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METHOD OF DRYING FIBROUS BOARDS

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2 Sheets-Sheet 1

Fig. 1

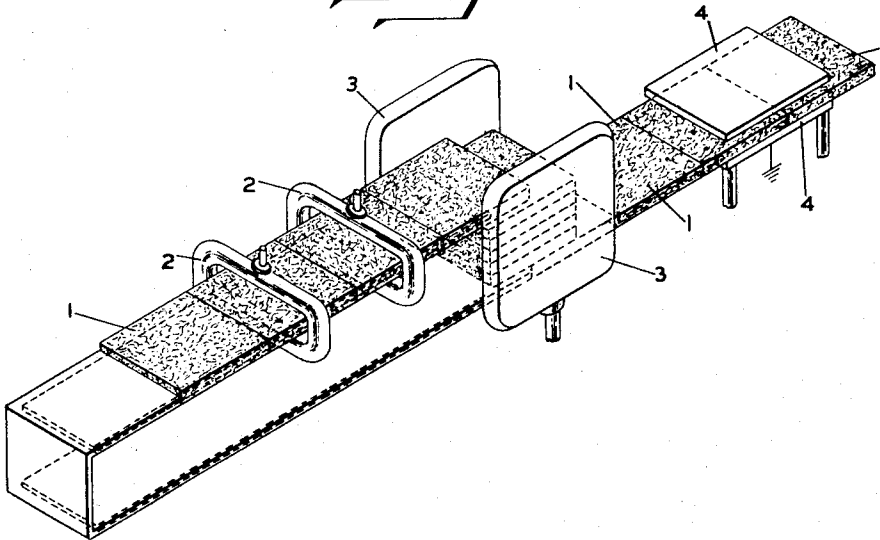
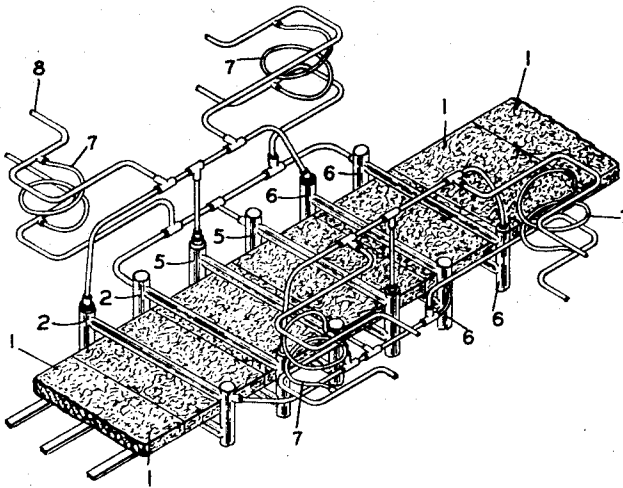


Fig. 2



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Fig. 3

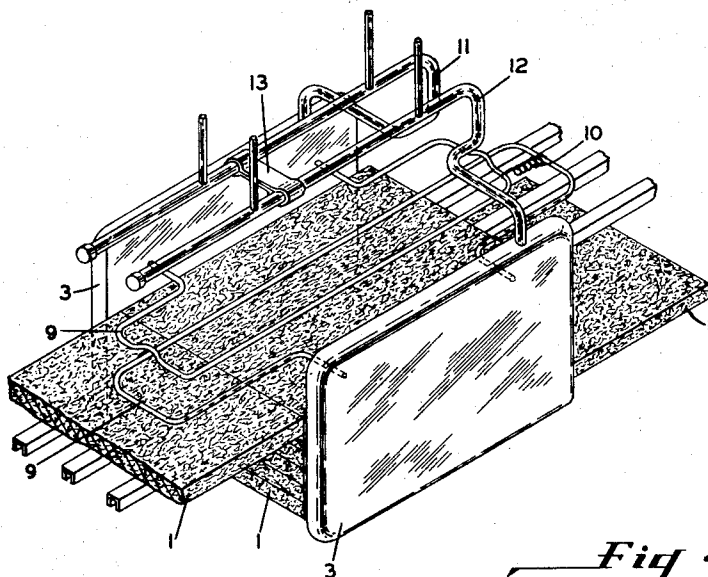


Fig. 4

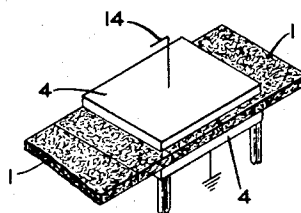
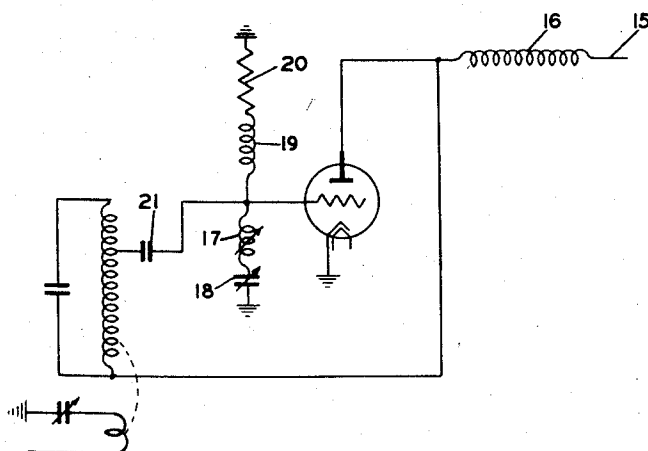


Fig. 5



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METHOD OF DRYING FIBROUS BOARDS

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2 Claims. (Cl. 34—1)

This invention relates generally to the treatment of materials with high-frequency electric energy, and more particularly to improved apparatus and method for removing water from materials by a more efficient dielectric heating system.

Dielectric heating creates heat uniformly throughout nonconducting materials. For this reason, dielectric heating is widely used to cause the development of heat inside materials without causing a heat-drop across the thickness of the material. Thus, dielectric heating has been exceedingly useful where heat is needed inside a material, either to cure or otherwise convert a reactable substance or to drive out volatiles such as water.

Dielectric heating is particularly useful in removing water from many materials. Such heating may be accomplished rapidly, and it has the further advantage that the heat is generated uniformly throughout the volume of the material being dried. Although dielectric heating may be used to remove all water, in certain instances it has been found that dielectric heating, coupled with more conventional heating methods such as oven drying, may produce an over-all drying system more efficient than either system used alone. In the conventional oven drying of moist products, the central section of the product remains moist after the areas near the surface have become essentially bone dry. Therefore, the more water removed from the product, the more difficult it is to remove the remaining water in a conventional oven. Thus, a large portion of the total oven capacity is required to remove a minor portion of the water.

Although it is recognized that the dielectric heating system herein described may be used to remove all the moisture from a given product, the invention will be described as applying to products which have been partially dried in conventional oven equipment.

The products themselves may vary widely. The description given herein, however, will be limited to a product whose thickness is small compared to at least one other dimension. In particular, the description will be confined to the drying of an acoustical board whose thickness is small compared to its length and width and whose composition may generally be stated to be mineral wool and a binder system. Generally speaking, these boards measure about 1" to 2" in thickness and about 4' to 5' in length and width. Such boards well illustrate a problem commonly encountered in drying in that the last 10%–30% of water to be removed is the most difficult; this is true since conventional oven equipment requires the transferring of heat through the outer dry sections to the wet inner section of the board. Since the board is somewhat sensitive to heat degradation, the problem may not be resolved by simple subjecting it to higher temperatures.

The dielectric heating unit of the present invention is preferably arranged in the total drying system to replace the last sections of a conventional oven. This results in a large production capacity increase by allowing the use of the entire length of the conventional oven to operate

as a more efficient partial drying system preceding the dielectric heating unit of the present invention.

As the boards enter the dielectric heating unit after passing through a conventional oven, they may contain 20%–35% water and they will have dry outer areas and a wet central section as mentioned earlier. Specifically, a 1" thick fibrous board will have a wet central section of from $\frac{1}{8}$ " to $\frac{1}{2}$ " thick extending throughout the plane between the faces of the board. The temperature in the wet section will be rather uniform. This temperature will usually range from about 140° to about 170° F., depending upon the porosity of the board, the thermal conductivity of the outer dry sections, the temperature gradient maintained in the outer dry section, and the vapor pressure maintained in the conventional oven atmosphere. These conditions will generally prevail in the board as it leaves the conventional oven and enters the dielectric finish-drying phase of the present invention.

It is the principal object of the present invention to supply an apparatus and method for the dielectric heating of products. A further object of the invention is to provide a dielectric heating unit to supply heat to partially dried products wherein the remaining moisture in the product occupies a wet central section. A still further object is the provision of an apparatus for the dielectric heating of boardlike products.

The present invention relating to the dielectric heating of various products as disclosed herein contemplates, in combination, first electrode means for applying a first high-frequency electric field in a product in the plane of the area to be heated. Second electrode means applies a second high-frequency electric field in the plane of the area to be heated at an angle of substantially 90° to the first field. Finally, third electrode means applies a third high-frequency electric field in a direction substantially normal to the plane of the first and second high-frequency electric fields.

The invention is illustrated in the accompanying drawings, wherein:

Figure 1 is a simplified perspective illustrating apparatus for carrying out the present invention;

Figure 2 is a simplified perspective illustrating a preferred apparatus for applying the first high-frequency electric field;

Figure 3 is a simplified perspective illustrating preferred apparatus for applying the second high-frequency electric field;

Figure 4 is a simplified perspective illustrating the preferred apparatus for applying the third high-frequency electric field; and

Figure 5 is a schematic view of the circuitry in the oscillators which may be used to apply the high-frequency electric field to the load.

By referring to Figure 1, it can be seen that the present invention contemplates supplying the high-frequency electric fields to the boards 1 in three separate and distinct stations. In the first station, electrodes 2, 2 are of doughnut or annular shape and supply a high-frequency field in a horizontal plane in the direction of travel of the boards 1 as they move through the three stations and in the plane of the area to be heated; in the embodiment under discussion this plane is the area of the wet central section lying between the two broad faces of the boards.

After passing through electrodes 2, 2 in the first station, the boards pass into the second station and between electrodes 3, 3. Electrodes 3, 3 apply an electric field in a horizontal plane corresponding to the wet inner core but in a direction of about 90° from the direction of the field applied by electrodes 2, 2.

After leaving the second station, the boards pass to the third station between electrodes 4, 4 which apply a high-

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frequency electric field in a direction normal to the boards 1 and normal to the plane of the two previously applied fields.

The use of three distinct electric fields supplied to the board in different directions offers great advantages over known technics. If boards having a wet central section are placed in an electric field with the alternate wet and dry layers normal to the electric field, the electric stress in the wet and dry areas varies inversely as the dielectric constant of the wet and dry layers. A great percentage of the voltage is wasted in the outer dry layers of the board. However, if the boards are placed in an electric field with the wet and dry layers parallel to and in the electric field, the electric stress is the same in both the wet and dry layers. Under these conditions, the energy is in large part formed in the wet layers where it operates to vaporize the water without the mechanism of heat transfer and with relatively greater efficiency.

The use of both the first station 2, 2 electrodes followed by the second station 3, 3 electrodes is extremely advantageous if there exists an unequal transverse moisture distribution in the plane between the broad, flat faces of the board. If the moisture were uniformly distributed in this area, it might be theoretically possible to omit one of the first two stations. Even in such case, however, it is advantageous to utilize both stations from the point of view of maximum oscillator size or wattage commercially available and also in view of the energy density allowable in a particular product to be dried.

As shown in Figures 1 and 3, the boards are preferably stacked or bulked at the second station between electrodes 3, 3. Boards moving from the first station to the second station take their place on the top of the stack in the second station between electrodes 3, 3. Boards moving from the second station to the third station are removed from the bottom of the stack between electrodes 3, 3 and are advanced individually into the third station between electrodes 4, 4.

The boards are purposely bulked or stacked in the second station without ventilation between the boards to accomplish a redistribution of moisture within the board by the time it moves to the bottom of the stack. The energy density applied to the board in the bottom of the stack is low compared to that being applied to the boards at the top of the stack because of the essentially lower moisture content and more uniform moisture distribution at the bottom. The boards emerge from the bottom of the stack in the second station with the remaining moisture uniformly distributed throughout the thickness of the board. This stacking or bulking of the boards is more fully described in copending application Serial No. 560,942, filed January 24, 1956.

This latter result allows the board to be uniformly and completely dried in the third station between electrodes 4, 4 wherein the electric field is applied in a direction normal to the faces of the board and normal to the plane of the two previously applied fields. Although the most significant role of the second station is the redistribution of moisture throughout the boards, it must be emphasized that appreciable moisture will be removed entirely. Thus, as a board in the stack in the second station between electrodes 3, 3 moves from the top to the bottom of the stack, the remaining moisture in that board becomes both distributed and diminished. Even though the electrical losses diminish as the board approaches dryness, a high voltage stress can be applied to the remaining redistributed moisture in the third station between electrodes 4, 4, quickly completing the drying of the board.

Although the drawings do not show any means for moving the boards through the three stations, it should be apparent that various means will suffice. Pusher devices for advancing boards through dielectric heating apparatus are well-known in the art, and in fact the boards could be advanced through the stations by hand, taking

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care that the operator keeps a safe distance from the electrodes.

Discussing the method and apparatus in greater detail, Figure 2 illustrates a preferred embodiment of the first station of the dielectric heating unit of the present invention. Instead of using one pair of electrodes 2, 2 as illustrated in Figure 1, it is preferred to use three pairs of electrodes 2, 2; 5, 5; and 6, 6 as illustrated in Figure 2. Thus, the boards 1, as they move through the first station, are subjected to the high-frequency electric field between the three electrode pairs for a longer period of time than where only one pair is used. Furthermore, the use of three electrode pairs allows gradation of voltage differential by circuitry, which gradation is highly beneficial in the present application. The four inductances 7 may be connected across opposing electrode pairs as shown. The radio frequency high-voltage output from an oscillator may be supplied to the first station electrodes at 8. The result is that the phase relationship between the three pairs of electrodes differs one from the other. In electrodes 2, 2, one electrode will have a varying potential, while the other remains substantially at ground potential. Electrodes 6, 6 will be in an almost push-pull arrangement, while electrodes 5, 5 will be somewhere in between the extremes of electrodes 2, 2 and electrodes 6, 6. The inductances 7 may consist simply of an open coil or two of copper tubing of a suitable size.

Since the high-frequency electric field applied by the three pairs of electrodes in the first station is in the plane of the wet layer in the center of the board lying between the two broad faces of the boards, it can be seen that the first station accomplishes to some extent a redistribution of moisture throughout the board along with an appreciable amount of actual water removal. Since water is removed in the first station, all electrodes may be heated as by resistance heaters mounted within the electrodes, and the heaters may be supplied with electrical power leads, preferably through the center of the conductors forming the inductive elements from ground. These heated electrodes provide radiant heat to maintain an elevated temperature on the exposed periphery of the boards, thus preventing condensation on those areas as well as on the electrode system. In addition, an adequate exhaust system should be provided to remove the moisture evaporated from the boards.

Figure 3 illustrates a preferred embodiment of the second station electrodes 3, 3 wherein the second high-frequency electric field is applied in a plane parallel to the surface of the boards but at an angle substantially 90° from the direction of the first high-frequency electric field applied in the first station. The electrodes 3, 3 may be fabricated in the shape shown from copper or other suitable material. In order that the effect of the electric field existing between electrodes 3, 3 may not be dissipated to too great an extent midway between the two electrodes, it is preferred to install auxiliary electrodes 9, 9, particularly where the width of the boards is appreciable. Each electrode 9 starts from an electrode 3, crosses the width of the boards to a point beyond the middle of the boards, passes down the length of the boards parallel to electrodes 3, 3 for a distance about equal to the length of electrodes 3, 3, and then returns to the electrode 3 from which it started. The effect of electrodes 9, 9 is simply to aid in confining the electrical field existing midway between the electrodes 3, 3. An inductance 10 connects the auxiliary electrodes 9, 9. This inductance 10 makes a convenient location for the input to the electrodes from a high voltage oscillator.

To enable the attaining of additional control over the impedance in the electrode configuration of the second station, two bars 11 and 12 may be conformed as shown to form additional inductance. This inductance may be varied as desired by the use of the shorting bar or tuning stub 13. The apparent capacity of the second station electrodes 3, 3 is practically determined by the

amount of moisture in the boards 1 within the electrode system. Depending upon the degree of dryness desired, the tuning stub 13 may be placed anywhere along the bars 11 and 12, thus allowing graduation from wet to dry. This aids in fixing the amount of water needed in the load made up of the stack of boards to effect the resonance necessary to transfer efficiently energy from the high-frequency generator to this load. In this connection, there are various means which might be used to indicate the existence of this resonant condition as well as the proper matching conditions in the oscillator supplying power to this second station. However, the oscillator grid current is preferred, and it may be used as a positive indication and as a control over the resonant condition. Thus, the rate of feeding the boards through the system may be controlled so as to maintain a substantially constant grid current and concomitantly a constant amount of moisture in the stack of boards between the second station electrodes 3, 3.

Figure 4 shows the third station adapted to supply a high-frequency electric field in a direction normal to the plane of the faces of the board and normal to the plane established by the two high-frequency electric fields applied in the first and second stations. Electrode supports, not shown, will hold the electrodes 4, 4 in the desired spaced relationship from the boards lying therebetween. Usually the electrodes 4, 4 will be about $\frac{1}{4}$ " to about $\frac{1}{2}$ " away from the faces of the boards. The third station electrodes 4, 4 serve to remove any moisture remaining in the boards which have passed through the first and second stations. The high-frequency input to electrodes 4, 4 is schematically shown at 14. The third station electrodes 4, 4 are usually confronted with the task of removing 0-5% by weight of well-distributed moisture from the boards. The distribution of moisture throughout the entire thickness of the boards is the feature which allows the electrodes 4, 4 to operate efficiently on the boards. Electrodes 4, 4 can finish-dry without risk of scorching the faces of the product.

Figure 5 shows one of the possible oscillator circuits wherein the high voltage direct current enters at 15, passes a radio frequency choke 16, and is then coupled both to the plate and the tank. The grid is connected to a grid leak circuit including a variable inductance 17 and variable capacitance 18 and also to a radio frequency choke 19 and a ground resistance 20 before going to ground. The grid is also coupled to a point near one end of the tank inductance through the blocking condenser 21. Power to be supplied to the electrodes may be taken off near one end of the tank inductance as shown and coupled to the inputs of the various electrode systems, as has been shown. The cathodes may be indirectly heated as shown in Figure 5 or they may be directly heated. Although Figure 5 shows a single tube, two tubes in parallel may be utilized and are preferred. Each station will operate from its own oscillator. It is preferred that the first station operate at about 13.2 megacycles per second, the second station at about 16-16.4 megacycles per second, and the third station at about 24 megacycles per second with the boards under discussion. The characteristics of each oscillator will depend, to some extent, on the type of material being dried, on the water content of the material, and on the degree of water-removal desired. In view of the frequency at which the oscillators operate, it is necessary that steps be taken to avoid broadcasting. This is most readily accomplished by shielding the entire unit in known manner.

I claim:

1. The method of drying a substantially planar dielectric article having a pair of substantially flat parallel faces and a relatively wet central section comprising moisture non-uniformly distributed in the plane of said article between said faces, comprising the steps of applying high-frequency electric fields to said article in three suc-

cessively different orientations thereby to successively redistribute and dry said non-uniformly distributed moisture in different orientations, said method comprising the first step of applying a high-frequency electric field to said article in the plane of said article and in a first direction through said wet central section substantially parallel to the flat faces of said article thereby to partially redistribute and dry said non-uniformly distributed moisture in a first orientation, the second step of applying, immediately subsequent to completion of said first step, a further high-frequency electric field to said article in the plane of said article in a second direction through said wet central section substantially parallel to the flat faces of said article, said second direction being transverse to said first direction in the plane of said article whereby said second step further redistributes and further dries said non-uniformly distributed moisture in a second orientation parallel to said flat faces but different from the drying and moisture redistributing first orientation of said first step, whereby said first and second steps partially dry said article and redistribute the remaining moisture in said article substantially uniformly throughout said article between the flat faces thereof, and the third step of applying, immediately subsequent to said second step, a still further high-frequency electric field to said article in a direction substantially perpendicular to the flat faces of said article thereby to finish-dry said substantially uniformly redistributed remaining moisture from said article in a third orientation transverse to each of said first and second orientations.

2. The method of removing non-uniformly distributed moisture from a plurality of dielectric articles comprising the steps, occurring in succession one after the other, of applying a first high-frequency electric field in a first direction through each of said articles successively thereby to partially dry and to partially redistribute the moisture in said articles, stacking said partially dried articles one upon the other, applying a second high-frequency electric field to said stacked articles with the direction of said second field in each of said articles being substantially coplanar with but disposed substantially 90° to the first electric field applied to said articles by said first field applying step thereby to further partially dry and to further redistribute the moisture in said articles, whereby said first and second field applying steps apply successive transversely oriented but substantially coplanar fields to each said article thereby to partially dry and to redistribute said moisture throughout said articles in successive steps, the moisture remaining in said articles subsequent to said first and second field applying steps comprising a small fraction of the original non-uniformly distributed moisture in said articles and said remaining moisture being substantially uniformly distributed throughout said articles, and thereafter applying to said articles a third high-frequency electric field disposed in a direction transverse to the substantially common plane of the high-frequency electric fields produced in said articles by both of said first and second field applying steps whereby said third field applying step is operative to finish-dry said remaining substantially uniformly redistributed moisture from said articles.

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