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Barnes et al.

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[54] **METHOD FOR DRYING MATERIALS WITH MICROWAVE ENERGY**

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[52] **U.S. Cl.** **34/1**

[51] **Int. Cl.** **F26b 3/34**

[58] **Field of Search** ..... 34/1; 219/10.55; 324/58.5 A

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[57] **ABSTRACT**

Method for drying moisture-laden dielectric materials in individual pieces by directing microwave energy against each piece during relative movement between a microwave generator and the piece. The moisture content of the piece is detected throughout the length thereof, and the generator is controlled so as to adjust the microwave energy in accordance with the moisture content of the portion of the piece against which the microwave energy is being directed.

4 Claims, 3 Drawing Figures

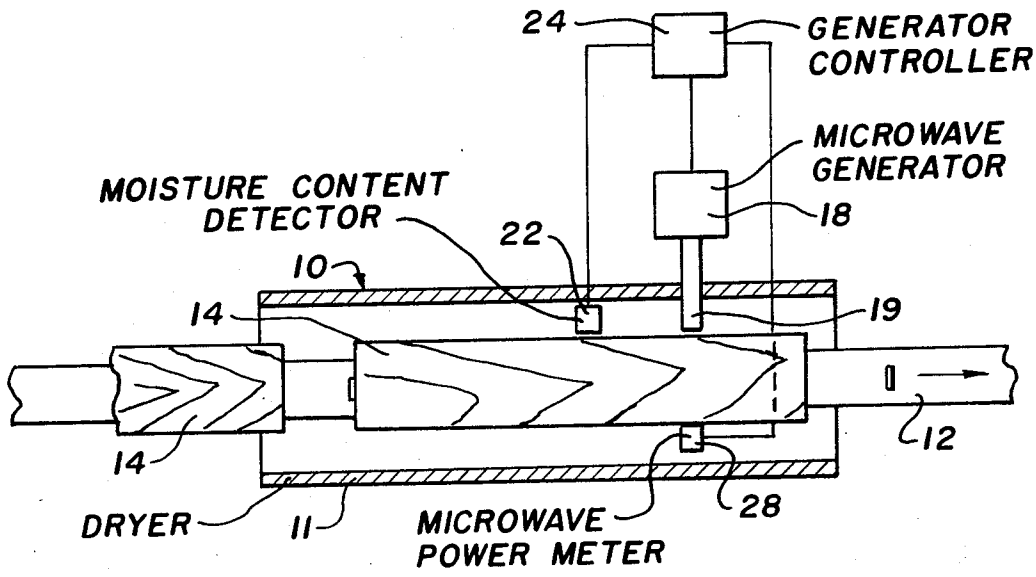


Fig. 1.

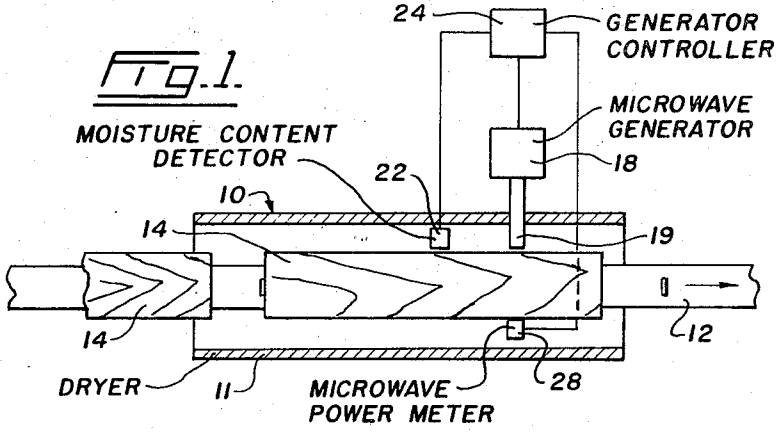
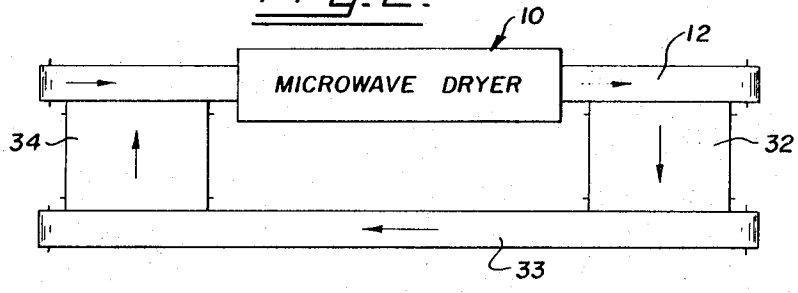


Fig. 2.



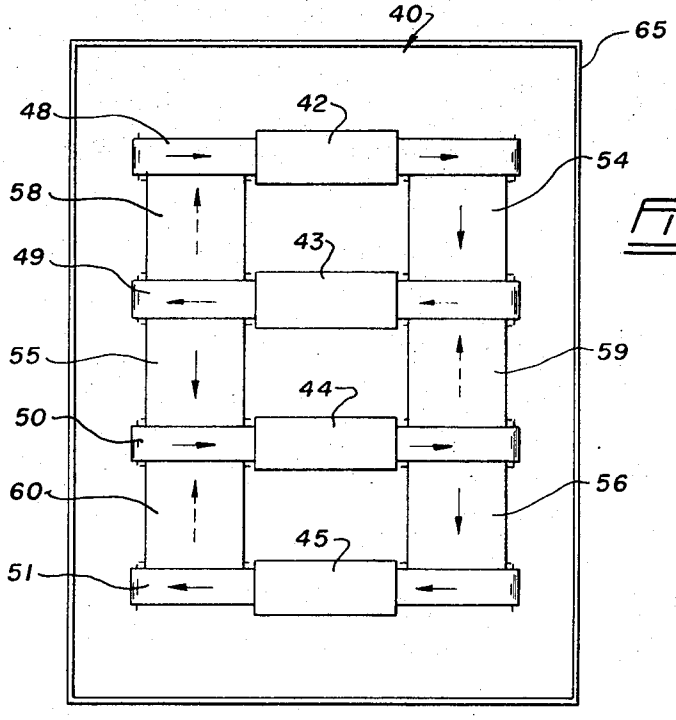


Fig. 3.

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METHOD FOR DRYING MATERIALS WITH MICROWAVE ENERGY

This invention relates to a method for drying moisture-laden dielectric materials, such as lumber, wood based materials, bagasse, paper and the like, with microwave energy.

Although many different types of materials may be dried by the present method and apparatus, they are primarily designed for lumber and are so described herein for the sake of convenience.

According to the prior art, the standard way of drying lumber from a sawmill is in a drying kiln. This of necessity is a batch process, and all the lumber in the kiln is subjected to substantially the same drying conditions. Thus, relatively dry lumber is subjected to exactly the same drying conditions and for the same time as relatively wet lumber. It is well known that the lumber in the center of a stack in a kiln is not dried at the same rate as lumber at the surfaces of the stack, but this is roughly balanced out by keeping the wood in the kiln for relatively long periods of time. Soft woods, such as, for example, Douglas fir and hemlock, are usually kept in the kiln from 5 to 12 days, whereas hardwoods are kept in for much longer periods. The lumber or boards have different dimensions, moisture contents, and densities, and these, along with the different species of wood, affect the drying of the lumber. As a result, a large percentage of lumber dried in a kiln can be off-grade since whole pieces or different parts of a given piece can have a moisture content above the necessary standard. These off-grade boards either have to go out to the market as they are or have to be returned to the kiln with another batch. In either case, this in effect reduces the output of the kiln, and it results in partially dried boards being subjected to the same drying conditions as undried boards.

The prior art has no way of properly drying a board that has different moisture contents in different portions thereof, a very common occurrence. If the board is dried long enough to reduce the moisture content of its wet spots to the desired level, the remaining areas are usually overdried and/or the entire board is held back until the wet spots are dried.

The present invention eliminates or reduces the problems enumerated above. Each board is dried individually by microwave energy, and each portion of the board is dried in accordance with the moisture content thereof. The drying time is cut down to something of the order of from 2 to 10 hours. Each piece of lumber is selectively dried down to a desired even moisture content, and all dried pieces will have substantially the same moisture content.

Each piece of lumber is individually dried, and the microwave power is applied in proportion to the profile of the moisture content along the piece. Microwave energy is applied to a limited area of each piece at a given instant, and the power is adjusted in accordance with the moisture content of that limited area. It is preferable to apply the microwave energy to the lumber intermittently. This makes it possible to dry or start to dry very wet wood without danger of harm from the microwave energy. If too much energy is applied to the wood at one time, it will explode, or if the energy is applied over too long a period the same result may be attained or the wood may be charred. One of the advantages of microwave drying is that the wood is dried from the inside to the outside, but if the energy and time are not properly controlled, the wood can char inside, even though this may not be seen from the outside.

The method of drying lumber in accordance with the present invention comprises directing a beam of microwave energy from a microwave source against a piece of lumber during relative movement between the piece and the source, detecting the moisture content of the piece during relative movement between said piece and a moisture detector before or during the microwave energy application, and controlling the intensity of the microwave energy in accordance with the detected moisture content of the portion of the lumber piece against which the microwave energy is being directed.

Apparatus in accordance with this invention for drying lumber comprises a microwave generator, a moisture content detector, means for causing relative movement between a piece of lumber and the detector and generator, the generator being located to direct a beam of microwave energy on to the lumber piece and the detector being located to detect the moisture content of the piece ahead of or at the energy beam during said relative movement, and control means operated by the detector to control the generator to adjust the intensity of the microwave beam in accordance with the moisture content of the portion of the lumber piece against which the microwave energy is being directed.

For production purposes there should be relative movement between each piece of lumber and both the detector and the microwave generator. Although the lumber can be stationary and the detector and generator moved relative thereto, this entails a batch system with its attendant disadvantages. For example, the lumber could be placed in an oven and the detector and the generator moved therealong. However, it is much more practical to move the lumber relative to the detector and the generator, and the invention will be described herein with this arrangement.

Basically there can be a single microwave dryer with a moisture content detector and a microwave energy generator associated therewith and arranged so that the moisture content of each board is detected as it moves through the dryer. A controller for the generator operates in accordance with the moisture content of the board to adjust the intensity of the microwave energy anywhere from zero to the maximum capacity of the generator. The board can be stopped in the dryer and the energy applied thereto, intermittently if necessary, until that area reaches the desired moisture content. However, this is mainly a theoretical arrangement since it would be too slow for reasonable economical production rates.

Another arrangement in accordance with this invention involves the use of a single dryer as set out above and with means for recycling boards through it until their moisture contents are lowered to the desired level. This also would be a rather slow process.

For production purposes, the most desirable arrangement is a plurality of microwave dryers arranged in series. Each dryer has its own moisture content detector and microwave generator. The boards are moved in succession through these dryers and are treated in accordance with their various moisture contents in each dryer. This arrangement makes it possible to remove boards from the line that have reached the desired moisture content level before going through all of the dryers. In addition, the microwave energy application

is controlled individually at each dryer. Furthermore, this enables the microwave generators at one or more dryers to be operated at full capacity all the time, and enables generators of different capacities to be used in different dryers. This makes it possible to use relatively low powered microwave generators in the dryers or heaters that handle boards that have already had their moisture contents reduced. This particular arangement is very flexible and allows for many variations in the drying process. Another advantage results from the fact that the microwave energy is applied intermittently to the boards, and this allows time between dryers for the dissipation through the wood of the heat energy generated by the microwave power.

The microwave dryers may be aligned, but this would require a very long area for operation. In view of this, it is preferable to set up the dryers in a zig zag arrangement so that the boards move in one direction through the first dryer, and move in the opposite direction through the second dryer and so on. This makes for a more compact arrangement, makes it easier to remove boards after passing through any dryer that have reached the desired moisture content level, and allows for the recirculation of boards through a given heater should this be necessary. In addition, the entire arrangement can be set up in a housing in which the atmosphere is heated. This has the advantage that none of the microwave energy is wasted in heating the surrounding air and equipment.

The term "board" as used herein is intended to cover pieces of lumber or wood of any dimensions, and is used for the sake of convenience. It is obvious that boards, studs, beams, timbers, and other forms of wood can be subjected to this process.

The basic method according to this invention comprises moving each board through a microwave heater or dryer. The movement may be intermittent or continuous, and is preferably the latter. Some boards have different moisture contents in different portions throughout the length thereof. The board is moved past a moisture content detector which detects these variations in the moisture content, or the moisture content of the entire board if the latter is fairly constant throughout its length. At the same time as or immediately after this board is moved past a suitable microwave generator which directs a beam of microwave energy on to the moving board from one or both sides. The microwave power is controlled within the capacity of the generator, and the detector operates the generator controller so that the microwave energy is in accordance with the moisture content of the portion of the board against which the beam is being directed. With this arrangement, the microwave energy is increased for portions of the board that are very wet, and is correspondingly decreased for the board portions having lower moisture contents. If the moisture content of a portion of the board is very high, the board can be stopped and the microwave energy intermittently applied to that portion until the moisture is reduced to a desired degree, but it is preferable to subject each board to a plurality of drying steps so that it can move continuously until the desired moisture level is reached.

The preferred method is to run each board through a series of these microwave dryers. The controls in each dryer and the equipment are in accordance with the general moisture content level of boards being directed to that particular dryer. If the moisture of the board reaches the desired level before it gets to the end of the line, the board can be removed immediately. On the other hand, this board can move through the subsequent dryers without harm since the moisture detectors thereof will shut off their respective microwave generators as the board moves through the latter.

Examples of apparatus in accordance with this invention are illustrated in the accompanying drawings, in which

FIG. **1** is a diagrammatic sectional view through a microwave dryer with two different types of moisture content detectors for controlling the microwave generators,

FIG. **2** diagrammatically illustrates a microwave dryer with means for recirculating boards therethrough and,

FIG. **3** diagrammatically illustrates a preferred form of microwave dryer arrangement.

Referring to FIG. **1, 10** is a microwave dryer in accordance with this invention which consists of a tunnel housing **11** through which a conveyor **12** extends, said conveyor being adapted to move boards **14** through the housing. A microwave generator **18** is provided for directing a beam of microwave energy through a waveguide **19** to the boards **14** as they move through the housing. If desired, the microwave energy may be directed to opposite sides of the boards through a waveguide system, not shown. A suitable moisture content detector **22** is positioned in housing **11** so as to detect the moisture content of each board immediately ahead of waveguide **19.** Any suitable detector may be used for this purpose, such as a power loss meter, power absorption meter, capacitance meter, or microwave meter. The detector operates a controller **24** for the microwave generator so that the latter is controlled in accordance with the moisture content detected by detector **22.**

In place of detector **22,** the moisture content detector may be in the form of a microwave power meter **28** which is positioned opposite waveguide **19** so as to measure the residual microwave power that is transmitted through and emerges from the board. This power meter is connected to generator controller **24** so as to control the microwave power generated by the generator. The amount of energy absorbed in the board depends upon the moisture content thereof so that if the moisture content is high, the power emerging from the board is low, in which case power meter **28** operates controller **24** to increase the power of the generator. As the moisture in the board lessens, the microwave power is reduced accordingly.

As stated above, the moisture contents of the different boards being moved through the dryer may vary greatly, and the moisture in any given board may be quite different in different portions thereof. With the present apparatus, the microwave energy directed to the board is increased or decreased as the moisture of the portion of the board against which the energy is being directed increases or decreases. This keeps the amount of electrical power consumed down to a minimum, and it prevents relatively dry areas of the boards from being overdried.

It is possible to operate conveyor **12** so as to stop a board in front of the waveguide so that sufficient energy is applied to reduce the moisture content to a desired level. In this case, it would be desirable to operate

generator **18** intermittently so that the board would not be harmed by the microwave energy during this time.

FIG. **2** illustrates dryer **10** with conveyor **12** extending therethrough. Additional conveyors are provided so that boards can be recirculated through the dryer should this be necessary. Boards emerging from the dryer can be discharged from the end of conveyor **12,** or a transfer **32** may be operated to shift the boards to another conveyor **33** which directs them to a transfer **34.** The latter transfer shifts the boards back to conveyor **12** for recirculation through dryer **10.**

FIG. **3** diagrammatically illustrates a preferred form of drying apparatus **40** in accordance with this invention. Apparatus **40** includes a plurality of microwave dryers arranged in series, the illustrated example including dryers **42, 43, 44** and **45.** Each of these dryers is the same as dryer **10,** and the capacity of the microwave generators thereof may be the same as or different from each other. Dryers **42** to **45** have conveyors **48** to **51,** respectively, extending therethrough and running in opposite directions, as indicated by the arrows. A transfer **54** extends from the outlet end of conveyor **48** to the inlet end of conveyor **49,** a transfer **55** extends from the outlet end of conveyor **49** to the inlet end of conveyor **50,** and a transfer **56** extends from the outlet end of conveyor **50** to the inlet end of conveyor **51.** If desired, transfers **58, 59** and **60** may be provided between the outlet and inlet ends of conveyors **49** and **48, 50** and **49,** and **51** and **50,** respectively.

It will be understood that any board can be discharged from the outlet end of any one of the conveyors **48** to **51** if it is considered to be dry enough at said conveyor end. Moisture detectors, stops, and transfer controls are all well known in the industry and therefore do not need description herein. There are many different types of transfers in everyday use and any of these can be used.

Each board is successively exposed to microwave drying in dryers **42** to **45.** There are many advantages to this arrangement or system. The detectors and the microwave generators for the different dryers can be set in accordance with the moisture contents of the boards likely to be received by the various dryers. This eliminates the danger of damaging the boards by overexposure to microwave energy, reduces the amount of electrical power required, ensures each board being substantially uniformly dried throughout its length without danger of being overdried in some areas, and allows time for heat dissipation throughout the boards between driers. Transfers **58, 59** and **60** are provided in case it is desired to recycle a board after leaving one dryer back through the preceding dryer.

It is better to operate a microwave generator in a given capacity range and to shut it off when not required rather than to vary its output outside of this range. With apparatus **40,** some of the generators can be kept operating at full capacity since they are receiving relatively wet boards, for example, generators **42** and **43.** The other generators can be operated at different energy output ranges in accordance with the moisture content of the boards. In addition, the dryers near the end of the line may have microwave generators of lower capacities since they are dealing with boards that have been partially dried.

Another advantage of apparatus **40** is that the dryers and their respective conveyors and transfers can be located within a housing **65** so that the temperature and humidity in the housing can be controlled. It is desirable to maintain the atmosphere within housing **65** at a temperature of about 212°F. With this arrangement, no microwave energy is wasted in heating the air and the equipment surrounding the boards. The heated air does not contribute an appreciable amount of energy to the removal of water from the wood, differing in this respect from conventional kiln drying where energy is supplied solely by heated air directed over the wood surface by force.

This system will dry any width or length of lumber and is restricted in the thickness of wood that can be dried only by the generator and microwave frequency. For example, wood up to 3 inches thick can be dried by means of a waveguide type of generator and a microwave frequency of 915 MHz. Halving this frequency will double the possible lumber thickness.

As stated above, it is preferable to apply the microwave energy intermittently. This allows dissipation throughout the wood of the heat energy generated by the microwave power. There is no restriction of the length of the pieces of wood that can be tried by a given microwave generator, and there is no restriction on the width of the wood, it only being necessary to select a microwave generator with the necessary power output. Dried pieces can be removed from the process when desired, and pieces can be recirculated, if necessary.

One of the advantages of microwave drying is that wood is dried from the inside to the outside. If the apparatus operates in a heated atmosphere, care must be taken that the temperature of the atmosphere is not too high and the relative humidity too low so as not to dry out the surface layers of the wood. To do so will result in a closing off of the capillaries through the cellular structure by which water can be removed, in which case you would be restricted to diffusion through the structure of the cellular wall substance itself, and this is slower than capillary action by a factor of something like 6 to 7,000. The main reason for operating in an air temperature of 212°F. is to prevent loss of heat from the wood to the air and the structure of the heating system, thus restraining the use of electric energy solely to the drying of the wood.

It is obvious that each of the dryers of FIGS. **1** and **2** and their associated equipment can be enclosed in a housing similar to housing **65** of FIG. **3,** and the temperature therein controlled as described above.

We claim:

1. The method of drying moisture-laden lumber which may be of varying moisture content comprising the steps of: moving a stream of long, relatively narrow, moisture laden lumber pieces which may be of varying widths through a plurality of microwave drying chambers in series, said drying chambers being spaced apart a distance sufficiently to allow dissipation of heat throughout the lumber piece as it moves in the space between driers; in each drying chamber directing a beam of microwave energy from a microwave source against a small portion of a side of each moving lumber piece so as to travel through the latter to the opposite side thereof, said beam applying drying energy to said each piece across the full width thereof, said piece of lumber being heated only by said microwave energy while in said chamber; controlling the temperature and humidity in the environment between successive driers through which the lumber pieces are moved; detecting the moisture content of each piece before or during the

microwave application; and controlling the intensity of the directed microwave energy in accordance with the detected moisture content of said each piece of lumber against which the microwave energy is being directed, any lumber piece, after passing through a plurality of said microwave drying chambers, which has a sufficiently low detected moisture content, being removeable before being moved through the remaining drying chambers.

2. A method as claimed in claim **1** including the step of recycling said lumber piece back through at least one of said drying chambers for further drying while permitting heat dissipation in the material before the recycling.

3. A method as claimed in claim **1** in which the moisture content of each piece of lumber is detected during the microwave energy application by measuring the amount of microwave energy emerging from said opposite sides of said each piece.

4. A method as claimed in claim **1** in which the lumber piece is moved past the detector and the microwave source.

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