Jan. 27, 1959 G. E. GARD 2,870,543

METHOD AND APPARATUS FOR DIELECTRIC HEATING

Filed Jan. 24, 1956 4 Sheets-Sheet 1

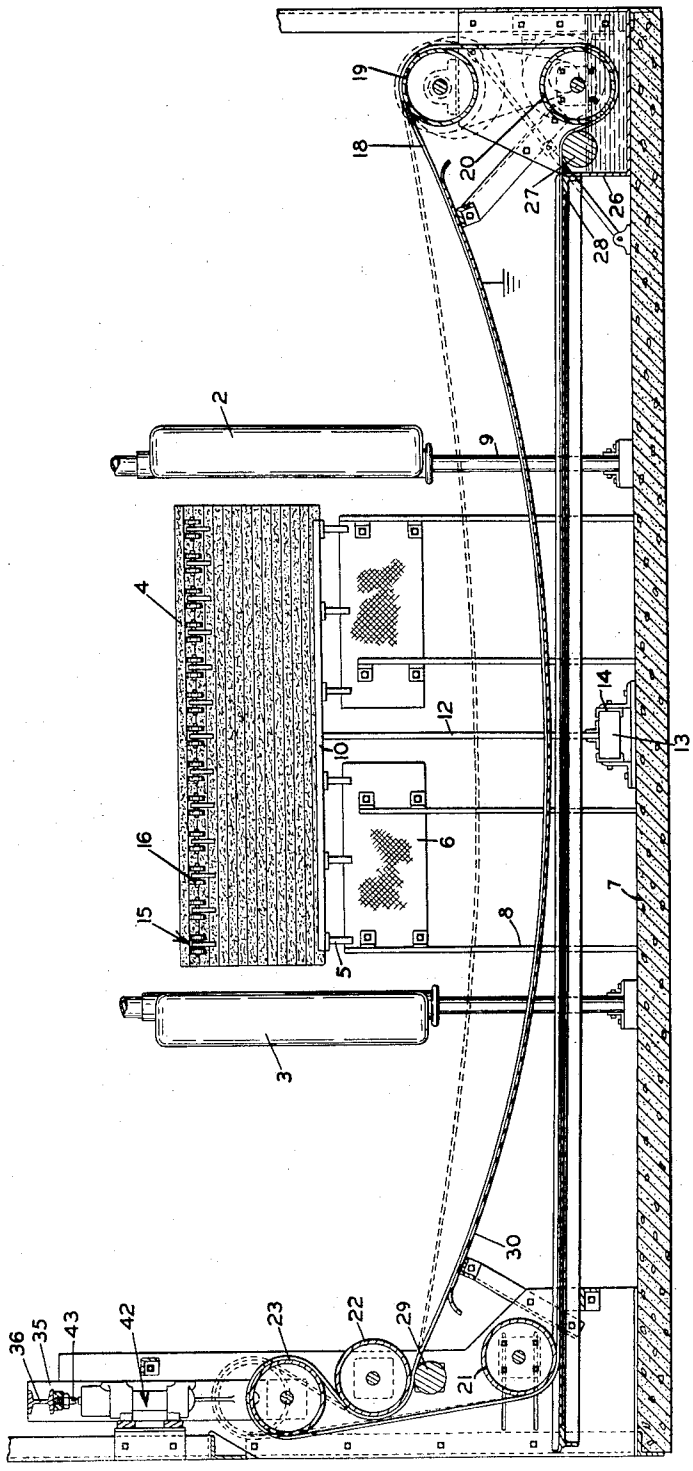

Fig. 1

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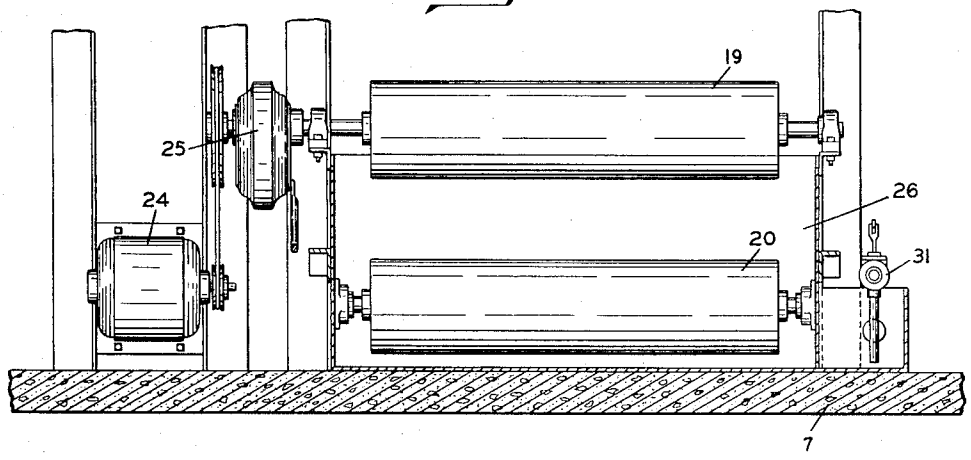
Fig. 2



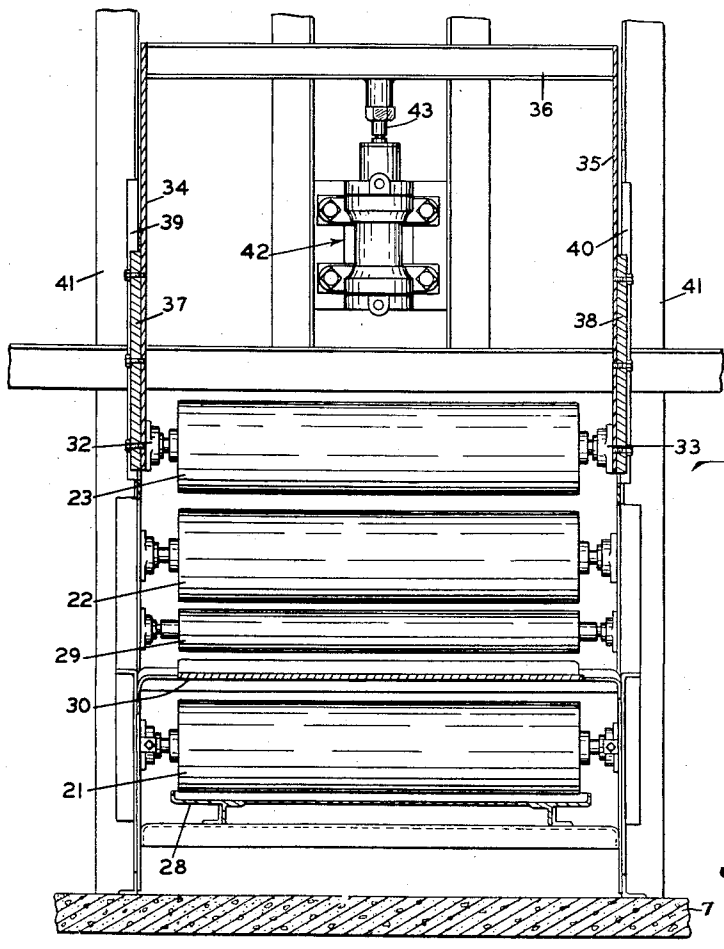


Fig. 3

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METHOD AND APPARATUS FOR DIELECTRIC HEATING

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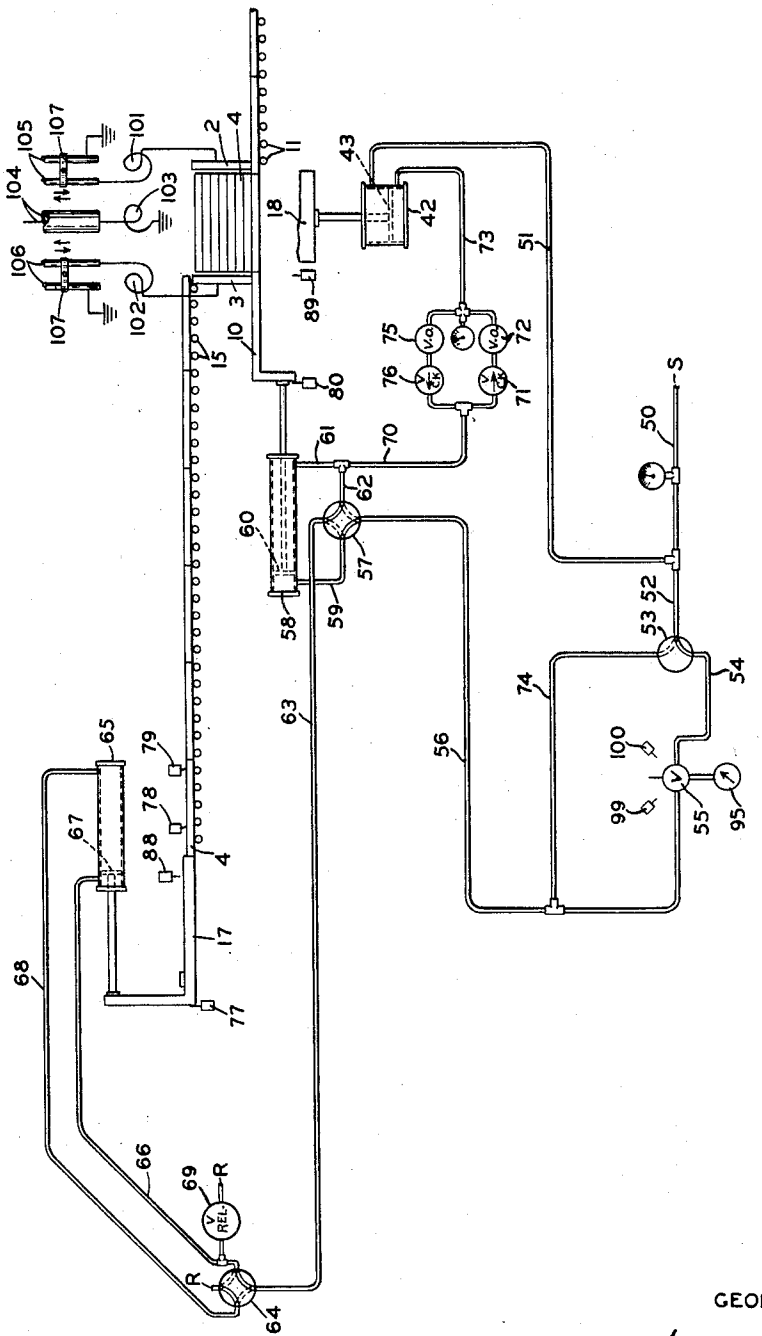
Fig. 4



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METHOD AND APPARATUS FOR DIELECTRIC HEATING

Filed Jan. 24, 1956 4 Sheets-Sheet 4

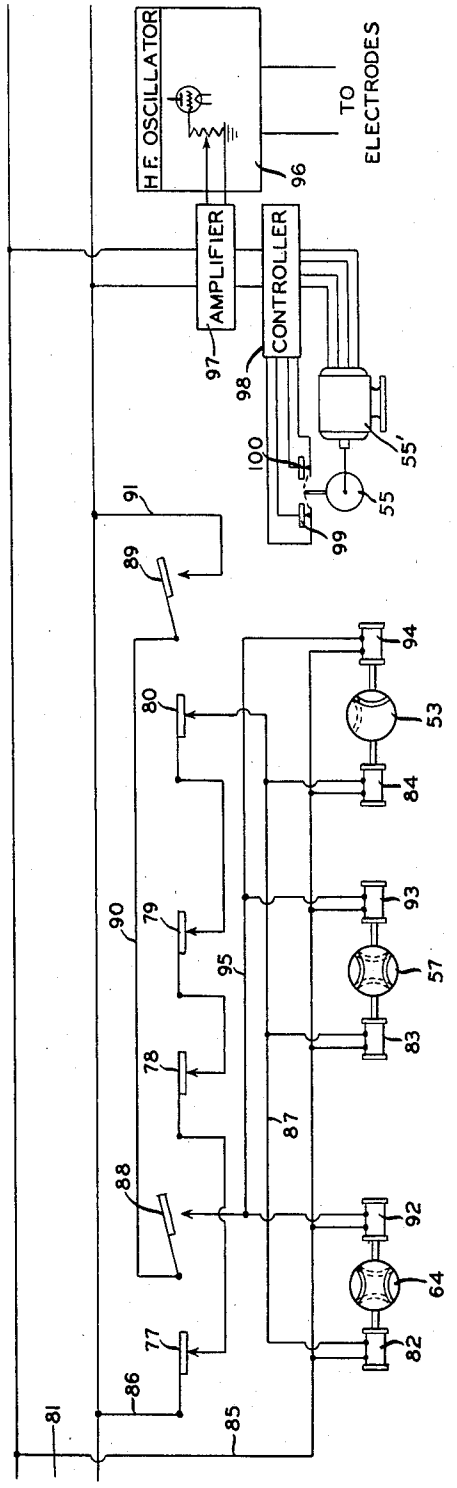

Fig. 5

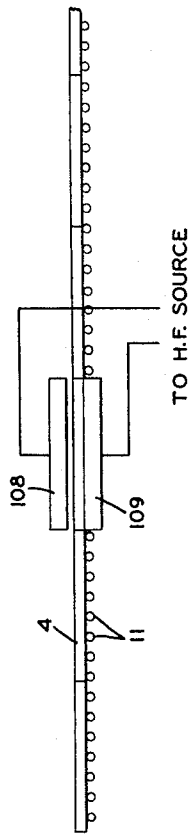

Fig. 6

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2,870,543

METHOD AND APPARATUS FOR DIELECTRIC HEATING

George E. Gard, East Hempfield Township, Lancaster County, Pa., assignor to Armstrong Cork Company, Lancaster, Pa., a corporation of Pennsylvania

Application January 24, 1956, Serial No. 560,942

16 Claims. (Cl. 34—1)

This invention relates to a method and apparatus for dielectrically heating materials and is concerned particularly with the dielectric drying of fibrous materials.

The invention is particularly useful in connection with the drying of fibrous insulation materials where removal of water from a porous material has been found to be particularly difficult, especially the portion which remains in the center of the product after the outer surfaces have become quite dry. The heat insulating qualities of such a product militate against the penetration of the heat necessary to remove the water. The invention will be described in conjunction with the drying of a fibrous acoustical insulation product as a typical embodiment illustrating the field to which the invention relates.

In the manufacture of one type of acoustical material, nodulated mineral wood fibers are formed into an aqueous slurry with a small quantity of binding material, such as starch, and the slurry is formed into a sheet on a traveling wire screen. A continuous sheet is formed as water is drained from the slurry through the screen. The wet sheet is severed into "mats" which may be 51" x 51" x 1⅛". These mats are delivered to a gas or oil fired or other similar drier where a substantial portion of the water remaining in the mat is removed. In this type of drying unit, the moisture is removed outwardly, and the outer surfaces of the mat may be essentially dry while the central portion of the mat may be quite wet. The removal of this water from the center of the mat is quite expensive and slow. Not only is there a substantial fuel cost involved, but there is a considerable additional capital investment required for drying equipment. This relatively small amount of water—it may constitute about 16–17% of the total weight of the mat, for instance—may be concentrated principally in the central ¼" to ½" of the 1⅛" thick mat.

The drying of dielectric type materials by high frequency electrical energy has been proposed. Conventional practice in dielectric heating of materials where a mass to be heated is disposed between flat electrodes to which the high frequency power is applied, such as followed in the dielectric bonding of plywood, is not commercially feasible for drying a mat of insulation material, where the moisture is concentrated in the central portion of the mat. If the mat is disposed on edge between the electrodes, with the wet central area and the dry outer areas being in effect in essentially a parallel relationship between the electrodes and thus the dielectric constant and voltage gradient in the mass between corresponding points on the electrodes (parallel to the direction of the applied high frequency stress) being essentially uniform, the loss factors of the various areas will control the dielectric heating effect and the major portion of the heating energy will be concentrated in the wet central area where it should be for most efficient drying. This follows the well-known dielectric heating formula,

$$\text{Heat } \delta f(k \tan \delta)\left(\frac{E}{d}\right)^2$$

where f is the frequency of the applied alternating electrical energy, k is the dielectric constant, tan δ is the dissipation factor, (k tan δ) is the loss factor of the mass under treatment, and

$$\left(\frac{E}{d}\right)^2$$

is the voltage gradient or electric field. Since the loss factor of the wet central area is much greater than the loss factor of the dry areas on opposite sides thereof, the heating effect will be greatest in the wet area, the frequency and voltage gradient through the mass from electrode to electrode being essentially uniform with the wet and dry layers being in parallel relationship.

In a typical mat such as referred to above, the loss factor may be about 160 times as great for the wet area as the loss factor for the dry areas. This would occur if the values for the wet and dry areas were as follows:

Dry Area	Wet Area
k=1.5 tan=.01 (k tan δ)=.015	k=8 tan=.30 (k tan δ)=2.4

Therefore, if efficient drying of a nonuniformly wet mat is to be accomplished, the electrical stress should be applied in a direction essentially parallel to the wet and dry areas or, in other words, parallel to the flat faces of the mat rather than perpendicular thereto. With large mats such as those here under consideration, it is not commercially practicable to so apply the high frequency stress to individual mats, because of the problems of field concentration, electrode configuration, stray capacitance problems, and other factors.

If the mats are piled one upon another to form a stack of substantial height, it is possible to apply the high frequency electrical energy to the stack of mats in a direction substantially parallel to the flat faces of mats; and while this results in an enormous improvement in dielectric heating efficiency, the mats when so heated in bulk are not uniformly dried, the outermost mats in the stack generally being drier than those in the center of the stack, probably because of more ready paths for the escape of moisture from such outside mats.

An object of the invention, therefore, is to provide a method and apparatus for dielectric drying of materials efficiently and substantially uniformly, preferably in a substantially continuous manner.

This object is accomplished according to this invention by stacking the workpieces and moving each of the workpieces progressively to each of the positions in the stack, from an entrance position, for instance, where the workpiece contains its maximum amount of moisture through intermediate positions to an exit position where the workpiece contains its minimum amount of moisture. Where the workpieces are in the nature of the mats discussed above and they are stacked horizontally (with their flat faces horizontal) between vertically disposed electrodes positioned adjacent to opposite edges of the stack, this may be accomplished by feeding the untreated mats progressively onto the top of the stack and progressively removing the treated boards from the bottom of the stack. Thus, as heating and drying are effected, the mat will be moved in sequential steps from the top of the stack to the bottom.

An important advantage of this stepwise movement of the workpieces is that as the workpiece moves from the uppermost position in the stack to the interior, steam and vapors which are developed by the dielectric heating move throughout the thickness of the porous mat, escaping principally at the edges. Thus, when the mat finally

reaches the bottom of the stack and is discharged therefrom, any moisture which remains in the mat will be essentially uniformly distributed throughout the thickness of the mat and may be more readily removed, either by dielectric heating with the stress applied to the mat in a direction perpendicular to the flat faces, as disclosed and claimed in my copending application Serial No. 560,943, filed concurrently herewith, or by the use of conventional gas or oil fired driers, or the like.

Another important object of the invention, therefore, is to provide a method and apparatus for dielectrically heating a workpiece to substantially uniformly redistribute nonuniformly distributed moisture or the like within the workpiece.

In a progressive drying system for stacked workpieces as discussed above, one of the problems is to maintain a substantially contant load on the oscillator which supplies the high frequency electrical energy. If the workpieces delivered to the stack contain more or less moisture than the normal amount or if the dielectric constant varies in the mats for other reasons, the system will fall out of balance and heating efficiency will suffer; for unless the oscillator is properly tuned to the load, maximum utilization of the energy of the oscillator will not be obtained. Also, in a large commercial system such as is required for massive loads, such as those under discussion here, retuning to compensate for changes in the load on the oscillator is difficult and undesirable.

Another object of the invention, therefore, is to provide a method and apparatus for controlling the delivery of workpieces to the stack between the electrodes to maintain a substantially uniform relationship between the oscillator and the tuned load including the workpieces.

This object is preferably accomplished by providing for control of the rate of delivery of workpieces to the stack and removal of treated workpieces from the stack through a control system responsive to the load on the oscillator.

There is another problem related to a progressive system for dielectric heating of workpieces disposed in a stack, and that is concerned with the maintenance of proper tuning of the oscillator to the load when for some reason there is an inadequate supply of untreated workpieces for delivery to the stack as might occur at the end of a production run, in the event of a breakdown in the oven drier, the delivery of mats substantially drier than the normal mats, or other cause. Under such circumstances, it might not be possible to speed up the rate of delivery of untreated boards to the stack sufficiently to maintain the desired matching between the output of the oscillator and the load to be heated. It might be necessary also to interrupt the feeding completely in the case of a breakdown.

An additional object of this invention, therefore, is to provide a method and apparatus for interposing an artificial load into the system to aid in maintaining the system in proper balance.

This object is accomplished effectively by means of an artificial load in the form of a traveling apron, wetted with water, the apron being arranged for movement into and out of the dielectric heating field and adjustable therein during its travel.

Other objects of the invention will become apparent from consideration of the following description of a typical embodiment of the invention, reference being made to the attached drawings in which:

Figure 1 is a diagrammatic view, partially in section, illustrating a portion of the apparatus of the invention;

Figure 2 is a detailed view to a slightly larger scale than Figure 1 illustrating a driving arrangement for the artificial load apron, with the apron removed for clarity of illustration;

Figure 3 is a view similar to Figure 2 showing an arrangement for adjusting the position of the artificial load apron with respect to the electrodes;

Figure 4 is a diagram of a hydraulic system forming part of a control arrangement useful in practice of the invention;

Figure 5 is a wiring diagram showing an electrical control arrangement with the high frequency oscillator and other elements being schematically illustrated; and

Figure 6 is a diagram of a two-stage dielectric drying system.

Referring to Figure 1, there is shown a pair of electrodes **2** and **3**. These may be of hollow construction, about 6' long and 30" high and about 6" in depth. The electrodes are preferably electrically heated internally to about 200–300° F. to prevent the condensation of water and other materials onto the outer surfaces of the electrodes. The electrodes are suitably connected to a high frequency oscillator, preferably in push-pull relationship, through a suitable coupling and tuning arrangement and a quarter wave length transmission line. Any suitable source of high frequency electrical energy, preferably in the range of 10–30 megacycles, with 16.1 megacycles being considered a typical example, may be used. A rating of 100 kilowatts output will provide sufficient power for drying. The coupling of the electrodes to the oscillator may be inductive with a tuning stub arrangement, as schematically illustrated in Figure 4. Other coupling and tuning arrangements may be provided; the essential requirement is to provide for effective dielectric heating of a load consisting of a plurality of workpieces 4 disposed between the electrodes and to provide for effective tuning of the oscillator to the load.

In the embodiment illustrated, there are 15 workpieces constituting the load. These may be mats of mineral fiber insulation board of the size mentioned above. It is preferable to utilize a relatively large stack of articles to increase the relative power factor of the load and thereby obtain better over-all efficiency of transfer of energy to the workpieces to be heated. This also assures better stability of the oscillator to frequency because of the higher power factor at the load. Also, with a large stack, it is possible to obtain more effective redistribution of the moisture.

The mats **4** are supported upon a plurality of rails **5** which extend along the length of the electrodes **2** and **3** and are disposed therebetween. The rails **5** are carried by plates **6** which are supported from the foundation **7** by columns **8**. Electrodes **2** and **3** are similarly supported from the foundation by columns **9**. A mechanical pusher **10** is provided to engage the lowermost workpiece in the stack and push it out from beneath the other articles in the stack and deliver it to an out-feed conveyor **11** which may be in the form of a roller conveyor as diagrammatically shown in Figure 4. The out-feed pusher **10** has an actuator arm **12** which extends to a slide **13** to which it is fixed. The slide **13** is operated in ways **14** by a hydraulic cylinder and piston unit as will be more fully described.

An in-feed conveyor **15** which is made up of a plurality of rollers **16** is so positioned that workpieces delivered therefrom are deposited onto the top of the stack, the workpieces being fed to the conveyor **15** by an in-feed pusher **17** (Figure 4) in synchronism with delivery of workpieces from the stack by the out-feed pusher **10**.

The various members such as the rails, supporting plates and brackets, columns, rollers, and fastening devices which are within the field of the dielectric heating unit are made of dielectric material such as glass cloth impregnated with polytetrafluoroethylene, silicone impregnated glass cloth, Mycalex, a glass bonded mica product, or other suitable insulating material.

The artificial load arrangement comprises an endless web or apron of cloth, such as a woven canvas belting, trained over rolls **19—23**. Roll **19** is driven as shown in Figure 2 by an electric motor **24** through an adjustable speed reducer **25**. Rolls **20**, **21**, **22**, and **23** are mounted for idling rotation. The roll **20** is positioned in

a tank 26 which may contain water for wetting the artificial load apron 18. A guide bar 27 (Figure 1) leads the apron 18 out of the tank and the apron is free to move along an inclined trough 28, over rolls 21 and 23, and between this last mentioned roll and the roll 22, being guided by a bar 29 onto a concave metal trough 30, back to roll 19, as an endless apron. The apron 18 is arranged for continuous rotation and a control valve arrangement 31 (Figure 2) is provided to maintain water at a desired level in the tank 26. This insures that the apron 18 will at all times be ready for service and will carry as uniform an amount of water as is necessary for its proper functioning as an artificial load.

An arrangement is provided for moving the artificial load into the effective high frequency electric field of the electrodes 2 and 3. In the embodiment illustrated, this function is accomplished by elevating the roll 23, decreasing the length of the apron between rolls 19 and 22, and thus moving the apron 18 from the solid line position shown in Figure 1 to the dotted line position shown in that view, or to any position intermediate the two.

A suitable hydraulic elevator mechanism for accomplishing this movement of roll 23 is shown in Figures 1 and 3. Bearings 32 and 33 (Figure 3) which support roll 23 for free rotation are secured to frame members 34 and 35 which are connected by a cross beam 36. Slides 37 and 38 are secured to members 32 and 34 and move in ways 39 and 40 positioned on the framework 41 of the unit.

A hydraulic cylinder and piston unit 42 is also mounted on the framework, and the piston 43 of this unit is connected to the cross beam member 36. Movement of the piston 43 lifts the roll 23 and its associated supporting and guiding mechanism, the unit moving along the ways 39 and 40.

The hydraulic cylinder and piston which effects movement of the artificial load apron to adjust its position relative to the heating field forms part of a hydraulic system which includes hydraulic actuators for the in-feed pusher 17 and the out-feed pusher 10. This hydraulic system is so controlled that it is effective for maintaining an essentially uniform load on the high frequency oscillator. The hydraulic actuators for the in-feed and out-feed pushers are speed controlled in accordance with the load on the oscillator and are effective for delivering and removing the workpieces at such rate as to maintain the heating system in reasonably close balance. The hydraulic actuator (the cylinder and piston unit 42—43) for the artificial load apron is integrated into the system in such manner that, should it be impossible to adequately meet the demands of the oscillator for an increase in the load to be heated, because of failure in the supply of boards to be treated, for instance, the artificial load will be inserted into the field to satisfy such demand and maintain the desired state of balance.

The hydraulic and electric control systems are illustrated in Figures 4, 5, and 6.

In the operation of the hydraulic system fluid under pressure is delivered from a source S to a line 50. Cylinder and piston unit 42 of the artificial load elevating mechanism is permanently connected on its minimum area side to the source S through a line 51. The piston 43 of this unit is connected to the elevating mechanism for the artificial load apron 18, as heretofore described. Thus, with the hydraulic fluid constantly supplied to the unit 42 in this manner, the artificial load normally will be moved to a position out of the active field of the dielectric unit.

A line 52 connects the source to a solenoid control valve 53 which when in the solid line position shown in the drawing delivers fluid through line 54, through a motor driven valve 55 which is controlled in accordance with the load on the dielectric heating unit, as will be more fully hereinafter described. A line 56 leads from valve 55 to another solenoid control valve 57 for a cylinder and piston unit 58 which actuates the out-feed pusher 10 which removes the workpieces 4 from the dielectric heating unit. When the valve 57 is in the solid line position shown in the drawing, fluid from the source is fed to the hydraulic unit 58 from valve 57 through a line 59 to move the piston 60 which is connected to the out-feed pusher 10 to deliver the lowermost workpiece 4 in the stack out of the dielectric heating unit.

Movement of the piston 60 then delivers fluid from the unit 58 through lines 61 and 62 through the valve 57 into a line 63 to a solenoid valve 64 which serves to control a hydraulic cylinder and piston unit 65 which is connected to the in-feed pusher 17 of the dielectric heating unit.

With the valve 64 in the solid line position shown in the drawing, fluid under pressure exhausted from hydraulic unit 58 will pass through lines 61 and 62, valve 57, line 63, and valve 64 to a line 66 connected to the hydraulic unit 65 to effect feeding movement of the in-feed pusher unit 17, through piston 67 to which it is connected. Hydraulic fluid exhausted from unit 65 ahead of piston 67 will flow through a line 68 which is connected through valve 64 (in its solid line position) to a return line R leading to the source.

A pressure release valve 69 is provided in line 66 so that, should there be any obstruction to the free feeding of the workpieces, the valve 69 will open and exhaust the hydraulic fluid to return line R, thus avoiding damage to the workpieces which would occur if the pressure were permitted to build up behind piston 67.

The hydraulic units 58 and 65 are similar in size and construction and are so connected, as shown in the drawing, that they operate in series, with the hydraulic fluid exhausted from the minimum area side of piston 60 being delivered to the minimum area side of piston 67 and when the valves 57 and 64 are reversed to deliver hydraulic fluid exhausted from the maximum area side of piston 60 to the maximum area side of piston 67 as will be described later. Thus, the feeding of each workpiece into the dielectric heating unit will be synchronized with the delivery of a workpiece from the unit. If the two hydraulic units 58 and 65 are not adequately synchronized in operation, suitable "make-up" fluid may be supplied through control valves in the manner well-known in the art.

The line 61 from hydraulic unit 58 also connects with a line 70, in which there is a check valve 71 and a variable orifice valve 72. A line 73 extends from valve 72 to the maximum area side of the piston 43 of hydraulic unit 42. With the piston 67 in motion during the feeding cycle of in-feed pusher 17, no substantial pressure will build up in line 70 and the pressure applied to the maximum area of the piston 43 will be inadequate to overcome the line pressure applied the minimum area side of the piston.

When the in-feed and out-feed pushers have completed their strokes, electrical controls, hereinafter fully described in conjunction with Figure 5, reverse the positions of the solenoid valves 53, 57, and 64 to deliver the hydraulic fluid under pressure through the valve ports shown in dotted lines in the drawing. When this occurs, the fluid under pressure from the source S will flow through line 50, line 52, valve 53, and a by-pass line 74 to line 56 and from there to valve 57, through the valve to lines 62 and 61 to the hydraulic unit 58 to return the piston 60 to the position shown in the drawing, retracting the out-feed pusher 10 to a position ready to engage the next workpiece to be removed from the dielectric heating unit.

At the same time, fluid which is exhausted from the hydraulic unit 58 will flow through line 59, valve 57, and line 63 to valve 64. From valve 64, the fluid will flow through line 68 to hydraulic unit 65 and will move piston 67 to the position shown in the drawing, retract-

ing the in-feed pusher 17 to a position ready to engage the next workpiece to be fed into the dielectric heating unit.

Hydraulic fluid behind the piston 67 of the hydraulic unit 65 now will be exhausted through line 66 and valve 64 for return to the source through return line R. When the pistons return to these positions, they bring the pushers to their starting positions, and the control of the supply of electrical energy for the solenoid valves 53, 57, and 64 is such that the valves reverse their positions and the operation is automatically repeated.

When the solenoid valve 57 is in the dotted line position of the drawing, fluid from the source S is free to flow through valve 57, lines 62 and 70, check valve 71, and variable orifice valve 72 and line 73 to the maximum area side of the piston 43 to cause the piston to be moved toward a position to bring the artificial load into the field of the dielectric heating unit. However, so long as the piston 60 is moving, there will be no substantial pressure applied to the piston 43. The applied pressure will be inadequate to move the piston 43 against the force of the line pressure continuously applied to the minimum area side of the piston. Should the piston 60 upon its return to its normal position as shown in the drawing remain in that position, with the valve 57 in its dotted line position, as will occur if there is an inadequate supply of workpieces to be fed to the dielectric heating unit which will result in interruption of the electric control circuit for the valve 57, as will be more fully hereinafter described, hydraulic fluid at full line pressure will be fed to the maximum area side of the piston 43. This will overcome the line pressure applied to the minimum area side of the piston 43, and piston 43 will be moved to bring the artificial load unit 18 into the field of the dielectric heating unit. The speed with which this is accomplished will depend upon the setting of the variable orifice valve 72.

Just as soon as a supply of workpieces is delivered to the feeding unit for delivery to the dielectric heating unit, valves 57 and 64 will be reversed automatically to feeding position, and piston 43 will move in a direction to withdraw the artificial load 18 from within the field of the dielectric heating unit. The hydraulic fluid in front of piston 43 will then flow through line 73, a variable orifice valve 75, and a check valve 76 into line 70. The variable orifice valve 75 will control the speed at which the artificial load unit is retracted.

The speed at which the workpieces are fed to the dielectric heating station and the synchronized speed of delivery of workpieces therefrom are controlled by the motor driven valve 55. The motor for the valve is preferably arranged to be controlled in accordance with the load on the oscillator connected to the electrodes in the dielectric heating station, with the valve being moved toward an open position as the load on the oscillator decreases and being moved toward a closed position as the load on the oscillator increases. This will be more fully discussed in conjunction with the description of the electrical control system which follows.

The electrical control system is diagrammatically shown in Figure 5 and should be considered in conjunction with the hydraulic system of Figure 4. With the hydraulic cylinders and pistons in the positions shown in Figure 4 and with a full-sized workpiece 4 lying in position for engagement by the in-feed pusher 17, limit switches 77, 78, 79, and 80 will be closed, the switch 77 being closed by the in-feed pusher 17 and the switch 80 being closed by the out-feed pusher 10. The switches 78 and 79 are so positioned that they are engaged by opposite corners of a full workpiece; and if the workpiece is broken or of less than the desired size, then one or both of the switches 78 and 79 will not be closed until the defective workpiece has been removed and a satisfactory workpiece has been fed into position.

When the switches are in this closed position (Figure 5), electric current will flow from the source 81 to actuator solenoids 82, 83, and 84 for the hydraulic fluid control valves 64, 57, and 53, respectively. One side of each of these solenoids is connected to one side of the source 81 by a lead 85. The switches 77, 78, 79, and 80 are connected in series as shown in Figure 5 and a lead 86 connects these switches to the other side of the source 81 and a lead 87 connects the solenoids 82, 83, and 84 to the lead 86 through the series connected switches. When these solenoids are actuated, the valves 64, 57, and 53 will be in the solid line positions shown in Figures 4 and 5 and the in-feed and out-feed pushers 10 and 17 (Figure 4) will be actuated to move the workpieces in their path.

When the pushers reach the ends of their strokes, control switches 88 and 89 will be closed, the switch 88 being actuated by the in-feed pusher 17 and the switch 89 by the out-feed pusher 10. These switches are connected in series (Figure 5) by lead 90 and are connected to one side of the source 81 by a lead 91. Actuator solenoids 92, 93, and 94 for valves 64, 57, and 53, respectively, have one side connected to the other side of the source by lead 85. A lead 95 completes the circuit for these solenoids through the series connected switches 88 and 89 and leads 90 and 91. Thus, when switches 88 and 89 are moved to a closed position, solenoids 92, 93, and 94 are actuated, reversing the positions of the valves 64, 57, and 53 from the solid line positions to the dotted line positions and hydraulic fluid will flow to the hydraulic units 58 and 65 to return the in-feed and out-feed pushers to their feeding positions.

The control mechanism for the motor driven valve 55 is also diagrammatically illustrated in Figure 5. This is accomplished in the embodiment illustrated by use of a reversible motor 55' which is controlled in accordance with the load on the high frequency oscillator 96. This may be effected in many different ways. As diagrammed in the drawing, one way is by utilizing variations in the grid current which result from change in the load on the oscillator, suitably amplified through an amplifier 97, to actuate a controller 98 for the motor 55' forming part of the motor driven valve 55. The controller will be arranged to operate the motor 55' to move the valve 55 toward its open position to speed the delivery of workpieces into the dielectric heating unit when the load on the oscillator decreases, causing the grid current to deviate from a mean valve, and to move the valve 55 toward a closed position when the load on the oscillator increases, causing the grid current to deviate in the opposite direction from the mean valve. Movement of the valve 55 toward its closed position serves to slow down the rate of feed of workpieces into the dielectric heating unit.

A similar arrangement utilizing the plate current of the oscillator output tube may be substituted; or, if desired, the motor controlled valve 55 may be manually actuated, with the operator following the load on the oscillator through inspection of a suitable indicating device which is responsive to the load.

Where automatic control is effected, it is desirable to provide limit switches 99 and 100, mechanically actuated by valve 55 to limit the movement of the valve toward its open and closed positions through the controller 98.

A typical coupling of high frequency source to the electrodes 2 and 3 is shown in Figure 4, where coupling coils 101 and 102 are connected to the electrodes and a coupling coil 103 is connected to the source through a quarter wave length transmission line 104 and to ground. Tuning stubs 105 and 106 are provided, each including a shorting strap 107 for tuning the unit to the load. As previously mentioned, other coupling and tuning arrangements may be provided.

In the operation of the unit, assuming a full load of 15 mats to be positioned between the electrodes 2 and

3 and the high frequency power to be applied and the oscillator properly tuned to the load, an untreated mat 4 will be pushed forward by the in-feed pusher 17 over the roller conveyor 15 and delivered onto the top of the stack between the electrodes. (Obviously, the electrodes may be disposed in a horizontal position with the workpieces stacked therebetween on edge in a vertical position and the workpieces may be fed in on one side of the stack and withdrawn from the opposite side.) Simultaneously with the feeding of a mat to the stack, the out-feed pusher 10 will engage the lowermost mat in the stack and push it out onto the out-feed conveyor 11. The high frequency alternating electric voltage applied to the electrodes 2 and 3 from the oscillator 96 will be absorbed by the mats disposed in the stack; and, as noted in the forepart of this specification, the major electric stress will be developed within the wet central areas of the mats. Most of the high frequency energy will be absorbed by the uppermost mats in the stack, for they will obviously contain more moisture than the lowermost mats in the stack.

The hydraulic units which drive the in-feed and out-feed pushers are so arranged that their feeding strokes are much slower than their return strokes. This may be adjusted so that the return stroke takes up but 5% of the total time required for each complete cycle of operation, for instance. As a result, the in-feed and out-feed pushers are moving mats into and out of the heating zone on an essentially continuous basis. The rate of such feed is determined in accordance with the load on the oscillator 96, through motor controlled valve 55. The oscillator will be tuned and the control 55 adjusted so that the desired heating of the workpieces 4 between the electrodes 2 and 3 may be accomplished with the workpieces being fed to and removed from between the electrodes at a rate of speed related to the rate of delivery of the articles from a conventional oven drier or from a dielectric drying unit such as described and claimed in my copending application Serial No. 560,941, filed concurrently with this application, assuming the workpieces to contain an amount of moisture falling within a known range.

As untreated workpieces are fed onto the top of the stack and heated workpieces are removed from the bottom of the stack, each mat is progressively moved from the top of the stack to the bottom. As dielectric heating continues, the moisture in the mats is vaporized and turned to steam. Since each mat is for a major portion of the heating time disposed with similar mats above and below it, the steam escapes principally at the exposed peripheral edges of the mat, as shown in Figure 1, and the moisture which remains in the mat tends under such circumstances to migrate essentially uniformly throughout the thickness of the mat. The mat, as noted above, may contain 16–17% of moisture; or if dielectric preheating has been effected in the manner taught in my copending application Serial No. 560,941, previously referred to, the moisture may be in the order of 10–12% as it is delivered to the top of the stack. Also, as noted above, the moisture may be concentrated principally in the central ¼" of the 1⅛" thick mat. (The invention is not limited, of course, to any specific quantity of moisture to be removed or to any specific localized wet area. The foregoing is merely illustrative of an embodiment of the invention.)

As the mats are discharged from the unit, they may contain about 5–6% of moisture, fairly evenly distributed throughout the thickness of the mat. If the product can tolerate this amount of moisture, no further heating will be necessary.

The speed of feed of the mats into and out of the dielectric heating unit will be controlled so as to maintain the heating system in proper balance, such control being effected through the valve 55, as previously described. During such normal operation of the dielectric heating unit, the artificial load apron 18 will merely idle, and this idling will continue so long as the rate of delivery of untreated articles to the dielectric heating system is adequate to provide sufficient mats to meet the demands of he dielectric heating unit, determined by the total load on the oscillator. Should the rate of delivery of untreated mats be inadequate, should there be a breakdown in the heating oven or the feeding system or should an incomplete board or mat be delivered for drying and the same be required to be removed with a consequent interruption in the supply of boards or mats to the dielectric heating unit, then the artificial load apron 18 will be elevated and brought within the field of electrodes 2 and 3. The apron which is continuously wetted with water by immersion in the tank 26 and in continuous motion will present a load to the oscillator adequate to maintain the desired balance. The apron will be dielectrically heated, and its moisture may be vaporized to steam; but since the apron is in motion and is wetted continuously in its travel, the load on the oscillator which it represents may be maintained at any desired level, depending upon the position to which it is elevated by actuation of the hydraulic unit 42.

When the supply of mats is adequate to satisfy the load requirements of the oscillator to which it is tuned, the artificial load apron will be retracted out of the high frequency field established between the electrodes 2 and 3.

The workpieces may be fed in multiples, if desired. For example, the out-feed pusher 10 may be arranged to remove the two lowermost articles in the stack one at a time. If desired, the mats may be delivered to the in-feed conveyor in superimposed position and two boards fed into the dielectric heating station as a unit. The mats also may be delivered to the dielectric heating station singly and removed in multiples, at timed intervals.

If it is desired to remove additional moisture from the boards after their travel through the dielectric heating unit between electrodes 2 and 3, this can be accomplished by further oven heating, for the moisture remaining in the mats is now distributed throughout the thickness of the mats and may be successfully removed by such oven heating. However, further dielectric heating may also be effected efficiently; for with an essentially uniform redistribution of the moisture, the mats may be positioned between electrodes connected to a source of high frequency alternating electrical energy, and a high frequency alternating electric stress may be applied to the mats in a direction substantially perpendicular to their flat faces, as shown in Figure 6, and additional water may be removed. This operation may be synchonized with the movement of mats along the out-feed conveyor 11. The mats (singly or in multiples) will be positioned between electrodes 108 and 109 connected to a source of high frequency alternating electric power, such as an oscillator having a frequency of 24 megacycles and a power output of 50 kilowatts. This will effect heating of the mats 4 by high frequency electric stress applied to the mats perpendicular to the flat faces thereof.

I claim:

1. In a method of dielectrically heating a stack of substantially flat workpieces disposed in face-to-face relationship with their peripheral edges exposed, the steps comprising subjecting said stack of workpieces to high frequency alternating electric stress applied thereto in a direction substantially parallel to the flat faces of the workpieces to heat said workpieces throughout by the dielectric effect, progressively adding workpieces to be heated to one side of said stack and removing heated workpieces from the opposite side of said stack to heat said workpieces progressively as they assume different positions in said stack, and thereafter subjecting said removed heated workpieces to further high frequency alternating stress applied thereto in a direction transverse to the direction of said first mentioned high frequency stress.

2. In a method of dielectrically drying workpieces

which contain moisture concentrated essentially in a limited interior portion of the thickness of the workpiece to remove moisture therefrom and redistribute the remaining moisture more uniformly throughout the thickness of the workpiece, the steps comprising subjecting a stack of workpieces which initially contain moisture concentrated essentially in a limited interior portion of the thickness thereof and which workpieces are disposed in superimposed face-to-face relationship to high frequency alternating electric stress applied thereto in a direction substantially parallel to the flat faces of said workpieces, periodically changing the position of the workpieces in said stack, and continuing the application of said stress until the desired moisture removal and redistribution have been accomplished, removing said workpieces from said stack in a partially dried condition with the moisture remaining in said workpieces being distributed substantially uniformly throughout said workpieces, and thereafter further drying said workpieces to remove additional quantities of said moisture, as redistributed, from said workpieces.

3. In a method of drying a substantially flat workpiece of porous dielectric material in which the moisture is concentrated in a limited portion of the workpiece, the steps comprising subjecting said workpiece to high frequency alternating electric stress applied thereto in a direction substantially parallel to the flat faces of said workpiece, thereby removing some of said moisture from said workpiece and effecting migration of the remaining moisture substantially uniformly throughout the thickness of said workpiece, and thereafter subjecting said workpiece to high frequency alternating electric stress applied thereto in a direction substantially perpendicular to the flat faces of said workpiece to further heat said workpiece and remove moisture therefrom.

4. In a dielectric heating apparatus, the combination of spaced electrodes coupled to an oscillator source of high frequency alternating electric energy, means for supporting a stack of articles to be heated by high frequency alternating electric stress between said electrodes whereby said stack of articles acts as a load on said oscillator, first means for delivering fresh workpieces to said stack, second means operative synchronously with said first means for removing heated workpieces from said stack, control means continuously responsive to the magnitude of said load on said oscillator for producing an electrical signal which varies with variations in said oscillator load, and means responsive to variations in said electrical signal for varying the rate of delivery of fresh workpieces to said stack by said delivery means thereby to maintain a substantially constant magnitude of load on said oscillator.

5. In a dielectric heating apparatus, the combination of spaced substantially vertically disposed electrodes, an oscillator generating high frequency alternating electric energy, means coupling said oscillator to said electrodes, means for supporting a stack of flat dielectric articles in contiguous substantially horizontal face-to-face position between said electrodes for heating by high frequency alternating electric stress, first feeding means for progressively feeding workpieces to be treated onto the top of said stack, second feeding means for progressively delivering heated workpieces from the bottom of said stack, whereby each of said flat articles is progressively shifted in position from the top to the bottom of said stack in response to operation of said first and second feeding means, and control means for selectively varying the feed rate of at least one of said feeding means thereby to control the load presented by said dielectric articles to said oscillator.

6. In a dielectric heating apparatus, the combination of spaced electrodes coupled to a source of high frequency alternating electric energy establishing a field between said electrodes, means for supporting dielectric workpieces within said field whereby said workpieces act as a load on said source which load is heated by high frequency alternating electric stress between said electrodes, an artificial load comprising a dielectric element normally positioned adjacent to but outside of said high frequency field, and means for moving said dielectric element into said high frequency field upon occurrence of a predetermined reduction in the load presented by said workpieces to said source thereby to maintain a desired substantially constant magnitude of load on said source of high frequency alternating electric energy.

7. In a dielectric heating apparatus, the combination of first spaced electrodes coupled to a first source of high frequency alternating electric energy, means for supporting a stack of at least three flat workpieces containing moisture in such position between said first electrodes that said workpieces are heated by high frequency alternating electric stress applied by said first electrodes to said stack in a direction substantially parallel to the flat faces of said workpieces, second spaced electrodes coupled to a second source of high frequency alternating electric energy, means for supporting flat workpieces in such position between said second electrodes that said workpieces are heated by high frequency alternating electric stress applied by said second electrodes to said workpieces in a direction substantially perpendicular to the flat faces of said workpieces, and feeding means for successively removing heated workpieces from said first electrodes and delivering the same to said second electrodes whereby said workpieces are progressively dried by the transversely oriented fields produced by said first and second electrodes relative to said workpieces.

8. The combination of claim 6 wherein said dielectric element comprises an elongated web of dielectric material, and means for moving said web in a closed path.

9. The combination of claim 8 including means for wetting said elongated web as it is moved in said closed path.

10. In a dielectric heating apparatus, the combination of spaced electrodes coupled to an oscillator source of high frequency alternating energy operative to produce a high frequency field between said electrodes, means for supporting a stack of articles between said electrodes to be heated by said high frequency field, first feeding means for delivering fresh workpieces to said stack, second feeding means for removing heated workpieces from said stack, control means coupled to said first feeding means for controlling the rate of delivery of fresh workpieces to said stack, said control means including means responsive to variations in the load presented by said stack to said oscillator for varying the rate of workpiece delivery to said stack by said first feeding means thereby to maintain a substantially constant load on said oscillator, an artificial load comprising a movable dielectric element normally positioned outside of said high frequency field, and means responsive to a predetermined reduction in the load presented by said stack to said oscillator for moving said dielectric element into said high frequency field thereby to maintain said substantially constant load on said oscillator.

11. In a dielectric heating apparatus, a pair of spaced electrodes coupled to a source of high frequency energy operative to establish a high frequency heating field between said electrodes, means adjacent said electrodes for supporting a stack of plural substantially flat dielectric articles superimposed face-to-face between said electrodes whereby each of said plural articles is subjected to the heating effects of said high frequency field, first conveyor means disposed adjacent one end of said stack, first feeding means operative to feed dielectric articles sequentially along said first conveyor means onto one end of said stack, second conveyor means disposed adjacent the other end of said stack, and second feeding means operative at a rate related to the feeding rate of said first feeding means for feeding heated dielectric articles off the other end of said stack sequentially onto said second conveyor means whereby dielectric articles fed sequentially along

said first conveyor means are caused to progress in position through said stack whereafter they are fed sequentially out of said stack along said second conveyor means.

12. The combination of claim 11 wherein said first feeding means comprises a feeder element, a fluid pressure actuating system coupled to said feeder element for operating said feeder element, electrical control means for determining the electrical load presented by said stack to said source of high frequency energy, said control means including means producing a signal which varies with variations in said load, and means responsive to variations in said signal for varying the operation of said fluid pressure actuating system thereby to control the rate of operation of said feeder element.

13. The combination of claim 11 including further heating means disposed adjacent said second conveyor means for further heating said dielectric articles during their sequential passage along said second conveyor means.

14. In a dielectric drying apparatus adapted to dry a plurality of substantially flat fibrous dielectric workpieces and to redistribute moisture throughout a plurality of such workpieces, means for producing a high frequency dielectric heating field, means for supporting a stack of said fibrous workpieces within said field in such position that said field extends through said stacked workpieces in a direction substantially parallel to the flat faces of each said workpiece, the outer edges of said stack being exposed to air to permit the free escape of moisture therefrom and each of said workpieces in said stack being directly contiguous with other of said workpieces in said stack to permit the free migration of moisture through said workpieces while they are in said stack, first feeding means for feeding relatively wet dielectric workpieces onto one end of said stack, second feeding means for feeding relatively dry dielectric workpieces off the other end of said stack, and fluid pressure actuating means for controlling the operation of said first and second feeding means, said first and second feeding means being operative at related feed rates whereby each of said dielectric workpieces is caused to progress in position from said one end to said other end of said stack during said moisture escape and migration.

15. In a dielectric drying apparatus, electrode means coupled to a source of high frequency energy for producing a high frequency heating field, first and second conveyor means disposed in spaced laterally offset relation to one another adjacent said field, the spacing between said laterally offset conveyors being sufficient to permit a plurality of dielectric workpieces to be simultaneously disposed, in stacked array, within said field between said conveyor means, support means for supporting a stacked array of said workpieces within said field between said laterally offset first and second conveyor means, in-feed pusher means for sequentially feeding relatively moist ones of said workpieces along said first conveyor means into said field and onto one end of said stacked array, and out-feed pusher means operative substantially simultaneously with said last-named means for sequentially feeding relatively dry ones of said workpieces off the other end of said stacked array onto said second conveyor means and out of said heating field, said support means being adapted to support said workpieces in directly contiguous relationship to one another in said stacked array whereby the moisture in each of said workpieces is caused to migrate through the workpieces in said array as each said workpiece progresses through said heating field from said one end to said other end of said array.

16. A method of dielectrically drying moisture from plural substantially flat dielectric workpieces, each of which workpieces contains moisture between the flat faces thereof, comprising the steps of stacking said workpieces one upon the other with the flat faces of said workpieces being contiguous with one another whereby moisture redistribution and drying of a plurality of the workpieces in said stack may be simultaneously effected, applying a high frequency alternating electric field simultaneously to a plurality of the workpieces in said stack with said field extending through the stacked workpieces in a direction substantially parallel to the flat faces of the workpieces in said stack, successively adding further flat dielectric workpieces, to be dried, to one end of said stack with each said added workpiece being placed in said contiguous relation to the outermost workpiece at said one end of said stack, continuing said directional application of said high frequency electric field to said plurality of workpieces in said stack throughout each of said workpiece adding steps, successively removing the outermost ones of said flat workpieces from the other end of said stack while continuing said directional application of said high frequency electric field to said plurality of workpieces in said stack during said workpiece removing steps, each of said successive workpiece adding steps being effected substantially concurrently with one of said successive workpiece removing steps whereby each of the workpieces added to and already in said stack is caused progressively to change position from said one end of said stack through said applied field and thence to said other end of said track with said substantially parallel direction high frequency electric field being containuously maintained in each of said plurality of workpieces during said workpiece changes in position between the ends of said stack thereby to at least partially dry said workpieces, and thereafter further drying said workpieces after their removal from said other end of said stack.

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UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 2,870,543 January 27, 1959

George E. Gard

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 1, line 29, for "wood" read -- wool --; column 3, line 17, for "contant" read -- constant --; column 10, line 5, for "he" read -- the --; column 14, line 42, for "track" read -- stack --; line 44, for "containuously" read -- continuously --.

Signed and sealed this 12th day of May 1959.

(SEAL)

Attest:

KARL H. AXLINE
Attesting Officer

ROBERT C. WATSON
Commissioner of Patents

UNITED STATES PATENT OFFICE

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