair of parallel monoplanar conducting surfaces which are normal to the focal line of the parabolic plane of the reflecting surface. A conveyor belt system is provided to place workpieces to be heated in juxtaposition with an opening of the waveguide system formed by the mutual intersections of each of the conducting surfaces with the mouth of the parabolic plane of the reflecting surface. A linear radiator coupled to the generator by suitable load matching means, is placed in substantial coincidence along its longitudinal axes with the focal line which is located, because of the presence of the workpieces and/or the conveyor belt at the opening, within the parabolic plane between the vertex line and mouth thereof. In order to intercept the direct radiations from the focal line, i.e., the linear radiator, and provide a uniform electro-magnetic field of constant intensity at the opening, reflector means are disposed between the opening and the focal line causing substantially the whoe radiation from the linear radiator to be reflected from the parabolic planar reflecting surface in the direction of the opening. To provide radiations from emanating from the sides of the opening, the linear radiator irradiates a linearly polarized field having an electrical field vector parallel to the direction of the linear radiator and in a direction coincident with the direction of movement of the belt of the conveyor belt system past the opening. The energy vector (Poynting vector) is at right angles to the electric field vector and hence has no component in the direction of movement of the conveyor belt, and, consequently, only stray rays can emanate from the sides of the opening. Coupled to each side of the opening and at right angles to the parallel boundary surfaces are two aligned passages which further attenuate these stray rays and also provide an entrance and exit guide passages to the opening of the waveguide system for the belt and the workpieces supported thereon. Beneath the opening the parabolic shaped surface is extended at the mouth thereof past the boundary conducting surfaces to form a rectangular trough below the conveyor belt. The trough contains an absorbing material to absorb the radiations which pass through the belt, so that the generator and waveguide system are adequately loaded even in the absence of workpieces to be heated. In operation, the workpieces when placed in juxtaposition to the opening, are heated by the dielectric displacement currents produced in the workpiece when subjected to the electro-magnetic field.

In the heat furnaces of the co-pending application, substantially described herein above, while generally providing for satisfactory uniform heating, it was found that certain workpiece materials, for example, those comprising a heterogeneous mixture, would experience a non-

uniform heat distribution because, inter alia, of the non-uniform energy absorption of the heterogeneous mixture. In heating applications where the aforedescribed heat furnaces are utilized to heat frozen foodstuffs, it was found that because of the small penetration depth and energy absorption of the food in the frozen state, as well as the "run away" effect of melted parts at the surface, the non-uniform heat distribution was even more noticeable, and, more especially, if the frozen foods were, also, of a heterogeneous nature. In addition it was often found, that the vapors, steam, etc., released by the workpieces during the heating process, besides contaminating the surfaces and parts of the system, also caused variations in the dielectric medium of the waveguide system resulting in undesirable changes in the operating characteristics of the system, such as loss of power, etc., as well as, contributing to the heat distribution problems mentioned above. Moreover, if these workpieces happened to be foodstuffs, it was found, that they often released malingering odors, vapors and the like, in the system that would contaminate and/or obnoxiously permeate similar or different foodstuffs subsequently prepared and render them inedible or undesirable.

An object of this invention is to provide a high frequency heat furnace with an improved uniform heat distribution for the workpieces heated thereby.

Another object of this invention is to provide a heat furnace that alternately subjects the workpieces to zones of injected microwave energy by which heat is generated within the workpiece, and zones of microwave energy inactivity wherein the heat previously generated becomes uniformly dispersed throughout the workpiece.

Among other objects are included the stabilization of the variations in the dielectric medium caused by vapors and the like released from workpieces heated by the heating furnace of this invention, and the mitigation and/or removal of such vapors and their effects.

Accordingly, this invention features a high frequency furnace for the heat treatment of workpieces by high frequency oscillations which comprises a plurality of heating units, and means to disperse the heat generated in the workpieces by each unit. Each heating unit and waveguide means has a first parabolic planar reflecting surface and second and third monoplanar conducting surfaces, such that the second and third surfaces are disposed in a substantially parallel relationship with each other and are at right angles to the first surface to provide an enclosure having an opening substantially normal to the principal axis of the parabolic planar surface. Radiating means are disposed at the focal line of the parabolic planar surface, with the focal line being disposed between the opening and vertex line of the parabolic planar surface. Wave energy reflecting means are disposed between the radiating means and the opening, as well as, means for coupling the generator to the radiating means. A conveyor belt member having a movable supporting surface is provided for conveying the workpieces normal to each of the openings to have heat energy generated in the workpieces by microwave energy emanating therefrom, the conveyor belt member being driven by suitable driven means. The heat dispersing means comprises a conductive hollow transport member disposed about the supporting surface of the belt member and the workpieces supported thereon, and the transport member also has a plurality, corresponding to the number of openings of the waveguide systems, of apertures spatially disposed at predetermined distances from each other. Each of the openings of the waveguide means are associated with one of the apertures, so that the workpieces may be subjected to the aforementioned microwave energy at the sites thereof and during the conveyance of the workpieces to

the next aperture, i.e., opening, of a succeeding waveguide means the heat generated in the workpiece by the preceeding waveguide means is therein distributed in a more uniform manner.

The above-mentioned and other features and objects of this invention will become more apparent by reference to the following description taken in conjunction with the following drawing, in which:

The single FIGURE is a perspective drawing of the heating furnace of this invention.

The high-frequency furnace according to the invention, shown in the drawing, is mounted on frame **1** and is suitable for high-frequency heating of workpieces, as for example, prepared frozen foodstuffs carried on conveyor belt **2** having a supporting surface **2***a* and associated driving rollers **3**, **4**, **5**, of which the roller **3** is directly driven by a driving motor **6**. In the illustration, the objects to be heated, consist of frozen meals having a temperature of, for example, —30° C., arranged on plates **7**, and are taken off the end of the conveyor belt system for direct consumption after being heated in the high-frequency furnace to a temperature of 90° C. for 2 to 4 minutes.

The high-frequency furnace comprises, for example, five separate high-frequency heating units, each having a high frequency generator, as for example, magnetron generator **8** of which only two are illustrated for the sake of clarity in the drawing. These generators may be, for example, rated at 2 kw., each, and produce oscillations having a wavelength of 12 centimeters. Associated with each generator is a separate voltage supply **9**. A common supervisory and control-panel **10** is provided with a plurality of anode current meters **11**, anode-current adjusting resistors **12**, on-off switches **13**, and safety fuses **14**, each of which is associated with one of the generators.

Each of the output circuits of the magnetron generators **8** is coupled by means of a coaxial conductor **15**, via adjustable load matching means **16**, in a manner well known to those skilled in the art, to its associated waveguide system **18**, **18'**, **18''**, **18'''**, **18''''**, respectively, which propagate the oscillations generated by the magnetron generators **8** to the outlet openings of the waveguide systems **18** to **18''''**. The outlet opening is formed by the surfaces **19**, **20** and **21**, and is located in a plane normal to the principal axis, illustrated in the drawing as extended broken line **19***a* of the parabolic planar reflecting surface **19**. Workpieces to be heated are transported on the conveyor belt **2** past these openings. In order to illustrate in greater detail the interior of the waveguide systems **18** to **18''''**, which are identical for each heating unit, the front wall of the second waveguide system **18'** is partly broken away.

To obtain, as described fully in the aforementioned copending application, a uniform heating throughout the width of the conveyor belt **2**, which may, for example, be 70 cms, each of the waveguide systems **18** to **18''''** is formed by a parabolic planar reflecting surface **19** and two parallel monoplanar conductive surfaces **20** and **21**, at right angles to the former. On the focal line, illustrated as extended broken line **19***b*, of the parabolic planar surface, a linear radiator **22** is arranged. Between the linear radiator **22** and the outlet opening **18'***a* of the waveguide system and remote from the vertex line, illustrated as extended broken line **19***c*, of the parabolic planar surface **19**, reflector means **23** is provided to reflect the direct radiation of the linear radiator **22** towards the parabolic planar surface **19**, so that by suitable arrangement of the linear radiator **22** and the reflector means **23**, a radiation pattern is obtained at the opening **18'***a* in planes at right angles to and along the linear radiator **22**, while alongside the openings of the waveguide systems **18** to **18''''** substantially no radiation occurs. In the embodiment shown, the reflector means **23** consists of two reflector rods, arranged parallel to the linear radiator **22**. The relative distance between the rods and their distance from the linear radiator are, for example, 0.4 and 0.2, respectively, of the wavelength.

Substantially the complete radiation from the linear radiator **22** emanated in accordance with the radiation pattern described above is reflected from the parabolic cylinder surface **19** in the direction of the parabola axis **19***a* towards the openings of the waveguide system **18** to **18''''**. At the outlet openings, in the directions extending parallel to the boundary surfaces **20**, **21**, a uniphase, electromagnetic field of substantially constant intensity is produced, so that workpieces to be heated on the conveyor belt **2** passing the opening are heated substantially uniform.

The linear radiator **22** produces a linearly polarized field, of which the direction of the electric field vector E extends parallel to the direction of the linear radiator **22**, so that at the openings of the waveguide system **18** to **18''''** it extends in a direction indicated by the broken arrows **24** in the broken-off part of the waveguide **18'**. As a consequence, the energy vector (Poynting vector), which is at right angles to the electric field vector E, has no component in the transport direction of the conveyor belt **2**, and, therefore, stray rays leave the waveguide system **18** to **18''''** with considerable attenuation, for example by 25 db, with respect to the field in the waveguide system **18** to **18''''**.

While using the aforedescribed properties of the heating unit of a high-frequency furnace in accordance with the teachings of my aforementioned co-pending application, the present invention provides a considerable further improvement which consists in the use of a plurality of high-frequency heating units, with the further provision of a transport channel **25**, surrounding the supporting surface **2***a* of the conveyor belt **2** and the workpieces supported thereon. The channel **25** is made from conductive material and is illustrated, by way of example, as having an upper and lower boundary surfaces **26**, **27**, respectively which extend parallel to the conveyor belt **2**, and extend in the direction of movement of the conveyor belt **2**. The transport member is provided with five apertures which are associated with the openings of the waveguide systems **18** to **18''''** and as illustrated in the drawing at system **18'**, the aperture of the channel **25** thereat is coincident with the opening **18'***a*. The parallel boundary surfaces **20**, **21** of these openings, such as opening **18'***a*, are substantially at right angles to the common transport channel **25**. At the area of the openings of the waveguide systems **18** to **18''''** each boundary surface of the common transport channel **25** opposite the waveguide system is bent over in a direction leading away from the conveyor belt in the form of a rectangular trough **28**, which acts as a support means for absorbing material which is placed therein to absorb the radiation from the linear radiator **22** which passes through the conveyor belt **2**. Thus, the magnetron generators **8** are adequately loaded, even in the absence of workpieces to be heated on the belt **2**.

The various waveguide systems **18** to **18''''** with their associated magnetron generators **8** are arranged, at distances which are most favorable for the heating process, by proper selection of the spacing between adjacent apertures of the channel **25** due to the low emanating stray radiation of each of the waveguide systems **18** to **18''''**, the magnetron generators **8** are relatively substantially decoupled, so that a relative destructive influence between adjacent waveguide systems is not effected, even under excessive varying operating conditions. The high-frequency furnace described above provides a material increase in the output power, which results in a corresponding acceleration of the heating process and a material reduction of the overall stray radiation. The stray radiation existing outside of the multi-heating unit furnace herein described is substantially the same as that existing in the single heating unit described

in my aforementioned co-pending application because of the necessity of requiring damping in the transport channel for only one equivalent unit; viz., the damping of the stray radiation from the inlet to the first waveguide system **18** and the outlet of the last waveguide system **18''''**, respectively. For example, in the high-frequency furnace described herein, the maximum power of the stray radiation occurring beyond the high frequency furnace at the area of the attending staff personnel is only one milliwatt per square centimeter. Also, a material improvement in the heating process and in the efficiency thereof, is provided by the heat furnace of this invention, as will be explained more fully hereinafter.

When the workpieces to be heated, illustrated in the drawing in the form of frozen meals, are arranged at the inlet of the transport channel **25**, they are heated by high-frequency oscillations on their journey through the high-frequency furnace when passing by the outlet opening of each waveguide system **18** to **18''''**. During the time required by the object to reach the outlet opening of the next following waveguide no high-frequency heating ocurs, so that alternate time periods with and without high-frequency heating are provided. In the time period without heating the heat developed during the preceeding heating period is allowed to disperse in the object to be heated, which is advantageous for a uniform heating of the workpieces, especially those comprised of a heterogeneous mixture. Due to local variations in the dielectric constant of the workpieces to be heated, local discontinuities may occur in the high-frequency heating; in the present embodiment this occurs, for example, at the instants when the frozen meals thaw. In order to attain optimum conditions, the distances between the successive waveguide systems, which distances determine the time periods without heating, are to be judiciously selected since in the case of a selection of too small a distance the heat may not have the possibility of dispersing uniformly in the object, whereas in the case of too great a distance the object may become chilled.

With the high-frequency furnace described a uniform heating of the objects is obtained, which is further improved in the embodiment shown by connecting to the transport channel **25** at least one of the heating units, as for example, the waveguide system **18''** of the third heating unit, in a direction opposite to that of the other waveguide systems **18**, **18'**, **18'''**, **18''''**, which allows workpieces having a small penetration depth to be exposed to bilateral radiation.

In the high-frequency furnace described the material increase in efficiency is important. The objects to be heated pass, during various heating stages, by the outlet openings of the waveguide systems **18** to **18''''** of the various high-frequency heating units, so that these objects constitute different loads for these high-frequency heating units. By adapting each of the magnetrons **8** by means of its adjustable load matching means **16** to the workpieces the efficiency is raised to a maximum; for example, increases in efficiency of 30% are obtainable.

Consequently, by using the principles according to the teachings of this invention, a high-frequency furnace is obtained which is distinguished not only by a considerable increase in the output power, for example, 10 kw. and still maintaining a minimum stray radiation, but also a material rise in efficiency and an improvement in the heating process is realized.

A high-frequency furnace of the kind set forth tested thoroughly in practice had the following specifications:

Magnetrons **8**: Philips 7091/7292,

Length of transport channel: 132 cms.

Width of the waveguides **18**: 5 cms.

Relative distance between the waveguides **18**: 23 cms.

The exceptional adaptability of the high-frequency furnace according to this invention permits of realizing further improvements. In order to remove the vapors

produced during the high-frequency heating, a blower system having a compressed air duct **30** is used in conjunction with the high-frequency furnace. The duct **30** communicates through gaps **31** extending parallel to the linear radiators **22** in the parabolic cylinders **19** in the proximity of the vertex line **19***c* directly with the waveguides **18**, **18'**, **18'''**, **18''''**. The gaps **31**, which extend parallel to the current paths in the parabolic cylinder, do not produce a disturbance of the satisfactory operation of the high-frequency furnace, so that in the high-frequency furnace according to this invention, the vapors developed during high-frequency heating can be removed in a simple manner from the high-frequency furnace without the need for particular measures, and, thereby, mitigate their aforementioned effects.

It is to be understood that the heating units described herein are selected by way of example to teach the principles of my invention and that, therefore, other types of microwave heating units may be utilized, as well as, different arrangements and/or quantities of component parts of the units may also be utilized, as for example, the utilization of a single high-frequency generator means associated commonly with two or more of the heating units. Thus, while I have described my invention in connection with specific embodiments and applications, other modifications thereof will be readily apparent to those skilled in the art without departing from the spirit and scope of the invention as defined in the appended claims.

What is claimed is:

1. A high-frequency furnace for the heat treatment of workpieces by high-frequency oscillations comprising high-frequency generator means, a plurality of heating units, each of said units having waveguide means having a first parabolic planar reflecting surface and second and third mono-planar conductive surfaces, said second and third surfaces being disposed in a substantially parallel relationship and at right angles to said first surface to provide an enclosure having an opening substantially normal to the principal axis of said parabolic planar surface, radiating means disposed substantially at the focal line of said parabolic planar surface, said focal line being disposed between said opening and the vertex line of said parabolic planar surface, and means for coupling said generator means to said radiating means, a conveyor belt member having a movable supporting surface for conveying said workpieces past each of said openings to generate heat energy in said workpieces by microwave energy emanating therefrom, means to drive said conveyor belt member, and means to disperse said heat energy comprising conductive hollow member means disposed about said supporting surface and the workpieces supported thereby, said hollow member means having a plurality of apertures spatially disposed at predetermined distances from each other, each of said openings of said waveguide means, being associated with one of said apertures.

2. A high-frequency furnace for the heat treatment of workpieces by high-frequency oscillations comprising a plurality of heating units, each of said units having a high-frequency generator, waveguide means having a first parabolic planar reflecting surface and second and third mono-planar conductive surfaces, said second and third surfaces being disposed in a substantially parallel relationship and at right angles to said first surface to provide an enclosure having an opening substantially normal to the principal axis of said parabolic planar surface, radiating means disposed at the focal line of said parabolic planar surface, said focal line being disposed between said opening and the vertex line of said parabolic planar surface, wave energy reflecting means disposed between said radiating means and said opening and means for coupling said generator to said radiating means, a conveyor belt member having a movable supporting surface for conveying said workpieces past each of said openings to generate heat energy in said workpieces by microwave energy emanating therefrom, means to drive said con-

veyor belt member, and means to disperse said heat energy comprising conductive hollow member disposed about said supporting surface and the workpieces supported thereby, said hollow member having a plurality of apertures spatially disposed at predetermined distances from each other, each of said openings of said waveguide means, being associated with one of said apertures.

3. A high-frequency furnace according to claim 2, further comprising means to adjust the coupling of each generator of said heating units to the associated radiating means thereof.

4. A frequency furnace according to claim 2, further comprising a blower system having a duct member commonly coupled to each waveguide means of said heating units to remove vaporous mixtures formed by said workpieces during the said heat treatment thereof.

5. A high-frequency furnace for the heat treatment of workpieces by high-frequency oscillations comprising a plurality of heating units, each of said units having a high-frequency generator, waveguide means having a first parabolic planar reflecting surface and second and third mono-planar conductive surfaces, said second and third surfaces being disposed in a substantially parallel relationship and at right angles to said first surface to provide an enclosure having an opening substantially normal to the principal axis of said parabolic planar surface, radiating means disposed at the focal line of said parabolic planar surface, said focal line being disposed between said opening and the vertex line of said parabolic planar surface, wave energy reflecting means disposed between said radiating means and said opening and means for coupling said generator to said radiating means, a conveyor belt member having a movable supporting surface for conveying said workpieces past each of said openings to generate heat energy in said workpieces by microwave energy emanating therefrom, means to drive said conveyor belt member, and means to disperse said heat energy comprising a conductive hollow member having at least first and second boundary surfaces disposed in parallel relationship with and about said supporting surface of said belt member and the workpieces supported thereby, said hollow member having further a plurality of apertures spatially disposed at predetermined distances from each other located on at least one of said boundary surfaces each of said openings of said waveguide means being associated with one of said apertures.

6. A high-frequency furnace according to claim 5, wherein at least one of said apertures is located on said first boundary surface and the remaining said apertures are located on said second boundary surface.

7. A heat frequency furnace according to claim 5, further comprising means to support absorbing material on the boundary surface of said channel opposite each of said apertures located on the other of said boundary surfaces.

No references cited.