April 28, 1964 J. E. MARSH 3,131,034

PROCESS FOR DRYING LUMBER

Filed March 2, 1961 5 Sheets-Sheet 1

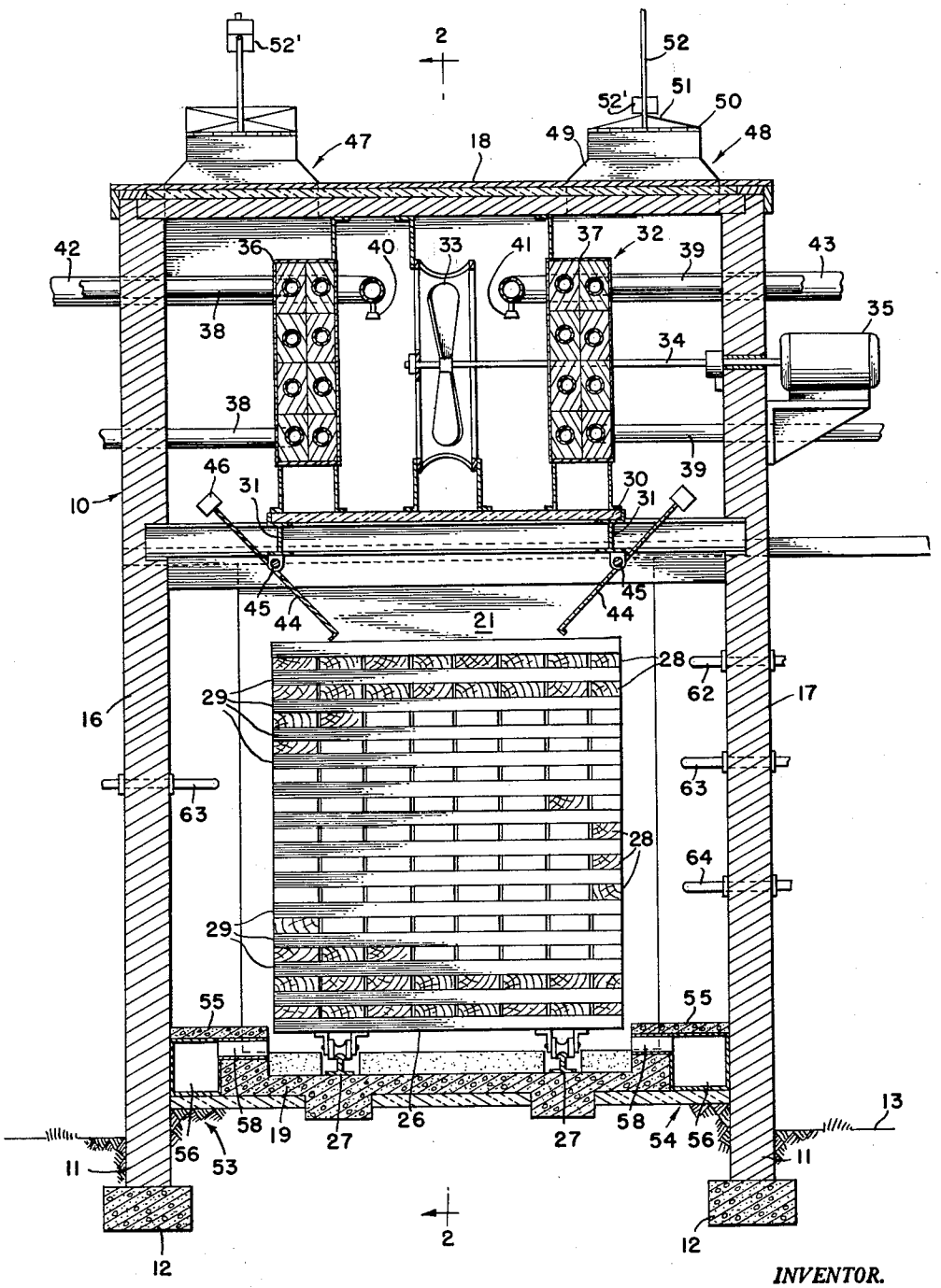


FIG. 1.

INVENTOR.
J. EVERETT MARSH
BY Garvey & Garvey
ATTORNEYS

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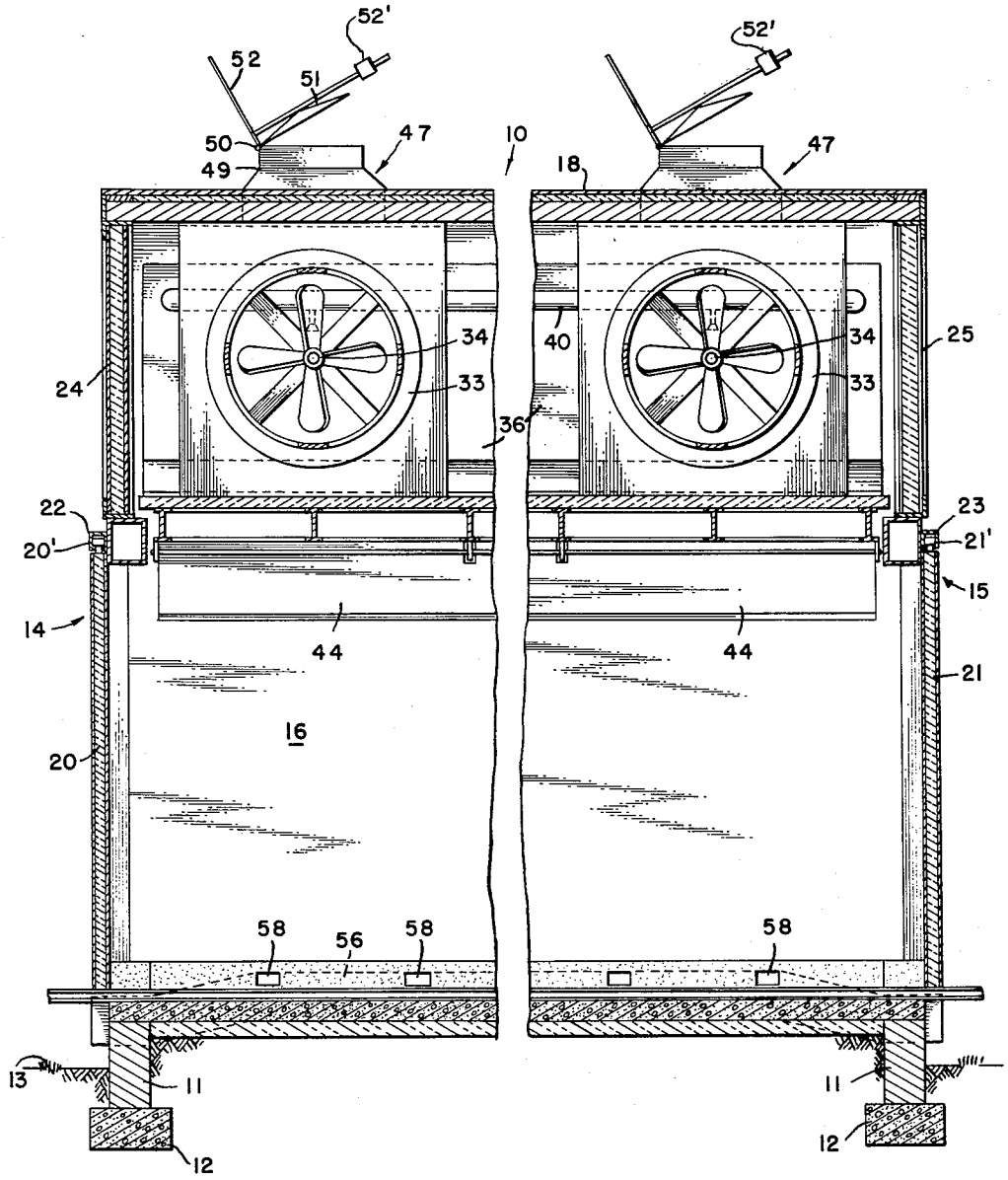


FIG. 2.

INVENTOR.
J.EVERETT MARSH
BY
Garvey & Garvey
ATTORNEYS

April 28, 1964 J. E. MARSH 3,131,034

PROCESS FOR DRYING LUMBER

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FIG. 4.

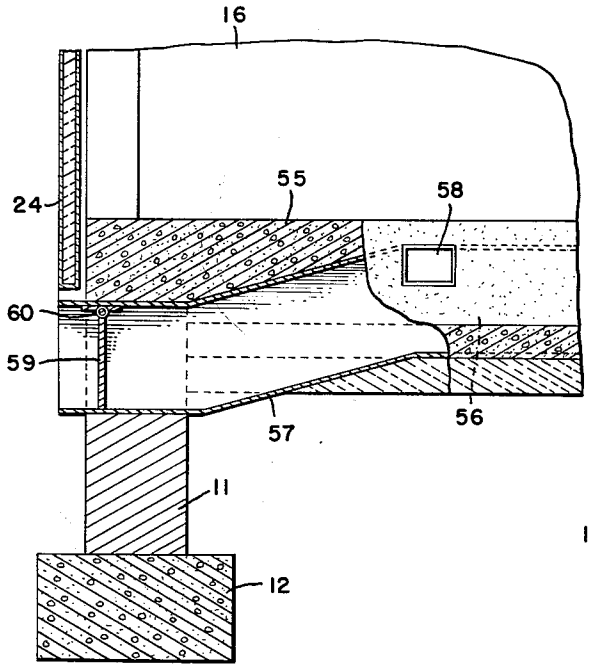


FIG. 3.

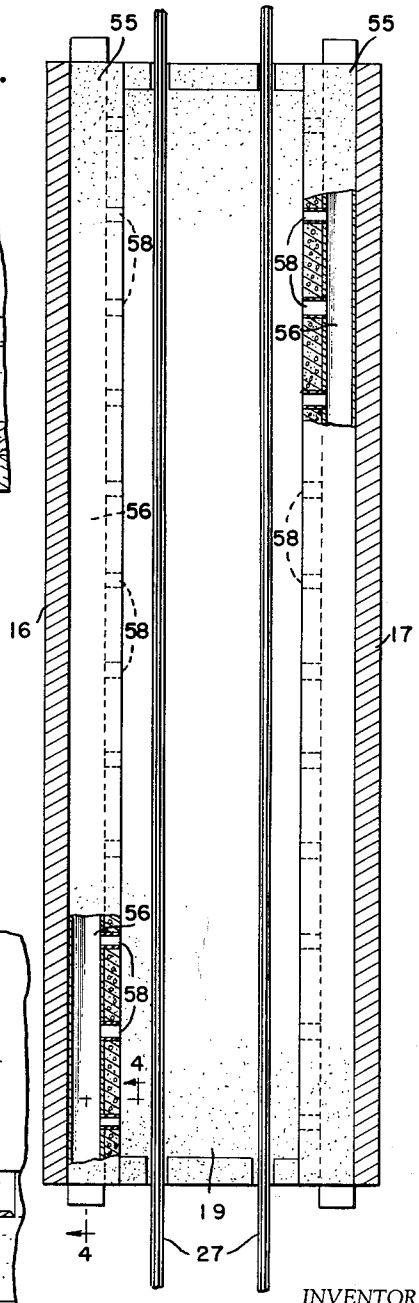
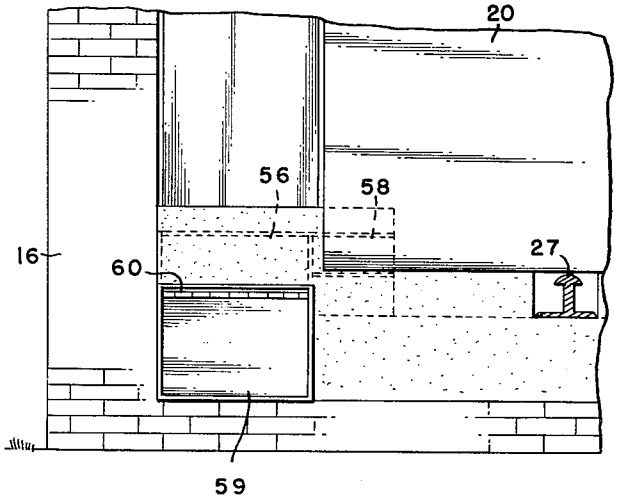


FIG. 5.



INVENTOR

J. EVERETT MARSH

BY Garvey & Garvey

ATTORNEYS

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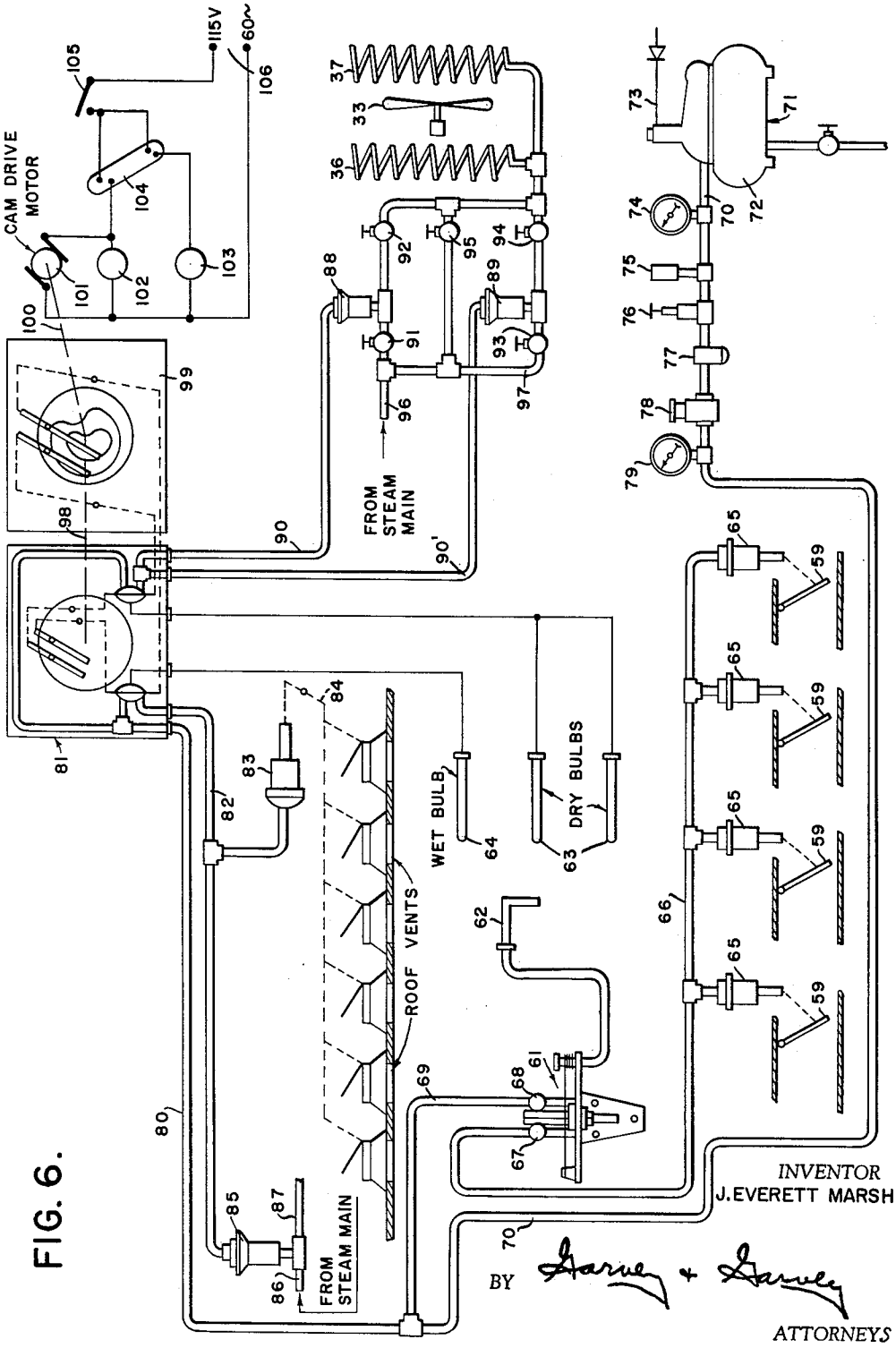


FIG. 6.

INVENTOR
J. EVERETT MARSH

BY Harvey & Harvey

ATTORNEYS

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PROCESS FOR DRYING LUMBER

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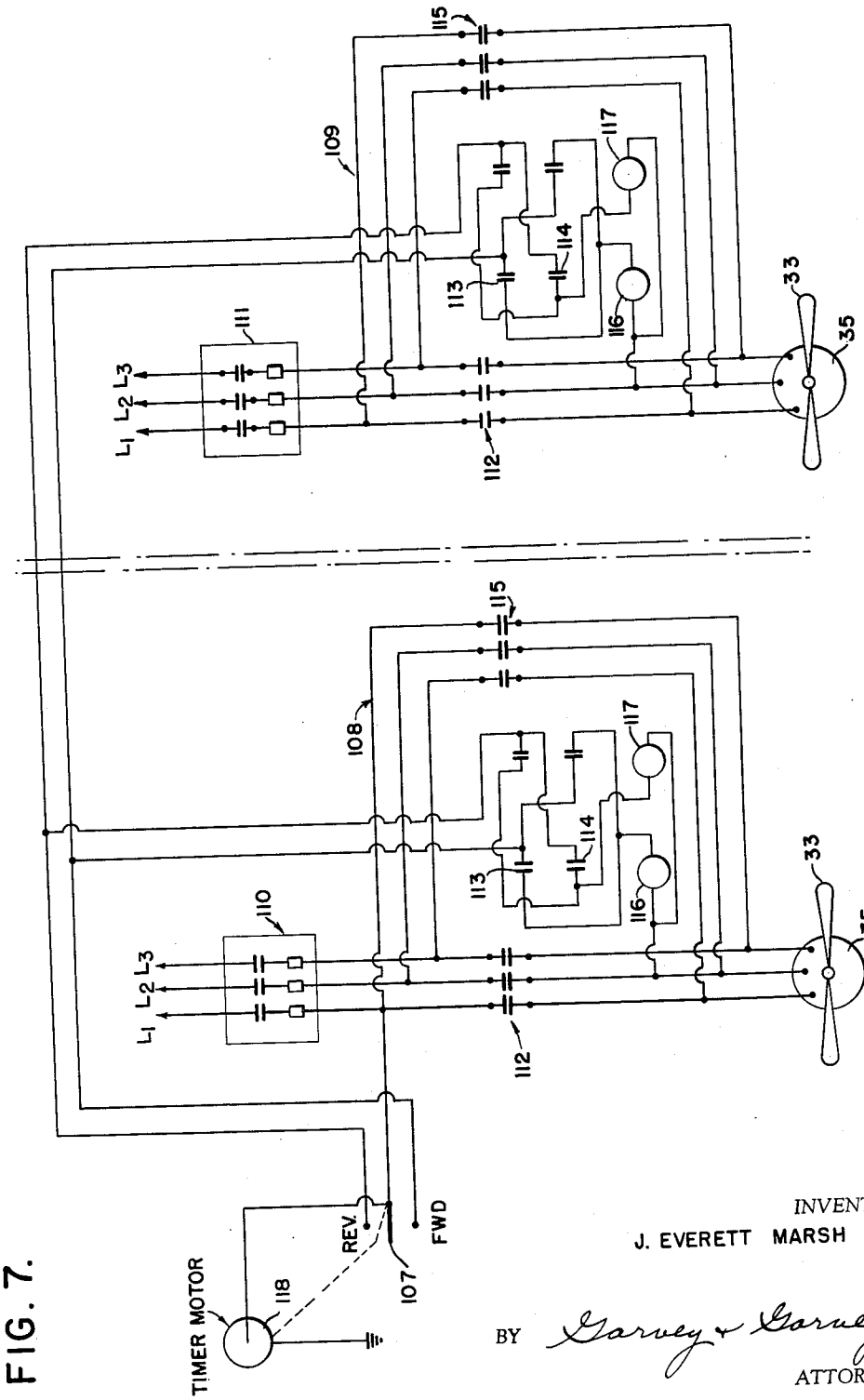


FIG. 7.

INVENTOR
J. EVERETT MARSH

BY Garvey & Garvey
ATTORNEYS

United States Patent Office

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Patented Apr. 28, 1964

3,131,034

PROCESS FOR DRYING LUMBER

Julius Everett Marsh, Box 870, High Point, N.C.

Filed Mar. 2, 1961, Ser. No. 92,997
4 Claims. (Cl. 34—30)

This invention relates to a process for drying lumber whereby the moisture content of the lumber may be rapidly decreased with incident reduction in operating time and expense, the present application being a continuation-in-part of application Serial No. 846,112, filed October 13, 1959, now abandoned.

Lumber cut from newly felled live trees contains varying amounts of sap, which is composed primarily of water. The amount of the moisture content may range from 30 percent to more than 200 percent, of the oven-dry wood, by weight, depending upon species of the wood, location of growth, location in log and other factors. This moisture is contained in the wood in two forms: first, as a bulk liquid in the cell cavities; second, as absorbed moisture in the cell walls. Wood is a hygroscopic material, in that it takes on or releases moisture until the amount of moisture it contains reaches a point of balance with the surrounding medium. The wood changes dimension with changes of moisture content, swelling with increase in moisture content; shrinking with decrease in moisture content.

The strength of wood is also intimately related to the amount of moisture it contains; the strength increasing as the wood dries and decreasing as the wood regains moisture. Lumber in commercial use contains moisture in varying amounts, depending upon the moisture content being in equilibrium under the dry bulb and wet bulb temperature, with corresponding vapor pressure conditions of the surrounding medium. For example, wood in an ambient atmosphere of 70 degrees Fahrenheit dry bulb temperature and 53 degrees Fahrenheit wet bulb temperature, will have an equilibrium moisture content near 6 percent; on the other hand, exterior lumber held in ambient atmosphere at 70 degrees Fahrenheit dry bulb temperature and 69 degrees Fahrenheit wet bulb temperature, will have an equilibrium moisture content near 25 percent. It is obvious that the moisture content of lumber in commercial use is much lower than the moisture content of freshly cut or "green" lumber. In order to insure greater stability, greater strength, lower shipping costs and other desirable features, it is necessary to reduce the moisture content of lumber before placing the same in use.

In curing lumber for use in locations where low equilibrium moisture content conditions are prevalent, the drying or seasoning process has conventionally followed either one or the other of two distinct methods. The first method heretofore used is the kiln-dry system and involves at least the following steps. After being cut from the log, the lumber is tiered in vertical spaced relation by means of spacers with individual boards displaced laterally in a horizontal spaced relation, upon racks or kiln trucks and placed in a kiln where the dry-bulb temperature and the vapor pressure of the kiln atmosphere are maintained at various predetermined conditions to reduce the moisture content of the lumber to an amount near that desired in final use. The kiln atmosphere or medium surrounding the lumber may be circulated over the surfaces of the lumber, removed and replaced as requirements in the process demand.

The time consumed in removing an amount of the moisture from lumber varies according to the amount and distribution of the moisture to be removed; species, thickness and temperature of the lumber; dry bulb and wet bulb temperatures and quantity of kiln atmosphere in contact with lumber surfaces per unit time; and may

vary from 144–240 hours for 4/4 inch thick basswood and 240–360 hours for 4/4 inch thick tupelo to 600–1,200 hours for 4/4 inch thick lowland oak in the hardwoods and from 48–144 hours for 4/4 inch thick Douglas fir to 192–480 hours for 4/4 inch thick cypress in the softwoods, starting from the green lumber and drying to 6 percent moisture content. The lumber is dried in schedules which are adopted as a result of test and are dependent upon the species and thickness of the lumber and the kiln operating characteristics. The schedules consist of sets of dry bulb and wet bulb temperatures to be maintained in the kiln at the various designated lumber moisture contents.

The art of drying lumber heretofore used prescribes that the softwoods with more than 30 percent moisture content be started with the kiln atmosphere temperatures in the range between 180 and 135 degrees Fahrenheit dry bulb with a corresponding wet bulb range between 175 and 130 degrees Fahrenheit. As the moisture content of the lumber decreases, the dry bulb temperature is increased to the range between 190 and 150 degrees Fahrenheit with the respective wet bulb temperatures being decreased to the range between 160 and 125 degrees Fahrenheit when the lumber is near 30 percent moisture content. As the moisture content of the lumber continues to decrease, the dry bulb temperature is increased to the range between 200 and 175 degrees Fahrenheit with the respective wet bulb temperature decreased to the range between 150 and 130 degrees Fahrenheit until termination of the process. The art also prescribes that the hardwoods with more than 30 percent moisture content be started with the kiln atmosphere temperature in the range between 140 and 110 degrees Fahrenheit dry bulb with a corresponding wet bulb range between 130 and 105 degrees Fahrenheit. As the moisture content of the lumber decreases, the dry bulb temperature is increased to the range between 150 and 115 degrees Fahrenheit with the respective wet bulb temperatures decreased to 140 and 105 degrees Fahrenheit when the lumber is near 30 percent moisture content. As the moisture content of the lumber continues to decrease, the dry bulb temperature is increased to the range between 170 and 135 degrees Fahrenheit with the respective wet bulb temperatures decreased to 115 and 105 degrees Fahrenheit until termination of the process.

The second, and more predominant, method heretofore used in drying lumber is the air-dry plus kiln-dry system and involves at least the following steps. After being cut from the log, the lumber is tiered in vertical and horizontal spaced relation as heretofore described and arranged upon elevated racks in open yards to take advantage of the moisture removing capacity of the natural atmosphere. The length of time necessary for the moisture content of the lumber to decrease a desirable amount varies according to the thickness and species of the lumber; method of stacking; dry bulb temperature and vapor pressure in the surrounding atmosphere; prevailing winds; original moisture content; desired final moisture content; and other factors. This time lapse may range from 40–150 days for 4/4 inch thick basswood and 70–200 days for 4/4 inch thick tupelo to 100–300 days for 4/4 inch thick lowland oak, starting from green and dried to 20 percent moisture content. This part of the second method is termed air-drying or air-seasoning.

After the moisture content thereof has decreased to some desirable amount, the lumber is tiered upon racks or kiln trucks and placed in a kiln where the dry bulb temperature and water vapor pressure of the surrounding medium are maintained at various predetermined conditions to continue reducing the moisture content to an amount near that desired in final use. The kiln and schedule are the same as that described for drying green

lumber except that the air seasoned lumber is started in the schedule according to its initial moisture content. The moisture content of the air seasoned lumber is frequently in the range of 20–40 percent. The amount of time required to remove the desired quantity of moisture varies according to the factors affecting the drying of lumber previously discussed. The time expended will be less than for green lumber and may vary from 48–144 hours for 4/4 inch thick basswood and 72–168 hours for 4/4 inch thick tupelo to 120–360 hours for 4/4 inch thick lowland oak, starting from 20 percent moisture content and dried to 6 percent moisture content.

All of the steps in schedules for drying lumber in the methods heretofore used were carried out with the total pressure in the kiln at the same pressure as the exterior atmospheric pressure and with the dry bulb temperatures lower than the temperature of saturated steam at atmospheric pressure. The movement of the moisture within the lumber is mostly dependent upon moisture content differences to cause moisture movement through transitory passageways within the cell walls comprising the wood.

One of the objects of this invention is to provide a process for rapidly drying lumber or other articles while simultaneously maintaining a minimum amount of case hardening, cracking and shrinking.

Another object of this invention is to provide a process for drying lumber wherein the lumber is treated in an ambient atmosphere under elevated controlled conditions of dry bulb temperature and vapor pressure according to the moisture content of the lumber.

Other objects are to provide a process for drying lumber wherein the medium within the kiln enclosure may be circulated across the surfaces of the lumber while the kiln atmosphere is at elevated controlled temperature and controlled pressure conditions; to provide a process wherein the medium within the kiln may be replenished or reduced at said controlled temperature and pressure conditions; to provide a process for drying unseasoned lumber in approximately two days and air-dried lumber in approximately one day, depending upon the difference between the initial and final moisture contents of the lumber; and to provide a process of the character described capable of producing dried lumber, free of stresses and strains.

Other objects of the invention will be manifest from the following description of the present preferred form of the invention; taken in connection with the accompanying drawings, wherein:

FIG. 1 is an end elevational view of a lumber-drying kiln constructed in accordance with the present invention, portions thereof being removed to disclose novel details of construction;

FIG. 2 is a fragmentary longitudinal sectional view taken along the lines 2—2 of FIG. 1 looking in the direction of the arrows;

FIG. 3 is a transverse sectional view of the lumber-drying kiln showing to advantage the air supply ducts forming a part of the present invention;

FIG. 4 is an enlarged vertical sectional view taken along the line 4—4 of FIG. 3, looking in the direction of the arrows;

FIG. 5 is a fragmentary and elevational view of a lumber-drying kiln embodying novel features of the present invention;

FIG. 6 is a schematic diagram of an automatic control system for the lumber-drying kiln of my invention, showing a method of automatically controlling the dry bulb temperature, vapor pressure and total pressure in the kiln; replenishing and removing the atmosphere in the kiln, and recording the dry bulb and wet bulb temperatures in the kiln; and

FIG. 7 is a fragmentary schematic electrical wiring diagram of the circulating fan motor power and control system, the view illustrating two separate motor power circuits of which there may be a multiplicity in the kiln structure of my invention.

Referring now in greater detail to the drawings, there is illustrated in FIGS. 1 to 5 a lumber-drying kiln generally designated 10 shown of masonry construction adapted to be supported on pillars 11 which rest on footings 12 beneath the ground 13. Kiln 10 includes a front wall 14 and a rear wall 15, side walls 16 and 17, a top 18 and a bottom 19, all of which are suitably insulated to reduce heat and vapor transmission. Front wall 14 and rear wall 15 are provided with entrance and exit doors 20 and 21, respectively, having rollers 20' and 21' connected to their upper edges which are engageable with superjacent tracks 22 and 23 that extend beyond the lateral extremities of the walls. The upper portions of front and rear walls 14 and 15 are closed by removable panels 24 and 25. Doors 20 and 21 are moved to open position to admit flat cars 26 which are mounted on tracks 27 supported by bottom 19, the track extending longitudinally through the kiln. Lumber 28 is tiered on flat cars 26 in layers of vertically spaced relationship by use of a plurality of spacing members 29 which extend transversely of the tiered lumber at predetermined intervals. Open passageways are formed between the horizontal lumber surfaces and vertical spacer surfaces.

Intermediate top 18 and bottom 19 of the kiln is a platform 30 spaced equidistant from side walls 16 and 17, which is supported by members 31, on which platform is mounted a heating and circulating assembly 32. Assembly 32 includes a plurality of suitably supported conventional reversible fans 33 disposed in spaced relation centrally of the kiln and coextensive with its length. Each of fans 33 is operated by a separate drive shaft 34 actuated by a separate motor 35. Heat transfer coil units 36 and 37 are mounted on platform 30 and extend longitudinally thereof in spaced parallel relationship to fans 33 and to each other, the heating units being positioned in the path of the movement of air circulated by fans 33. Steam supply pipes for units 36 and 37 are indicated at 38 and 39. In association with the heating and circulating assembly 32 there are provided spray nozzles 40 and 41 fed by steam supply pipes 42 and 43 which spray nozzles are interposed between heating unit 36 and fans 33 and between heating unit 37 and fans 33, respectively.

In connection with the heating and circulating assembly of the present invention there are provided a pair of movable baffle plates 44 carried by the lateral edges of platform support members 31, which baffle plates extend longitudinally of the kiln and serve to direct the flow of the circulated kiln atmosphere between the spaced surfaces of the lumber. Baffle plates 44 are pivoted intermediate their lengths to members 31, as indicated at 45, and the baffles are provided with armed counterweights 46 for rotating plate 44 about pivot point 45.

Kiln 10 is provided with two longitudinal rows of vents designated 47 and 48 which serve to alternately admit air to the kiln and to exhaust the kiln atmosphere. Each of these vents includes a body member 49 aligned with a complemental opening in the top 18 of the kiln. The upper extremity of the body member is hingedly connected at 50 to a vent cap 51 having operating arms 52, one of which has adjustable weight 52' for mainatining pressure in the kiln.

In order to maintain the total pressure of the kiln atmosphere at a definite amount, in performing the steps in the lumber drying schedule, this invention contemplates providing a pair of air relief duct systems 53 and 54 located adjacent the base of the kiln and extending longitudinally thereof substantially in alignment with the track bed. For this purpose, curbs 55 are used to house the duct units. Each air relief duct system includes a duct 56 of any suitable material, the fore and aft ends of which are bent downwardly, as indicated at 57, to prevent interference with sliding doors 20 and 21. Referring now to FIG. 3, it will be seen that ducts 56 are provided

at intervals with inwardly extending air nozzles 58 connecting kiln interior to the ducts. Control of the flow of air through the ducts into the kiln is by means of louvers 59, movable to open position in relation to the ducts about a pivot 60, the louvers being located immediately adjacent the fore and aft terminals of the ducts. Louvers 59 are actuated to either open or closed position by motors 65 (see FIG. 6) in response to a static pressure regulator 61, which is controlled by a sensing probe 62 extending into the interior of the kiln to sense the static pressure in the kiln. The static pressure regulator 61 is connected pneumatically to the louver motors 65 by compressed air pipe 66. Pressure of the control air in pipe 66 is indicated by gauge 67 and pressure of the control air supply in pipe 69 is indicated by gauge 68. The static pressure regulator and the motors are respectively similar in operation to Powers Regulator Company Type No. 1269 and "power-stroke."

The control air in pipe 69 is supplied from the main control air supply line 70, which in turn receives its air supply from the air compressor system 71. The air compressor system 71 includes air compressor and compressed air storage tank 72 having an air suction intake 73 for supplying air under pressure to the pipe line 70 through a connection for pressure gauge 74, a connection for pressure relief valve 75, gate valve 76, air filter 77, pressure reducing valve 78 and a connection for low pressure gauge 79. The compressed air is also supplied through pipe 80 to the time-cycle recorder-controller 81, which is similar in operation to Powers Regulator Company Series 100 instrument.

Time-cycle recorder-controller 81 controls the vapor pressure in the kiln by operating motor 83, which is connected by mechanical linkage 84 to vent cap operating arm 52, and by operating motor valve 85. Time-cycle recorder-controller 81 is connected pneumatically to motor 83 and to motor valve 85 with pipe 82. Motor 83 and motor valve 85 are operated by time-cycle recorder-controller 81 in response to wet bulb sensing unit 64, which is located in the interior of the kiln and which indirectly senses the vapor pressure therein. The time-cycle recorder-controller programs motor 83 and motor valve 85 in such manner that motor 83 closes vent caps 51 through the vent cap operating arm 52 to prevent escape of kiln atmosphere, and simultaneously opens motor valve 85 to permit addition of vapor to the kiln interior when the vapor pressure in the kiln is lower than that required by the instant step of the drying schedule. Steam or liquid is taken from an adequate source 86 and passed through the valve 85 to pipe 87 which is connected to steam pipes 42 and 43. The time-cycle recorder-controller programs motor 83 and motor valve 85 in such manner that motor 83 opens vent caps 51 through the vent cap operating arm 52 to permit escape of kiln atmosphere and simultaneously closes motor valve 85 to prevent addition of vapor to the kiln interior when the vapor pressure in the kiln is higher than that required by the instant step of the drying schedule.

The time-cycle recorder-controller 81 also controls the dry bulb temperature in the kiln by operating motor valves 88 and 89 which are pneumatically connected to the time-cycle recorder-controller with pipes 90 and 90'. Each valve or both valves are capable of being isolated by closing valves 91, 92, 93, 94 or alternatively are capable of being by-passed by closing 91, 93, or 92, 94 and opening by-pass valve 95. Steam is introduced to the valve assembly from an adequate source through pipe 96 to the distribution loop 97. The outlet of the loop is connected to steam supply pipes 38 and 39 which in turn are connected to heat transfer units 36 and 37. Motor valves 88 and 89 are operated by the time-cycle recorder-controller 81 in response to dry bulb sensing units 63 which are located in the interior of the kiln, one on each side. The sensing unit in the highest ambient temperature is the unit in command of the dry bulb

temperature. Two valves 88 and 89 are used for closer control of the steam flow and to reduce wire drawing of valve seats on lowest steam flow demand with one valve set to open before the other. When the valve which opens first is unable to allow passage of sufficient steam, the second valve opens and by the same arrangement of control, the second valve closes first as the steam demand decreases.

The time-cycle recorder-controller 81 programs valves 88 and 89 in such a manner that either one or both valves are open to permit passage of steam through pipes 38 and 39 to the heat transfer coil unit when the dry-bulb temperature in the kiln is lower than that required by the instant step of the drying schedule.

The dry bulb temperature of the kiln atmosphere is increased when the temperature of the kiln atmosphere is lower than the steam temperature in the coils and the vapor in the kiln is not in a phase change. The time-cycle recorder-controller 81 also programs valves 88 and 89 in such manner that both valves are closed to prevent passage of steam through pipes 38 and 39 to the heat transfer coil units 36 and 37 when the dry bulb temperature in the kiln is equal to or higher than that required by the instant step of the drying schedule.

The time-cycle recorder-controller also makes a continuous record of the dry-bulb and wet bulb temperatures prevailing instantaneously throughout the steps of the drying schedule. The dry-bulb temperature record is made in response to the dry-bulb sensing unit 63 which is in the highest ambient temperature. The wet bulb temperature record is made in response to the wet bulb sensing unit 64.

The time-cycle recorder-controller also determines the dry-bulb and wet bulb temperatures which will be maintained and the length of time which each will be maintained in each step of the drying schedule. This function is performed by controller section 99, which contains a pair of cams and followers and which is a part of the time cycle recorder-controller 81. One cam and follower sets the control point for the dry bulb temperature; the other cam and follower sets the simultaneous control point for the wet bulb temperature. The cams are shaped to position the cooperating follower which in turn resets the control point for the respective dry-bulb temperature and wet bulb temperature required by the instant step in the drying schedule.

The record dial and the control cams are rotated at a uniform rate through shaft 98 extended to shaft 100 by an electrically powered drive motor 101. This invention contemplates that the motor power circuit will contain a red signal light 102, a green signal light 103, a single-pole, double-throw mercury switch 104, a single-pole, single-throw manual switch 105 and a power source 106. With the manual switch 105 in the open position, the control system is not in operation. With the manual switch in closed position and the cam follower at the starting point of the control cam, the red light 102 is on and the green light 103 is off. With the manual switch 104 in closed position and the cam follower at the starting point of the steps in the drying schedule, the green light 103 is on, the red light 102 is off and the motor drive 101 starts. At the complete rotation of the control cam, the cam follower is at the end point of the steps in the drying schedule and the red light 102 is on and the green light 103 is off and the cam drive stops.

It is within the contemplation of this invention to periodically reverse the direction of rotation of the circulating fans 33 by reversing the rotation of the fan drive motors 35 in order to maintain a more uniform drying condition across the tier of lumber 28. With attention now directed to FIG. 7, note that the power and control wiring is for a three phase, three wire, alternating current system. In order to reverse the rotation of a three phase motor it is only necessary to interchange the

connections of any two phases to the motor. The wiring and switching arrangement consists of a single-pole, double throw switch 107, reversing magnetic starter 108, 109 for each circulating fan motor, a fused disconnect switch 110, 111 for each circulating fan motor, adequate electrical energy service at L–1, L–2, L–3, connections to fan motors 35 and connecting power and control wiring as shown. The common phase is L–2, the interchange phases are L–1 and L–3. The contactors which cause rotation in one direction are 112 and the contactors which cause opposite rotation are 115. The phases to the motors are interchanged by the forward or reversing relays 113, 114 in response to the forward or reversing solenoids 116, 117 as controlled by the position of the switch 107. The position of the switch 107 is periodically changed by the timer motor 118 which also introduces a time delay to permit the motors to stop before power for opposite rotation is applied. Each circulating fan motor disconnect switch, magnetic starter and motor terminals are cooperatively phased such that the circulation caused by all fans is simultaneously in the same direction across the kiln and through the tier of lumber.

It is also within the contemplation of this invention that the fan arrangement and combination will be such that the quantity of circulated kiln atmosphere will be very nearly equal in each direction of flow through the tier of lumber, with a resulting greater uniformity of drying across the tier of lumber. To accomplish this purpose with propeller fans having characteristics of handling different quantities of atmosphere in forward and reverse rotations, altern fans 33 are mounted on shafts 34 for opposite axis of rotation. With an even number of fans, all of which are turning either clockwise or counter-clockwise, one half of the fans are in forward rotation and one half in reverse rotation and the total quantity of atmosphere handled by the combinaiton of fans is the same in each direction of flow through the tier of lumber.

The invention may be practiced with the aid of properly modified existing dry kilns available in the industry; the modifications being of known mechanical principles. For this reason, no claim is made herein for the apparatus as such although the combination and application of the facilities and instrumentation for carrying out the process is believed to be new in the art of seasoning lumber.

Attention is now directed to the process comprising my invention for drying lumber. The total moisture content of the lumber is a factor in the process because the initial moisture content is greater than that which will prevail in the lumber in final use and the reduction of the moisture content is the purpose of the process. The form in which the moisture is contained in the wood, namely, whether it is held as bound moisture in the cell walls only or is also held in the form of bulk liquid in the cell cavities, is a factor in the process. In drying, the first moisture released by the lumber is that which is contained in the cell cavities. Conversely, in moisture regain, the first moisture reabsorbed by the lumber is into the cell walls. The point at which the cell walls contain the maximum amount of moisture and the cell cavities contain no moisture is termed the fiber-saturation point. All shrinking and swelling in wood with changes of moisture content occur below the fiber-saturation point, therefore, large differences in moisture content may exist across a board of lumber without "checking" the lumber when all points within the board are higher than the fiber-saturation point.

The distribution of the moisture within a board of lumber is a factor in the process in that differences in moisture content within the board cause the contained moisture to move from points of higher content to points of lower content, with the rate of movement increasing as the difference increases. The upper limit of the difference in moisture content is determined by the amount of shrinkage in the wood as it changes moisture content. If the difference in shrinkage is too great, the lumber will check on the surface or honeycomb in the interior. Therefore, in drying lumber, without damage by checking or honeycombing, the difference in moisture content near the surface and near the center of the board is especially important because the moisture is moving from the center to the surface.

Another factor in the process is the distribution of heat energy within the board of lumber and is contained moisture because the heat content determines the temperature and pressure of the moisture and the difference in pressure determines the rate of flow of the moisture from points of higher to points of lower pressure through cell cavities, pit chambers, pit membrane openings and intercelluar spaces. The size and arrangement of the cells, fibers, pit chambers, pit membrane openings and intercellular spaces composing the wood constitute a factor in the process because these items determine the rate of flow of moisture through the lumber and vary with each species of wood.

The surface temperature of the lumber is another factor in the process because when the surface temperature is lower than the vapor saturation temperature at the vapor pressure in the ambient atmosphere, the vapor in the ambient atmosphere is condensed to liquid upon the lumber surfaces and when the surface temperature is higher than the vapor saturation temperature at the vapor pressure in the ambient atmosphere, the moisture on the surface of the lumber is evaporated into the ambient atmosphere.

The partial vapor pressure in the ambient atmosphere is a factor in the drying process because, in a mixture of air and water vapor, the vaporizing temperature of the moisture at the surfaces of the lumber depends upon the partial pressure of the vapor and not upon the total pressure of the mixture. The ratio of the vapor pressure to the total pressure of the ambient atmosphere is another factor because the air in the mixture releases heat to the lumber when the dry bulb temperature is higher than temperature of the wood and its contained moisture and the vapor in the mixture gives up heat to the lumber when the temperature is higher than the wood and its contained moisture and is also higher than its temperature of saturation. The total pressure of the ambient atmosphere is a factor because the total pressure may be translated to total weight and the ratio of partial pressures translated to ratio of weights of the components in the mixture.

The dry bulb temperature of the ambient atmosphere is still another factor in the process because the moisture in the lumber absorbs heat as its temperature increases and as it changes phase from liquid to vapor. The heat for temperature increase and the heat for vaporization is transmitted from the ambient atmosphere to the lumber moisture. The heat removed from the kiln atmosphere is replenished by the heat transfer coils. The rate of heat transfer increases with increase in difference between dry bulb temperature and lumber surface temperature.

Either one of the properties of dry bulb temperature, wet bulb temperature or partial pressure of the vapor for mixtures of air and water vapor at all total pressures of the mixture may be determined by using known graphs, tables or computations when the other two properties are known. The dry bulb temperature, wet bulb temperature and total pressure of the mixture comprising the kiln atmosphere are directly measurable; and using these properties, the partial vapor pressure, which cannot be measured directly by pressure gauge, is determined. The properties of dry bulb temperature, partial vapor pressure and total pressure determine the available thermal energy in the kiln atmosphere. When the wet bulb temperature reading is lower than the saturation temperature of steam which is defined as the boiling point of water at the prevailing pressure, no air is present; and when the wet bulb temperature reading is the same as the saturation tempera-

ture of steam with the dry bulb temperature greater than the saturation temperature of steam at the prevailing pressure, no air is present and the vapor is superheated.

The amount of time required to remove a quantity of moisture from lumber is governed by the quantity of atmosphere in contact with the lumber surfaces per unit time and by the thickness of the lumber in addition to the above listed factors. With other factors remaining constant, the time is decreased with increased circulation and decreased lumber thickness. When the lumber is releasing moisture, the dry bulb temperature of the kiln atmosphere is decreased and the wet bulb temperature is increased as the kiln atmosphere is circulated over the surfaces of the lumber; therefore, the combination of tier width, spacer thickness and fan capacity influence the time of drying. With other factors remaining constant, the time is increased with an increase in the amount of moisture removed.

A constant speed fan handles the same volume of air per unit time at various temperatures. When the volume of air handled by the circulating fans remains constant, and the dry bulb temperature, total pressure and partial pressures of the mixture components are changed, the weight of the mixture handled by the fans is changed. In order to handle the same weight of mixture when the dry bulb temperature, total pressure and partial pressures of the mixture components are changed, the speed of the fans is changed.

The drying process of this invention follows either one or the other of two methods, depending upon the moisture content of the lumber relative to its fiber-saturation point when the lumber is initiated into the process. The first method is for lumber which is unseasoned or has an initial moisture content greater than the fiber-saturation point and the second method is for lumber which has been air-seasoned or has an initial moisture content slightly greater than equal to or less than the fiber-saturation point throughout the board. In the process for both methods, the lumber is tiered, spaced and located in the kiln, as discussed in the detailed description of the drawings. The previously discussed factors which influence the drying of lumber are the effective conditions in the process of my invention and the variation of these factors determine the amount of time required to remove a quantity of moisture from lumber undergoing the process. The lumber is dried according to schedules, which are the result of computations and tests and which consist of sets of dry bulb temperatures and wet bulb temperatures to be maintained in the kiln atmosphere at the various designated corresponding moisture contents of the lumber.

Each set of dry bulb temperatures in each schedule is determined with consideration for the moisture and heat distribution within the lumber, surface temperature of the lumber, species of the wood and the total pressure of the kiln atmosphere. For example, in drying unseasoned lumber, with the total pressure of the kiln atmosphere maintained at 14.696 pounds per square inch absolute throughout the schedule, the following steps comprise the schedule. When the lumber is placed in the kiln, the dry bulb and wet bulb temperatures of the kiln atmosphere and the temperature of the lumber are near the exterior atmospheric temperature. The first step in the process is to increase the dry bulb temperature of the kiln atmosphere from the initial ambient property to a range near 210 degrees Fahrenheit while simultaneously holding a wet bulb depression of less than 25 degrees Fahrenheit and increasing the wet bulb temperature from the initial ambient property to the range between 185 and 205 degrees Fahrenheit. Throughout the first step in the process the partial pressure of the vapor in the kiln atmosphere is maintained such that the surface temperature of the lumber is lower than the saturation temperature of the vapor at the prevailing vapor pressure and a film of moisture deposits upon the lumber from the ambient atmosphere and the lumber with its contained moisture increases in temperature but loses no moisture. The second step in the process is to maintain the final dry bulb and wet bulb temperatures of the first step until the lumber is uniformly heated to the maximum temperature which it can attain within these ambient conditions. During the first stages of the second step the surface temperature of the lumber is lower than the saturation temperature of the ambient vapor at the prevailing vapor pressure and the film of moisture remains deposited upon the lumber surfaces. In subsequent stages of the second step the surface temperature of the lumber is equal to the vapor saturation temperature and in the final stages of the second step the surface temperature of the lumber is higher than the saturation temperature of the vapor in the kiln atmosphere at the prevailing partial vapor pressure; the film of moisture is evaporated into the kiln atmosphere and the lumber begins to dry. The third step in the process is begun after the second step is accomplished and consists of increasing the dry bulb temperature of the kiln atmosphere from the range near 210 to the range between 250 and 350 degrees Fahrenheit while simultaneously increasing the wet bulb temperature from the range between 185 and 205 to the range near 210 degrees Fahrenheit. The fourth step in the process is to maintain the kiln atmosphere at the final dry bulb and wet bulb temperatures of the third step until the moisture content of the lumber has been reduced to any desired amount but greater than fiber-saturation. The dry bulb and wet bulb temperatures are adjusted to maintain no more than 25 percent difference in moisture content between the center and surface of the board of lumber. The fifth step in the process is begun after the fourth step is accomplished and consists of reducing the dry bulb temperature of the kiln atmosphere from the range between 250 and 350 to the range between 190 and 210 degrees Fahrenheit while simultaneously reducing the wet bulb temperature from the range near 210 degrees to the range between 185 and 195 degrees Fahrenheit. Throughout the third, fourth and fifth steps in the process the partial vapor pressure in the kiln atmosphere is maintained such that the surface temperature of the lumber is higher than the saturation temperature of the vapor at the prevailing vapor pressure and the lumber loses moisture. The sixth step in the process is to maintain the final dry bulb and wet bulb temperatures of the fifth step until the moisture content of the lumber has reduced to a point near but more than the fiber-saturation point and the moisture in the lumber is uniformly distributed throughout the wood. At a stage in the sixth step of the process the partial pressure of the vapor in the kiln atmosphere reaches a point such that the surface temperature of the lumber is near the saturatiton temperature of the vapor at the prevailing vapor pressure and the lumber neither gains nor loses moisture. The seventh step in the process is begun after the sixth step is accomplished and consists of increasing the dry bulb temperature of the kiln atmosphere from the range between 190 and 210 to the range near 255 degrees Fahrenheit while simultaneously increasing the wet bulb temperature from the range between 185 and 195 to the range near 210 degrees Fahrenheit. The eighth step in the process is to maintain the final dry bulb and wet bulb temperatures of the seventh step until the moisture content of the lumber has reduced to the range near 10 percent and with very small differential in content between the center and surface of the board. The ninth step in the process is begun after the eighth step is accomplished and consists of reducing the dry bulb temperature of the kiln atmosphere from the range near 255 to the range near 240 degrees Fahrenheit while simultaneously maintaining the wet bulb temperature near 210 degrees Fahrenheit. The tenth step in the process is to maintain the final dry bulb and wet bulb temperatures of the ninth step until the moisture content of the lumber has reduced to a point near that desired in final use. Throughout the seventh, eighth, ninth and tenth steps in the process, the

partial vapor pressure in the kiln atmosphere is maintained such that the surface temperature of the lumber is higher than the saturation temperature of the vapor at the prevailing vapor pressure and the lumber loses moisture and the dry bulb temperature of the kiln atmosphere is maintained such that heat is transmitted to the moisture in the lumber for temperature and pressure increase and for vaporization.

For another example, in drying previously air-seasoned lumber, with the total pressure of the kiln atmosphere maintained at 14.696 pounds per square inch absolute throughout the schedule, the following steps comprise the schedule. When the lumber is placed in the kiln, the dry bulb and wet bulb temperatures of the kiln atmosphere and the temperature of the lumber are near the exterior atmospheric temperature. The first step in the process is to increase the dry-bulb temperature of the kiln atmosphere from the initial ambient property to a range near 210 degrees Fahrenheit while simultaneously holding a wet bulb depression of less than 25 degrees Fahrenheit and increasing the wet bulb temperature from the initial ambient property to the range between 185 and 205 degrees Fahrenheit. Throughout the first step in the process, the partial pressure of the vapor in the kiln atmosphere is maintained such that the surface temperature of the lumber is lower than the saturation temperature of the vapor at the prevailing vapor pressure and a film of moisture deposits upon the lumber from the ambient atmosphere and the lumber with its contained moisture increases in temperature but loses no moisture. The second step in the process is to maintain the final dry bulb and wet bulb temperatures of the first step until the lumber is uniformly heated to the maximum temperature which it can attain within these ambient conditions. During the first stages of the second step the surface temperature of the lumber is lower than the saturation temperature of the ambient vapor at the prevailing vapor pressure and the film of moisture remains deposited upon the lumber surfaces. In subsequent stages of the second step the surface temperature of the lumber is equal to the vapor saturation temperature and in the final stages of the second step the surface temperature of the lumber is higher than the saturation temperature of the vapor in the kiln atmosphere at the prevailing partial vapor pressure; the film of moisture is evaporated into the kiln atmosphere and the lumber begins to dry. The third step in the process is begun after the second step is accomplished and consists of increasing the dry bulb temperature of the kiln atmosphere from the range near 210 to the range near 255 degrees Fahrenheit while simultaneously increasing the wet bulb temperature from the range between 185 and 205 to the range near 210 degrees Fahrenheit. The fourth step in the process is to maintain the final dry bulb and wet bulb temperatures of the third step until the moisture content of the lumber has reduced to the range near 10 percent and with very small differential in content between the center and surface of the board. The fifth step in the process is begun after the fourth step is accomplished and consists of reducing the dry bulb temperature of the kiln atmosphere from the rang near 255 to the range near 240 degrees Fahrenheit while simultaneously maintaining the wet bulb temperature near 210 degrees Fahrenheit. The sixth step in the process is to maintained the final dry bulb and wet bulb temperatures of the fifth step until the moisture content of the lumber has reduced to a point near that desired in final use. Throughout the third, fourth, fifth and sixth steps in the process, the partial vapor pressure in the kiln atmosphere is maintained such that the surface temperature of the lumber is higher than the saturation temperature of the vapor at the prevailing vapor pressure and the lumber loses moisture and the dry bulb temperature of the kiln atmosphere is maintained such that heat is transmitted to the moisture in the lumber for temperature and pressure increase and for vaporization.

The moisture content of said lumber in the drying process is tested at frequent intervals for moisture content and moisture distribution. These tests are made by conventional methods such as weight comparison, electrical resistance, etc. The dry bulb and wet bulb temperatures are adjusted in accordance with these tests, to maintain no more than 25% difference in moisture content between the center and surface of the board of lumber.

In performing the above process, the dry bulb temperature of the kiln atmosphere is decreased as the heat energy contained therein is transferred to the lumber, transmitted through the kiln surfaces and diluted by replacement with and exhaust to the exterior atmosphere. The dry bulb temperature is maintained and increased by replacing and increasing the heat energy with the heat transfer coils **36, 37**. The wet bulb temperature of the kiln atmosphere is decreased as water vapor contained therein is condensed upon the lumber surfaces and diluted by replacement with and exhaust to the exterior atmosphere. The wet bulb temperature is maintained and increased by replacing and increasing the lost vapor with the spray nozzles **40, 41** and with the moisture evaporated from the lumber. The increase in wet bulb temperature also tends to increase the dry bulb temperature when the vapor from the spray nozzles has a higher pressure and temperature than the kiln atmosphere. The total pressure of the kiln atmosphere is decreased as the contained vapor is condensed. The total pressure is maintained by introducing exterior atmosphere to the kiln interior through the air relief duct systems **53, 54** when the total pressure of the kiln atmosphere is lower than the total pressure of the exterior atmosphere.

When using the process of my invention under the conditions discussed above, with constant speed circulating fans having capacity to handle the quantity of standard air necessary to maintain a velocity in the range between 900 and 1,200 feet per minute over the surfaces of the lumber, with spacers 1¼ inch thick and with tiers of lumber 8 feet wide, 4/4 inch thick tupelo is dried from 100 to 5 percent moisture content in less than 48 hours, 4/4 inch thick pine is dried from 100 to 5 percent moisture content is less than 36 hours, 4/4 inch thick cypress is dried from 100 to 5 percent in less than 48 hours, and 4/4 inch thick poplar is dried from 80 to 26 percent in less than 15 hours, using the first method; also 4/4 inch thick tupelo is dried from 35 to 5 percent moisture content in less than 18 hours, and 4/4 inch pine is dried from 50 to 17 percent in less than 12 hours, using the second method.

All or part of the steps in the drying schedule in each method are performed at various absolute total pressures of the kiln atmosphere, the dry bulb and wet bulb temperatures and the fan volume being adjusted accordingly. The dry bulb and wet bulb temperatures are decreased with the fan volume increased for total pressure below and the dry bulb and wet bulb temperatures are increased with the fan volume decreased for total pressures above 14.696 pounds per square inch absolute for results equivalent to those attained with the kiln atmosphere total pressure at 14.696 pounds per square inch absolute. The rate of drying at any point in the process is decelerated by reducing the total pressure and is accelerated by increasing the total pressure as a result of the influence on the capacity of the circulating fans in accordance with known fan laws and by the known laws governing changes in the pressure, temperature and volume of gases.

Lumber dried in accordance with the process of my invention is softer and less case-hardened than has heretofore been possible, and consequently can be machined with less power, less wear on the knives and with less tendency to chip-out under the knife cut.

While I have herein shown and described a preferred embodiment of my invention, it is nevertheless to be understood that various changes may be made therein without departing from the spirit and scope of the appended claims.

What is claimed is:

1. A process for the removal of moisture from lumber comprising the steps of enclosing lumber in a confined zone under controlled conditions of dry bulb temperature, wet bulb temperature and total pressure of the zone atmosphere, the initial conditions being substantially the same as those outside the zone, increasing the dry bulb temperature of the zone atmosphere to a point near the boiling point of water at the prevailing total pressure in the zone while simultaneously increasing the wet bulb temperature while holding a wet bulb depression of less than approximately 15 percent of the dry bulb temperature, varying the partial vapor pressure in the zone so that the surface temperature of the lumber will remain lower than the boiling point of water within the zone at the prevailing vapor pressure in order to prevent evaporation of moisture from the lumber, maintaining these conditions while uniformly heating the lumber and moisture contained therein to a temperature near the boiling point of water in said zone at the prevailing vapor pressure, thereafter increasing the dry bulb temperature of the zone atmosphere to a point at least 15 percent greater than the boiling point of water at the prevailing total pressure in the zone while simultaneously increasing the wet bulb temperature to accelerate and control the rate of moisture removal from the lumber and to replace the heat lost due to evaporation of moisture therefrom, maintaining these further increased dry bulb and wet bulb temperatures until the moisture content of the lumber is reduced to about 10 percent by weight of the oven-dry wood, and thereafter slightly decreasing the dry bulb temperature while maintaining the wet bulb temperature at the further increased level whereby additional removal of moisture may be accomplished at a decelerated rate and distribution of moisture remaining in the lumber may be equalized.

2. A process for drying previously air-seasoned lumber comprising the steps of enclosing air-seasoned lumber in a confined zone under controlled conditions of dry bulb temperature, wet bulb temperature and total pressure of the zone atmosphere, the initial conditions being substantially the same as those outside the confined zone, increasing the dry bulb temperature of the zone atmosphere to a point near the boiling point of water at the prevailing total pressure in the zone while simultaneously increasing the wet bulb temperature and holding some wet bulb depression but less than approximately 15 percent of the dry bulb temperature, varying the partial vapor pressure in the zone so that the surface temperature of the lumber is lower than the boiling point of water at the prevailing vapor pressure within the zone whereby the lumber increases in temperature and a film of moisture deposits on the surface thereof but no removal of moisture therefrom occurs, maintaining these conditions until the lumber and moisture contained therein are uniformly heated to a temperature which exceeds the boiling point of water at the partial vapor pressure in said zone, whereby evaporation of moisture from the lumber occurs, increasing the dry bulb temperature of the zone atmosphere to a point at least 15 percent greater than the boiling point of water at the prevailing total pressure in the zone while simultaneously increasing the wet bulb temperature to accelerate and control the rate of moisture removal from the lumber and to replace the heat lost due to evaporation of moisture therefrom, maintaining these further increased dry bulb and wet bulb temperatures until the moisture content of the lumber is reduced to about 10 percent by weight of the oven-dry wood, and thereafter slightly decreasing the dry bulb temperature while maintaining the wet bulb temperature at the further increased level whereby additional removal of moisture may be accomplished at a decelerated rate and distribution of moisture remaining in the lumber may be equalized.

3. A process for drying unseasoned lumber comprising the steps of enclosing unseasoned lumber in a confined zone under controlled conditions of dry bulb temperature, wet bulb temperature and total pressure of the zone atmosphere, the initial conditions being substantially the same as those outside the confined zone, increasing the dry bulb temperature of the zone atmosphere to a point substantially above the boiling point of water at the prevailing total pressure in the zone while simultaneously increasing the wet bulb temperature and holding some wet bulb depression but less than approximately 15 percent of the dry bulb temperature, varying the partial vapor pressure in the zone so that the surface temperature of the lumber is lower than the boiling point of water at the prevailing vapor pressure within the zone whereby the lumber increases in temperature and a film of moisture deposits upon the surface thereof but no removal of moisture therefrom occurs, maintaining these conditions until the lumber and moisture contained therein are uniformly heated to a temperature which exceeds the boiling point of water at the partial vapor pressure in said zone, whereby evaporation of moisture from the lumber begins, increasing the dry bulb temperature of the zone atmosphere to a point at least 15 percent greater than the boiling point of water at the prevailing total pressure in the zone while simultaneously increasing the wet bulb temperature to accelerate and control the rate of moisture removal from the lumber and to replace heat lost due to evaporation of moisture therefrom, varying the temperatures slightly to obtain no more than 25 percent differential in moisture content between the surface and center portions of the board of lumber, maintaining these increased dry bulb and wet bulb temperatures in the zone atmosphere until the moisture content in the lumber is reduced to any desired amount but greater than fiber-saturation and while maintaining the surface temperature of the lumber above the boiling point of water at the prevailing vapor pressure in the zone.

4. A process for the rapid drying of unseasoned lumber comprising the steps of enclosing unseasoned lumber in a confined zone under controlled conditions of dry bulb temperature, wet bulb temperature and total pressure of the zone atmosphere, the initial conditions being substantially the same as those outside the zone, increasing the dry bulb temperature of the zone atmosphere to a point near the boiling point of water at the prevailing total pressure in the zone while simultaneously increasing the wet bulb temperature and holding some wet bulb depression but less than approximately 15 percent of the dry bulb temperature, varying the partial vapor pressure in the zone so that the surface temperature of the lumber is lower than the boiling point of water at the prevailing vapor pressure within the zone, whereby the lumber increases in temperature and a film of moisture deposits upon the surface thereof but no removal of moisture therefrom occurs, maintaining these controlled conditions until the lumber and moisture contained therein are uniformly heated to a temperature which exceeds the boiling point of water at the partial vapor pressure in said zone, whereby evaporation of moisture from the lumber begins, increasing the dry bulb temperature of the zone atmosphere to a point at least 15 percent greater than the boiling point of water at the prevailing total pressure in the zone while simultaneously increasing the wet bulb temperature to accelerate and control the rate of moisture removal from the lumber and to replace heat lost due to evaporation of moisture therefrom, varying the temperatures slightly to obtain no more than 25 percent differential in moisture content between the surface and center portions of the board of lumber, maintaining these increased dry bulb and wet bulb temperatures in the zone atmosphere until the moisture content in the lumber is reduced to an average of any desired amount but greater than fiber-saturation and while maintaining the surface temperature of the lumber above the boiling point of water at the prevailing vapor pressure in the zone, decreasing the dry bulb temperature of the zone atmosphere

to a point lower than the boiling point of water at the prevailing total pressure in the zone while simultaneously decreasing the wet bulb temperature and holding some wet bulb depression but less than approximately 15 percent of the dry bulb temperature and while continuing to maintain the surface temperature of the lumber higher than the boiling point of water at the prevailing vapor pressure in the zone, maintaining the reduced dry bulb and wet bulb temperatures in the zone atmosphere until the surface temperature of the lumber is near the boiling point of water at the prevailing vapor pressure in the zone whereupon evaporation of moisture from the lumber substantially ceases and distribution therein is substantially equalized, increasing the dry bulb temperature of the zone atmosphere to a point at least 15 percent greater than the boiling point of water at the prevailing total pressure in the zone while simultaneously increasing the wet bulb temperature to accelerate and control the rate of moisture removal from the lumber and to replace the heat lost due to evaporation of moisture therefrom, maintaining these further increased dry bulb and wet bulb temperatures until the moisture content of the lumber

is reduced to about 10 percent by weight of the oven-dry wood, and thereafter slightly decreasing the dry bulb temperature at the further increased level whereby additional removal of moisture may be accomplished at a decelerated rate and distribution of moisture remaining in the lumber may be equalized.

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