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HIGH-FREQUENCY DIELECTRIC HEATING APPARATUS

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Fig. 1.

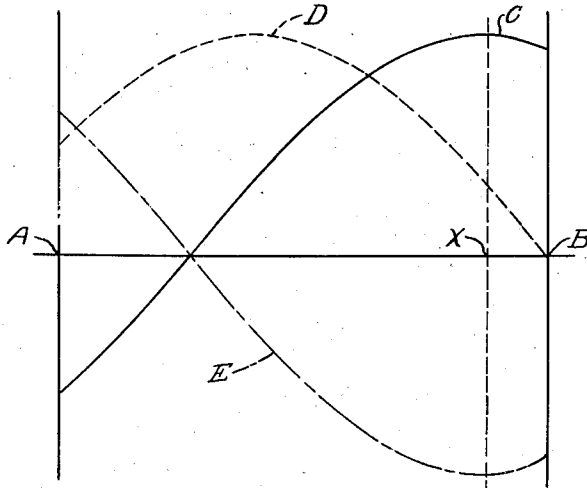
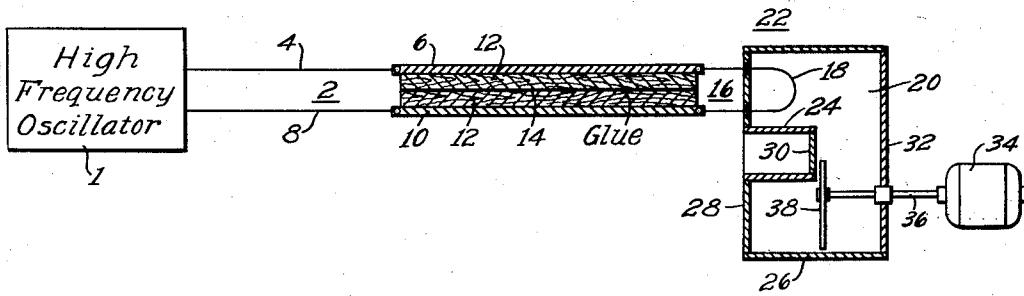


Fig. 2.

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HIGH-FREQUENCY DIELECTRIC HEATING APPARATUS

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4 Claims. (Cl. 219-47)

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This invention relates to high-frequency dielectric heating of large slabs or other objects between heating electrode-means having an electrical length or expanse comparable, in a sense, to the wave length of the high-frequency power supply; but in a more particular sense the invention may be considered to be directed to dielectric heat-treatment systems which utilize frequencies high enough in relation to the electrical characteristics of the power transmitting and consuming elements of the system to ordinarily establish an undesirable standing wave potential pattern along the surface of the heating electrodes between which the material being dielectrically heated is disposed, the part of the standing wave on the electrodes having maximum and minimum values separated sufficiently in magnitude to be a factor in the heating of the material.

An important object of my invention is to provide an economical and efficient dielectric heating system having electrically long heating electrodes, in which the material between the electrodes can be heated throughout with a satisfactory degree of uniformity.

A further object of my invention is to provide a dielectric heating system of a type described for use in successively heating material in batches, the system being such as to substantially uniformly heat-treat each batch without requiring adjustments or special attention to the electrical system.

In dielectric heating, with other factors unchanged or equivalent, the heat generated in a dielectric material between a pair of spaced electrodes of different high-frequency potentials, in a line directly across the material in a direction from one electrode to another, depends on the square of the voltage impressed across the ends of such line. With electrodes on which a standing wave pattern exists, the voltages across different pairs of opposite points on the electrodes will follow the standing wave pattern. If the wave pattern has relatively deep depressions, the voltages across the various elements of the material at different places between the electrodes will not be the same. If the system is such that these unequal voltages result also in unequal voltage-gradients for the respective elements of the material, the material will not be uniformly heated throughout.

A primary object of my invention is to provide a dielectric system of a type utilizing a power supply of such high frequency as to produce a distinct wave pattern on the heating electrodes, with means tending to counteract or nullify the

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variations in the rate of heat generation in the material which arise out of the different voltages across the different material-portions.

It is known that, under ideal conditions, standing waves on an electrically long transmission line which feeds a concentrated load as a terminal impedance, can be eliminated through the use of a stub line, or the equivalent, which provides an impedance of such value, paralleling the load, that the resulting terminal impedance, comprising the load and the stub in parallel, is equal to the characteristic impedance of the transmission line. For dielectric heating it has been suggested, as described in an article by Bierwirth and Hoyler entitled "RF heating applied to wood gluing," published on pages 529 to 537 of the October 1943, I. R. E., that the tendency for nonuniform dielectric heating between platen-electrodes might be minimized by loading the platen-electrodes at various points about their periphery with networks which, together with the reactance of the platen-electrodes, match the characteristic impedance of the line feeding the power to the platen-electrodes. Such matching, under some conditions, is claimed to eliminate standing waves.

Under practical conditions, the heating load between the electrodes forms a distributed varying impedance, and the standing wave pattern along the platen-electrodes does not remain constant during a heat-treatment cycle for a particular batch of material. One of the reasons for this is the changing electrical properties of the material as it is heat-treated. Any impedance matching is disturbed. As one batch which has been heated is replaced by another to be heated, still different conditions may be expected. Accordingly, a principal object of my invention is to provide a system in which the existence of standing waves, which may vary because of the changing electrical characteristics of the material being heated, is accepted, the system, however, being provided with separate means tending to equalize the heating of the different parts of the material. This is accomplished by forcing the wave pattern on the heating electrodes to continually or continuously migrate or shift so that the points of the wave pattern sweep over the electrodes, with each part of the material subjected to maximum or minimum voltages of the wave pattern for the same time periods. Thus, the average voltage distribution over the electrodes during a heating period tends to be equalized.

Other objects, features and innovations of my

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invention will be discernible from the following description and the accompanying drawing which diagrammatically illustrates a preferred form of my invention. In the drawing:

Figure 1, which is not to scale, is a view, with parts in section, of a simplified dielectric heating system embodying my invention, and

Fig. 2 is a curve for explaining the operation of the invention.

Referring to the drawing, a high frequency source of supply 1, which may be a tube-oscillator generator, supplies energy through a transmission line 2 having a conductor 4 connected to an edge of a flat plate-electrode 6 and another conductor 8 connected to the flat plate-electrode 10 which is insulated and spaced from the opposite plate-electrode 6. In a utilization of my invention, the electrodes 6 and 10 may be pressed in a direction toward each other for pressing on opposite sides of a plywood assembly or similar dielectric material. The plywood comprises the desired number of alternating layers of wood veneer 12 and glue 14 which are to be bonded under heat and pressure, three such layers being shown in the drawing for simplicity.

An end of a transmission line 16 is connected to each of the edges of the plate-electrodes 6 and 10, opposite to the edges to which the transmission line 4 is connected, the line 16 being as short as conveniently possible and terminating in a loop 18 coupled to a tunable metal chamber or resonant cavity 20. The electrical characteristics of the chamber 20 can be varied so that the transmission line 16 and chamber 20 comprise a variable impedance network indicated in its entirety by the reference numeral 22.

The chamber 20 includes a tube 24 concentrically inside a longer and larger tube 26, with an end of the tube 24 lying in the plane of an end of the tube 26. The space between these coplanar ends is closed by an annular disc 28; and the other ends of the tubes are closed by an inner closure 30 and an outer closure 32. An electric motor 34 has a metal shaft 36 conductively passing through the closure 32, the axis of the shaft being parallel to but spaced from, or out of line with, the axes of the concentric tubes 24 and 26. A circular metal disc 38 is eccentrically secured to an end of the shaft 36 in slightly spaced relation to the closure 30 of the inner tube 24. As the motor 34 rotates, the natural resonant frequency of the chamber 20 periodically changes so that the impedance of the network 22 is continuously varied in a cyclical manner. Preferably, the resonant value of the tunable chamber 20 corresponding to the frequency of the source 2, is reached when the disc 38 is at some point intermediate its maximum and minimum capacitive positions with respect to the closure 30. This means that the chamber 20 will present both inductive and capacitive reactance, in the preferred form, but at different times.

In dielectric heating, high frequencies in the order of megacycles are desirable for faster heating with practicable voltages. Frequencies in the order of 1.5-50 megacycles and much more are satisfactory or desirable. With air as a dielectric, a standing sinusoidal voltage wave has a wave length of 10 meters at a frequency of 30 megacycles. The distance between the maximum or minimum scalar values of such a wave is a quarter wave length or 2.5 meters. This corresponds roughly to 8 feet. The length of this quarter wave decreases in proportion to

the square root of the dielectric constant of the medium through which the incident and reflected waves, which establish the standing waves, are propagated. In a material with a dielectric constant of 3, the space-separation between the maximum and minimum magnitudes of the wave will be about 4.6 feet for the case mentioned. Heating electrodes about 9 feet in length and much more are usually desirable in making plywood, the spacing between electrodes being generally relatively much less.

Fig. 2 shows several positions of a wave pattern as it is shifted longitudinally along the electrodes having a length represented by the distance A—B, the point A corresponding to the point at which the transmission line 2 is connected. If the shift caused by a single revolution of the disc 38 is more than $\frac{1}{2}$ wave length, the change in voltage at any point on the electrodes will include the maximum and minimum values of the standing wave. Cyclical variations in potential are produced by continuous rotation of the disc 38 on the assumption that the shape of the standing wave does not alter. The power absorbed by the dielectric material is a function of the second power of the voltage so that the minimum value is that where the curve crosses the abscissae axis shown. The curve C indicates the standing wave pattern on the electrodes at a time when the voltage through the material on a line X distance from point A, perpendicular to the electrodes, is a maximum. As the disc 38 rotates, the wave pattern moves, and the curve D will represent the pattern at some other instant. The voltage at X at this time will be considerably less than the maximum but greater than the minimum. At some still later interval, the voltage at X has passed through the minimum value and becomes greater but in the opposite polarity-sense, as indicated by the curve E.

If the curves C and E represent the maximum shift of the wave pattern during a revolution of the disc 38, it is evident that the potential at every point on the electrodes will cyclically vary in accordance with the shape of the standing wave, and in order to get the same variation at each point, the shift caused by rotation of the motor 34 should also be at least a half of a wave length. However, it is obvious that lengths which are substantially multiples of a half of a wave length are utilizable for the same purpose.

The speed of the motor may be varied through a wide range, but the standing wave should sweep back and forth across the electrodes at least several times through a heat-treatment period for the material. However, a comparatively rapid sweep is desirable in order to keep the heating more uniform and to minimize the effects of heat radiation and conduction, and the changes introduced by the curing or setting of the material. Since the heat-treatment period may require from a few minutes to a few hours, a motor speed of 30 revolutions per second causes an adequate shift of the wave pattern back and forth across the electrodes through any of the aforesaid heating periods.

In narrow relatively long rectangular heating electrodes, the standing wave pattern can be considered as producing substantially the same potentials on a line across the narrow width of the electrodes. Where the electrodes have a greater width, which also causes a variation in potential therealong, it may be desirable to connect one or

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more networks 22 at several different points around the edges of the electrodes.

While I have described my invention in connection with a preferred form and operation thereof, it is obvious that other forms and networks can be used embodying the teachings and principles herein disclosed. Another system and a method for obtaining more uniform heating by forcibly changing the wave-patterns are disclosed and claimed in a copending application of Robert M. Baker, Serial No. 556,140, filed concurrently herewith.

I claim as my invention:

1. Dielectric heating apparatus comprising a pair of relatively large spaced electrodes for heating a dielectric material therebetween, a source of high-frequency electrical energy adapted to establish a non-flat wave pattern along said electrodes, a transmission line connecting said source of energy to said electrodes, a variable terminating impedance connected to said electrodes at a point removed from said transmission line, and means for automatically cyclically changing said impedance.

2. Dielectric heating apparatus comprising a pair of relatively large spaced electrodes for heating a dielectric material therebetween, a source of high-frequency electrical energy adapted to establish a non-flat wave pattern along said electrodes, a transmission line connecting said source of energy to said electrodes, a resonant chamber connected to said electrodes at a point removed from said transmission line, and means for cyclically continually changing the electrical characteristics of said chamber during a heating operation.

3. Dielectric heating apparatus comprising a pair of relatively large spaced electrodes for heating a dielectric material therebetween, a source of high frequency electrical energy, means connecting said source of energy to said spaced electrodes, a variable impedance network means also connected to said electrodes, said source of

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energy being such as to establish a wave pattern on the electrodes, said network means having a cyclically movable part for affecting its impedance for shifting the wave pattern substantially $n\pi$ radians, where n is any integer, and means comprising an electric motor mechanically coupled to said movable part for cyclically moving said movable part.

4. Dielectric heating system comprising a source of high frequency electrical energy, a terminating network of variable impedance, power transmission means comprising connections between said source of energy and said network, said connections including a pair of spaced heating electrodes for receiving dielectric material therebetween for a heat-treatment period, the system being such as to provide a wave-pattern on said electrodes, the wave-pattern having spaced maximum and minimum points, and separate means associated with said network operable for automatically varying said network in a predetermined manner for sweeping the wave-pattern back and forth over the electrodes, during a heat-treatment period, whereby to provide substantially the same average heating throughout said material.

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REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

35 Number	Name	Date
1,972,050	Davis	Aug. 28, 1934
2,147,689	Chaffee	Feb. 21, 1939
2,179,261	Keller	Nov. 7, 1939
2,241,976	Blewett et al.	May 13, 1941
2,244,756	Alford	June 10, 1941
2,303,444	Evans	Dec. 1, 1942
2,304,958	Rouy	Dec. 15, 1942
2,308,043	Bierwirth	Jan. 12, 1943