REVIEW OF INNOVATIVE DRYING METHODS

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INTRODUCTION

The drying of wood is the most energy intensive operation in forest products manufacturing, however, it is a necessary processing step to prevent in-service shrinkage, make wood gluable, prevent decay, decrease shipping weight, and improve machining and strength properties. There exist numerous drying methods for lumber that are not common to the Pacific Northwest, some of which could result in energy and/or cost savings for the forest products industry. The drying methods considered in this study are:

* dehumidification
* radio frequency
* microwave
* solvent
* vapor recompression
* press
* vacuum
* boiling in oil
* infrared
* heat recovery
* peg substitution

In the past these methods have neither been cost effective nor even practical for drying Pacific Northwest softwoods, however, for some operating situations some of these methods could be effective. Situations that could make these methods more attractive include

* no existing boiler
* limited boiler capacity
* boiler needs replacing
* no wood waste available as boiler fuel
* limited availability of wood waste as boiler fuel
* no existing kilns
* high value loss of wood during conventional drying

Although a number of the innovative drying methods listed above depend heavily on the use of electricity as their main source of energy, because of their high efficiency of energy conversion for drying and the high capital cost if new boiler capacity is required, some of these methods can be cost effective for some conditions that exist in today's business environment. Likewise, there are a number of other situations that can also make these drying methods cost effective.

This report covers only a discussion of various nonconventional drying methods in terms of their technical development and applicability. This report was done in preparation for a comprehensive study on the technical and economic feasibility of using a nonconventional method for commercially drying lumber in the Pacific Northwest. Our intent is to identify the most likely innovative drying method and then to conduct a demonstration project for the selected method to establish its commercial feasibility. These later results will be presented in subsequent report.

PRESENT DRYING PRACTICES

The amount of water that needs to be evaporated from lumber is sizable. To dry MBF (thousand board feet) of Douglas-fir lumber from 45 to 15% moisture content requires that 675 lbs. or approximately 81 gallons of water must be evaporated. To remove the desired amount of water requires heat, which translates into dollars. Table 1 shows the cost of drying MBF of lumber for various fuel sources. The calculations were based on the assumption that it takes 2,000 Btu's to evaporate 1 lb. of water in a commercial drying operation. This value can range to 3,000 Btu's per lb. of water if the dryer is old and/or poorly maintained.

Table 1. The cost of drying lumber and veneer using various fuel sources.

	Energy[2]	Fuel costs ($)[1]		
	(MMBTU)	Wood[3]	Oil	Gas
Lumber (MBF)	1.35	1.41	7.96	8.41

To avoid drying defects, kiln schedules have been developed to dry lumber as fast as possible without excessive stresses developing in the wood. These schedules usually start at a low temperature and high relative humidity and end with a more severe condition. An equalization period is then used to allow all of the lumber in the kiln to reach a similar moisture content. This is sometimes followed by a humid conditioning period in which casehardening is eliminated. A typical schedule for clear Douglas-fir starts at 160°F and a 10 to 20°F wet-bulb depression and climbs to 180 or 190°F with a 30 to 50°F wet-bulb depression by the end of the schedule. Drying may take three days for studs or seven days for clear dimension lumber. Approximately 80 percent of the Pacific Northwest mills use this type of conventional schedule. Approximately 20% of the mills in the Pacific Northwest use a high temperature schedule in which kiln temperatures are set at 205-240°F. This type of schedule is most often used for 2x4 dimension and studs. The result is drying times on the order of 24 to 40 hours, and degrade is increased (Bramhall and Wellwood, 1976).

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[1] Assumes conversion efficiencies of 66, 80 and 76% for wood, oil and gas, respectively. Fuel costs are for July 1984.

[2] Assumes 2,000 Btu's per lb. water

[3] Based on $20 per unit of Douglas-fir sawdust

Detailed information on drying and kiln operation may be found in Rasmussen (1961). In addition, a report in Bramhall and Wellwood (1976) contains similar information but is oriented more towards Western lumber production.

ENERGY USE COMPARISONS FOR VARIOUS KILN TYPES

One way of seeing the potential of these new methods for drying lumber is to compare their energy use for drying a board foot (BF) of lumber. A comparison is provided in Table 2. Although energy use is only one component in the cost of drying lumber, its relative consumption can provide some insight. Admittedly the cost of the energy source is also important in calculating the over-all drying cost. The energy use values given for the various methods were obtained from the literature or from the equipment manufacturer.

Table 2. Energy-based comparison of several kiln types.

Drying method	Energy Source (BTU/BF)		
	Electric[1]	Thermal	Total
Conventional	161	2,045	2,206
Dehumidification System A	546	none	546
Dehumidification System B	768	none	768
Dehumidification System C	1,188	none	1,188
Dehumidification System D	768	none	768
Vacuum System A	1,500	none	1,500
Vacuum System B	1,155	1,432	2,587
RF/Vacuum	1,500	none	1,500
Vapor Recompression	717	764	1,481

[1] kwh = 3,415 Btu's

DESCRIPTION OF NONCONVENTIONAL DRYING METHODS

All of the drying methods mentioned in the Introduction section have been used to dry wood. Each has advantages but in many cases the advantages are outweighed by the disadvantages. In this section, each method will be discussed in terms of its advantages, disadvantages, and practicality for drying softwood lumber in the Pacific Northwest.

Dehumidification kilns

In conventional lumber drying the vapor pressure of the water in the wood is increased by raising its temperature. The difference in vapor pressure between the wood and the air drives the moisture out of the wood. A dehumidification dry kiln lowers the vapor pressure of water in the air to establish the moisture gradient which acts as the driving mechanism to cause the water to leave the wood.

In dehumidification drying a heat pump is used to extract water from the air. This process is shown in Figure 1. Warm, moist air from the kiln passes through the evaporator, water condenses, and the air is cooled. This air then passes through the condenser, is reheated, and returned to the kiln. The working fluid, a refrigerant such as R-12 or R-114, is a hot pressurized vapor as it leaves the compressor. In the condenser it cools and condenses to a vapor-liquid mixture. It then passes through an expansion valve which regulates the flow rate, causes a pressure drop, and causes further cooling and condensation. The cooled fluid enters the evaporator and is heated and vaporized. The vapor is then compressed (a temperature increase accompanies compression) and repeats the cycle. No air is vented from the kiln unless the system starts to get sufficiently hot to damage the equipment. Supplemental heating, usually electric, is used during start-up to take the charge to 80°F and, if necessary, during later drying.

Significant advantages in energy consumption are obtained using a dehumidification system because all of the latent heat is recovered from the water being evaporated from the wood. The significance of this can be seen in Figure 2 where the total energy in a pound of water vapor at a low dryer temperature is diagrammed. The shaded portion represents the latent heat, or the heat which results from a phase change from a liquid to a vapor, and the remainder is the sensible heat due to the temperature change from ambient to the kiln temperature. A dehumidification system recovers the shaded portion. Equipment manufacturers claim that the capital cost of a dehumidification kiln may be as little as half that of a similar sized conventional kiln. They are very simple to operate and consume from a quarter to half the energy as does a conventional kiln. The energy used is all electric, thus, no boiler is required, which is particularly advantageous for a small mill or if additional boiler capacity is needed. Because the system operates at a low temperature, almost no degrade occurs.

The disadvantage of a dehumidification system lies mainly in the time required for drying. This may be twice as long as a conventional system due to the lower temperatures (120-140°F). However, dehumidification systems are being marketed lately that operate at 160-200°F, with drying schedules similar to conventional kiln drying. Start-up of dehumidification dryers is slow and should be supplemented with a heating system, usually electrical resistant heater. Drying to low moisture contents can also be slow. Both of these problems originate because water has to be evaporated before the heat pump begins to heat the kiln air at a sufficient rate to maintain temperature. When lumber is cool during startup or at a low wood moisture content, the evaporation rate is low. Also, heat pumps operate more efficiently in a given temperature range. During startup, operation is hindered because the dryer is below this temperature.

It is important to note that technology developments in heat pumps and working fluids in the past few years by companies such as Westinghouse have led to operating temperatures up to 225°F. At the higher temperature the efficiency of the dehumidification dryer decreases, construction costs increase because the kiln must be built to withstand the higher temperature, and the lower degrade characteristic of dehumidification drying ceases to be an advantage. However, the lumber does dry as fast as when conventionally dried.

Dehumidification kilns are in fairly common use in Europe and Asia. In North America numerous units are operating, mainly in the East, but recently dehumidification drying seems to be catching on in the West. The majority of the operations using dehumidification drying are hardwood manufacturers where the drying time is necessarily slow (3-40 days) to prevent degrade. In softwood production drying is done much more quickly (2 to 7 days) and dehumidification units are only now beginning to enter the market. A dehumidification kiln is being installed in Oregon to dry pine in a 180 MBF capacity kiln with a 3-1/2 day drying schedule. Newer designs capable of higher temperatures are improving the practicality of drying softwood lumber with dehumidification systems. However, a poor reputation exists for dehumidification drying due to early units which did not live up to manufacturers' claims and a name which is somewhat synonymous with dehumidification drying -- low temperature drying.

Ceck and Phaff (1978) compared dehumidification drying of spruce studs to conventional drying. Times were nearly twice as long at a dehumidification drying temperature of 93°F as they were at the 150 to 180°F temperatures of a conventional kiln. Degrade was similar in each case but the dehumidification system consumed one half as much energy. Chen and Helmer (1982) have done an excellent job of describing the principles of dehumidification lumber drying.

A dehumidification system could be practical for drying Northwest softwoods. Since the basic operation is really very similar to a conventional kiln, the main factor governing its practicality will be the cost of drying.

Drying in Steam Under Pressure

Drying defects occur in wood because the moisture gradients which are necessary to move the water to the surface of the wood cause various parts of the wood to shrink differently. If this differential shrinkage is large, stresses in the wood become too great and the wood fails, thus developing checks, honeycomb, and collapse. Drying stresses are conventionally reduced by lowering the kiln temperature. This, however, causes the rate of moisture diffusion to decrease, thereby extending the drying time. To maintain a high kiln temperature and rapid diffusion while minimizing the severity of moisture gradients, Rosen (1981, 1983) dried lumber in superheated steam. This method of drying has also been used in Sweden for pulp where it halved the drying costs (Suarez, 1980).

Several advantages become apparent when analyzing this drying method. Figure 3 is a plot of the equilibrium moisture content (EMC) of wood in superheated steam at various temperatures and pressures. At high temperatures an increase in the pressure causes the EMC to increase, thus reducing the drying stresses while maintaining a high diffusion rate. In addition, the heated air is not vented which in a conventional kiln may account for 20 to 30% of the energy consumption. Also, conditioning can be accomplished more quickly at the higher temperature.

The disadvantages of such a system include the need for a pressure vessel and the corrosion which might be more prevalent at higher temperatures. Wood strength and chemical changes caused by the high temperature are not well known. In addition, the extra energy consumed by the fans offsets the energy savings gained by not venting the air.

Rosen (1981, 1983) dried several hardwood species in steam at temperatures of 240 to 280°F and pressures of 16 to 30 psi. He concludes that nonrefractory species can be dried and the stresses relieved in 24 to 48 hours. Air-dried refractory woods can also be dried. The product is darker than conventionally dried lumber and degrade is less than 3 percent of the total charge value. Greater checking occurs near knots and mineral streaks are more frequent. Based on an economic analysis of a 2 MMBF per year operation, he concludes that drying costs for pressure steam drying are similar to conventional drying. A more complete economic analysis is presently being conducted by Idaho State University.

This method is difficult to compare to conventional drying because the equipment to steam dry lumber only exists on a laboratory scale. It does, however, seem that it could be used to dry softwood lumber or veneer.

Vapor recompression

To utilize the energy contained in the water vapor leaving the wood, a technique was patented by Justus in 1960 whereby the vapor is compressed and fed through a heating coil located in the dryer. The compression stage increases the temperature of the vapor which allows a temperature difference to exist between the heating coil and the kiln. In the heating coil the vapor condenses, gives up its latent heat, and leaves the process as hot water. This is similar to a heat pump except that the working fluid, in this case water, is not revaporized.

As an example of the energy to be recovered, consider a steam environment dryer operating at one atmosphere. The condition of the vapor in the dryer is given by the points 1, 2, and 3 in Figure 4. Compression of the steam occurs isentropically and the conditions of the compressed vapor are given at point 2 assuming a ratio of 5 between the pressure at point 1 and 2. As the compressed vapor goes through the heating coil, the temperature decreases and condensation occurs all at a constant pressure (in Figure 4, this change is from point 2 to point 3). The temperature difference across the heating coil is the temperature of point 3 minus the temperature of 126°F at point 1. The input of work required for compression from state 1 to state 2 is the enthalpy difference, 142 Btu's/lb. The heat obtained from cooling and condensation is taken as the enthalpy at state 2 minus the enthalpy at state 3 for a value of 1,018 Btu's/lb. The ratio of the heat-out to the work-in is a measure of the efficiency similar to the COP (coefficient of performance) for a heat pump. In the example, this value for efficiency is 7.2. If the ratio of P_2 to P_1 had been 2, the heat to work ratio would have been 18. This illustrates that as the compression ratio decreases the efficiency increases, which appears to be very advantageous. However, with a compression ratio of 2, the temperature difference across the heating coil is only 68°F so a larger heating coil would be required. Realistically the cost of electrical energy for the compressor would have to be compared to the cost of generating thermal energy to heat the kiln and this would lower the COP by a factor of 2 to 5. The optimum arrangement would be determined based on cost estimates for operation at various pressures.

The advantages of this system lie in its ability to efficiently recover heat. Vapor recompression systems have been used to feed steam heated cylinders in paper dryers using vent vapors (Choudhuring and Chance, 1975), to recover heat from evaporators, and to dry timber. Miller (1977) shows that a 65% energy savings can be realized through vapor recompression during timber drying. He makes no cost comparisons, however. For drying timber this system could be used advantageously when operated in conjunction with the steam dryer previously described. The disadvantages of a vapor recompression system are numerous. First, a drying environment which contains no noncondensible gases (air) must be maintained. This requires that the kiln be purged with steam during start-up and that tight seals be maintained. Any air leaking into the kiln will seriously decrease heat transfer in the coil and consume compressor energy. In addition, any water vapor leaking out of the kiln will carry out its latent heat. Compressor control is somewhat difficult because to maintain a constant kiln pressure only as much vapor may be compressed as leaves the wood. This compressor may have to operate at 750°F which would require special construction. In addition, the vapor entering the compressor may contain volatiles from the wood which could be corrosive.

Since vapor recompression is not used for lumber drying, a legitimate cost comparison is difficult. In any event, it could not be used on a conventional kiln without considerable modification to the kiln and the kiln schedule.

Radio Frequency

Heating materials with electromagnetic radiation, called dielectric heating, can be done at a number of frequencies which are usually separated into the radio and microwave frequency ranges. The energy transfer to the material is caused by the oscillating electric field interacting with molecular diopoles and ionic species. Because water has a strong permanent dipole, it is heated very readily in an alternating electronic field. This is advantageous for selectively heating water in materials of uneven moisture such as veneer and for drying hygroscopic materials to low moisture contents.

The radio frequency range is usually considered to be between 1 and 100 MHz in the electromagnetic spectrum. In the forest products industry this type of energy has been used to set adhesives in wood joints and for drying paper. More recently veneer and lumber have been dried in radio frequency dryers. The simplest way to envision a radio frequency heater is to imagine the materials being heated between two plates which are attached to a frequency generator, as shown in Figure 5a. The plates and the material to be dried are essentially a capacitor, the frequency of which must be tuned to match the generator. This can be done by adjusting the plate distance or by adjusting another inductor or capacitor in the circuit. Heating occurs because dipoles and ions oscillate and ions migrate through the body. This in effect, is a current flow and the associated resistance causes heating dependent on the loss factor, temperature, and moisture content of the material. The loss factor is a material property which describes the material's ability to be heated by the electric field. For thinner materials the other electrode arrangements shown in Figure 5b or c may be advantageous but the heating principles are the same.

One of the main advantages of a radio frequency dryer is its ability to selectively heat water more than the surrounding material. This is important in drying a hygroscopic material such as wood to a low moisture content. At low moisture contents, heat transfer through the material from the surface becomes more difficult to accomplish. Radio frequency generates the necessary heat internally, eliminating a slow step in the drying process.

Selectively heating water is also an advantage in an operation such as a veneer redryer or paper dryer where an uneven moisture profile may exist. For these applications radio frequency dryers have been shown to effectively level out uneven moisture distributions in the product (Joas and Chance, 1975).

The plant space required for a radio frequency dryer is less than for a hot air dryer, the weight is less so foundations are less costly, and no boiler is needed, a very important point if the boiler is already working at capacity or if no boiler is present. Depending on the specific application of this equipment, the operating and maintenance costs may be lower. The largest disadvantage is the installation cost, partly because of design considerations and partly because of the complexity of the equipment. As more radio frequency dryers come on line these costs may decrease.

Some work, such as that of James and Hamill (1965), has been done to determine the dielectric properties of wood. Other work's have examined the effect of time, energy consumption, degrade, and moisture profiles on radio frequency drying. Miller (1971, 1973) developed a radio frequency process in which dryer control is based on the air dry-bulb, air wet-bulb, and lumber surface temperature. A quarter of the time was required to dry 2-inch thick white spruce with radio frequency compared to conventional schedules, and degrade was minimal. He concludes that most wood can be dried in a radio frequency unit using available kiln schedules. If the species is prone to collapse, the schedule may need to be modified. Simpson (1980) dried 24-inch lengths of 4/4 red oak in a 5 kw radio frequency dryer. Moisture profiles, power consumption, and degrade were considered. He concludes that drying from 80 to 25% moisture content in 15 minutes was fast, but that boards dried to a moisture content lower than this exhibited obvious degrade and that radio frequency drying has potential as a predrying process to be followed by drying at a lower temperature.

Harris and Taras (1984) compared radio frequency/vacuum drying to conventional drying using end-matched samples of red oak. They found the moisture and stress profiles during drying to be similar in each case, although they were steeper for the radio frequency/vacuum method (RFV). The RFV process dried the wood in 1/17th the time and had 30 percent less shrinkage. In a similar study Lee and Harris (1984) compared RFV to dehumidification drying and found drying times of 60 hours and 35 days, respectively. The mechanical properties were similar but the specific gravity and equilibrium moisture contents were slightly different.

Radio frequency drying seems to have its greatest potential with a high value product, for example a hardwood species for furniture production. It also has potential as a redry system for veneer where selective heating of the wet spots is desirable. The available systems were compared to conventional drying.

Microwave

Microwave drying systems are the second generation of dielectric heating. In concept, microwave heaters operate in a manner similar to radio frequency dryers except they utilize a much higher frequency, in the range of 500 to 5000 MHz. The higher frequency allows a much higher rate of energy transfer to the material, however, as the frequency increases the depth of penetration into the material decreases. Rather than being between charged plates, microwaves are generated with a magnetron or a klystron. Wave guides are used to contain the microwave and deliver them to the material.

Like radio frequency, microwave dryers selectively heat water which makes them ideal for drying to even moisture profiles and to low moisture contents. The design of microwave dryers is somewhat complex, which contributes to their high initial cost. Dryer design considerations include wave reflection, distribution, penetration, attenuation, and power dissipation. The basic limitation to the microwave drying of non-conducting materials is cost. Generally, there must be some good reason to install this type of dryer. Considerations are often based on space savings, product quality improvements, or increase plant throughput.

Paper, lumber, and veneer have all been dried with microwaves using laboratory or pilot plant equipment. Hankin et al. (1970) tested a 30 kw unit for moisture leveling in a pilot fourdrinier paper machine. Depending on the paper properties the results were favorable. He estimates that a reduction in web moisture content from 15 to 8% would increase production by 4.5% and result in a 30% return on investment. Favorable laboratory results were obtained by Resch et al. (1970) when they redried veneer in a 50 kw microwave dryer with a 20 pass folded wave guide. The redried veneer was not over dried, remained flexible and was at least as gluable as hot air redried veneer. McAlister and Resch (1971) dried 1-inch thick ponderosa pine in a variable wattage microwave device in combination with and without hot air. They concluded that the method works to dry but there is a trade-off between microwave input and drying time. Charring, internal checking, and casehardening resulted if the drying rate was excessive. Barnes et al. (1976) developed a continuous drying system for lumber which utilized microwave energy. A low level of degrade was obtained with drying times of 5 to 10 hours for ten foot two-by-eights. Hot air was used but they state that its only advantage was to prevent heat loss from the wood. They further state that a microwave drying system for lumber would most likely be advantageous when the wood has a low moisture content, is prone to degrade, or has a high inventory value. More recently Olson and Arganbright (1983) dried sweetgum veneer with microwave energy and impinging hot air. They noted that drying uniformity peaked at a given microwave level, above and below which drying was less even. Drying variations between the heartwood and sapwood were observed.

Like radio frequency dryers, a microwave system may have good potential in certain situations. No systems are designed to dry lumber on a commercial scale, but, veneer has been redried with microwave energy. Cost comparisons for this case were not made because no commercial systems have been developed for lumber.

Press Drying

Press drying can best be described as the application of heat to opposite faces of a piece of wood by platens. Pressures of 25 to 100 psi provide good thermal contact between the platens and the wood. The temperatures used range from 250 to 450°F. Air in the wood expands and moisture vaporizes, moves to the surface, and escapes through ventilated cauls.

The advantages of press drying, besides the excellent heat transfer to the surface, include reduced width shrinkage and increased flatness in the veneer or lumber. If the material is quarter sawn, checking is reduced. The disadvantages are a darkening of the wood surface, high shrinkage in thickness, and increased checking in flat sawn lumber.

Hittmeier et al. (1968) press dried 1/2-inch thick hardwood and softwood pallet material to 4 to 6% moisture in 25 to 75 minutes. One inch material required 100 to 200 minutes. Refractory wood showed severe honeycombing. Cyclic shrinking and swelling indicated increased dimensional stability in the thickness direction. Turkia and Haygreen (1968) achieved similar results with aspen sapwood. Presently work is being conducted at the Forest Products Laboratory in Madison, Wisconsin, on the press drying of red oak (Simpson, 1984). Sapwood has been dried with success when it is quarter sawn, however, excessive checking occurs in flat sawn material. Breaking a log down to achieve mostly quarter sawn pieces seriously hurts recovery. Perhaps the only commercial operation in the world which press dries lumber is located in Denmark. They utilize small-diameter, low-quality beech logs. The beech wood is bucked to 2 foot lengths and the sapwood part is press dried in a multiple opening plywood press. The product is used for flooring. One of the major problems they have is the formation of tyloses in wood that is not dried soon enough after cutting. Some plywood operations use press drying for their redry operation but no information could be obtained on these. The Weyerhaeuser Company has developed a press drying system for veneer which they call the Wey-Dry system. At least three installations have been made. They claim that the veneer is flat, there are no dryer fires, recovery is increased 10 to 15 percent, gluing is improved, drying is fast (4 to 8 minutes), and energy consumption is reduced up to 50 percent. Presently, only one or two of the systems is in use.

Comparing press drying to conventional drying for lumber would be difficult since no commercial systems are being marketed. Press drying of veneer has been compared to a conventional system. For veneer, press drying seems like it would have a greater potential than for lumber because when a thinner material is dried an increase in the surface heat transfer coefficient has a more dramatic effect on the drying rate.

Infrared

Infrared radiant heat energy is an electromagnetic radiation of a wavelength longer than visible light energy but shorter than radio waves, and which lie between 0.7 and 1000 um. Generally, a heat source greater than 2500°F is needed to generate infrared energy for heating. Electrically, this is done with incandescent tungston filaments in globular lamps and translucent quartz tubes. These operate at around 4000°F compared to 4700°F for lamps used for lighting purposes. Infrared energy can also be generated from gas heated metal tubes.

Infrared systems are advantageous when heat needs to be transferred to an object's surface. For lumber drying, this can be damaging since a steep moisture gradient is established which results in severe surface checking. For veneer, gas-fired infrared heaters have been added at the wet-end of conventional convection dryiers. They were designed to heat the green veneer at 75 to 100°F as it entered the dryer. This allowed a 10 to 15% greater dryer throughput. This is the only application that was found for drying lumber of veneer by infrared techniques.

Vacuum Drying

In a vacuum dryer the boiling point of the water is lowered by lowering the pressure of the air. For example if a vacuum of 28.9 inches of mercury exists in a chamber containing a piece of wood, the water in the wood will boil at 80°F. At this temperature, the wood is not weakened and less degrade should occur. However, the large latent heat associated with this boiling would cool the wood and slow the drying rate. Heating the wood prior to applying the vacuum is limited by the amount of heat which can be stored in the wood and by the transfer of heat to the wood while it is in a vacuum, which is difficult to do by convection. For these reasons it has been proposed that alternating cycles of vacuum and heating or radio frequency heating be used. A couple of commercial scale systems exist for drying lumber under a vacuum.

Boiling in oily liquids

Excellent transfer of heat to the wood surface may be obtained by submerging the wood in a hot oil. At high wood moisture contents, steam leaving the surface of the wood helps to protect the wood from the severe drying condition of the oil. As the wood dries out, this protection no longer exists. The commercial use of this drying method has been restricted to conditioning timber prior to a preservation treatment.

Numerous disadvantages prevent the commercial use of hot oily liquids for drying lumber. There is a very uneven moisture profile at the end of drying, and casehardening is severe with no means for relief. Checking, honeycombing, and collapse are difficult to prevent. A significant portion of the oil is retained by the wood. And lastly, the oil is usually inflammable, resulting in an increased fire danger.

Vapor Drying

Vapor drying consists of exposing the wood to a hot organic vapor. The water in the wood evaporates into the vapor, both are removed from the drying chamber, condensed, and separated by gravity.

The advantage of the method is fast seasoning. Oak crossties can be dried to 40% moisture content in 12 to 16 hours, whereas air seasoning takes 12 to 15 months. Many small checks develop rather than a few large checks and performance is comparable to steam or air-dried material. The disadvantages in vapor drying are similar to boiling in oil.

Solvent Drying

Removing water from wood by most processes requires large amounts of energy to vaporize the water. In solvent seasoning the water is "washed" out of the wood by another polar solvent such as acetone, then the mixture is distilled. By this method the wood resins can be recovered and the water does not have to be vaporized. Some solvent is lost. Unless there is a substantial increase in the selling price of the resins, however, the benefits do not justify the costs involved (Bramhall and Wellwood).

Boiling in oil, vapor drying, and solvent seasoning, like many drying methods may have a niche in the industry where they work effectively. However, it is very unlikely that these drying methods could be used for commercial western softwood production and they were not considered.

PEG Substitution

A unique method for preventing shrinkage in wood carvings is to soak the object in a solution of water and polyethylene glycol (PEG). During subsequent drying teh PEG remains in the wood and reduces shrinkage and drying defects. This is a very specialized method and would not be used commercially. It is mentioned as a matter of interest.

CONCLUSION

Some of the innovative drying methods discussed are in commercial use in the U.S. or the world, while others are in the pilot plant or laboratory stages of development. The opportunity appears to exist for some of these drying methods to find commercial applicability for drying lumber in the Pacific Northwest. The time appears to be ripe in terms of energy cost, lumber value, pollution considerations, capital cost, and existing technology for exploring the use of these innovative drying methods. Our intent is to follow-up this review with a comprehensive study of the technical and economic feasibility of innovative methods for drying lumber commercially in the Pacific Northwest. In addition, we intend to conduct a mill demonstration study of our prime candidate(s) to actually determine if the method is practical for commercially drying lumber. This report will be available at a later date.

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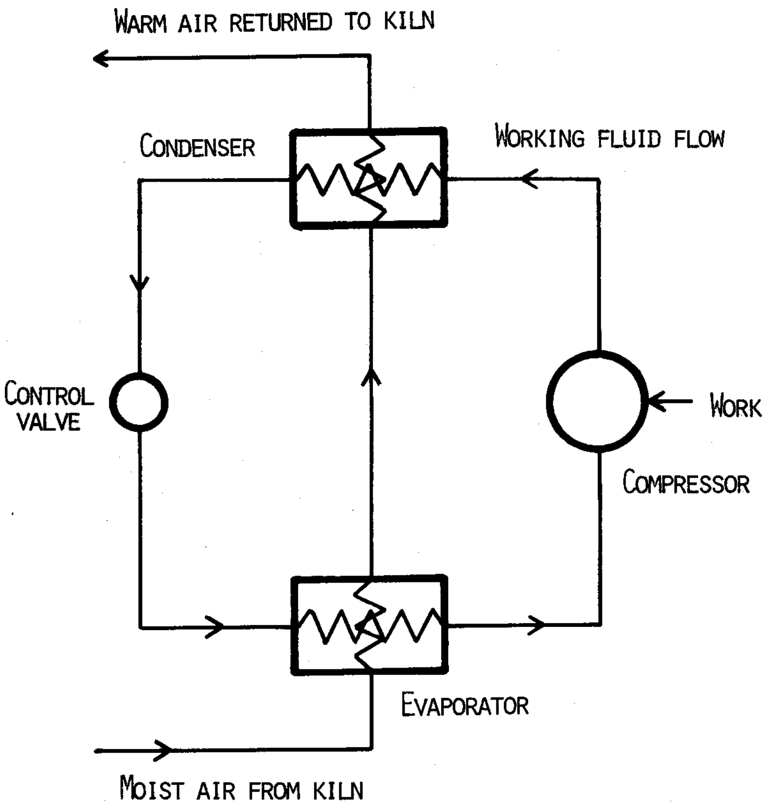


Figure 1. Schematic of kiln vapors and working fluid flows in a dehumidification dryer.

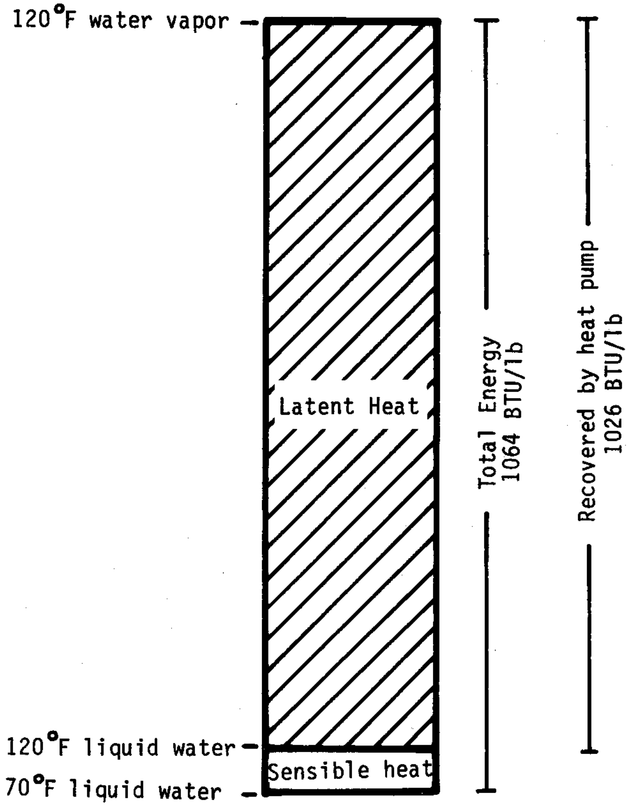


Figure 2. Energy in liquid and vapor water leaving the kiln at 120°F. A heat pump recovers the shade portion.

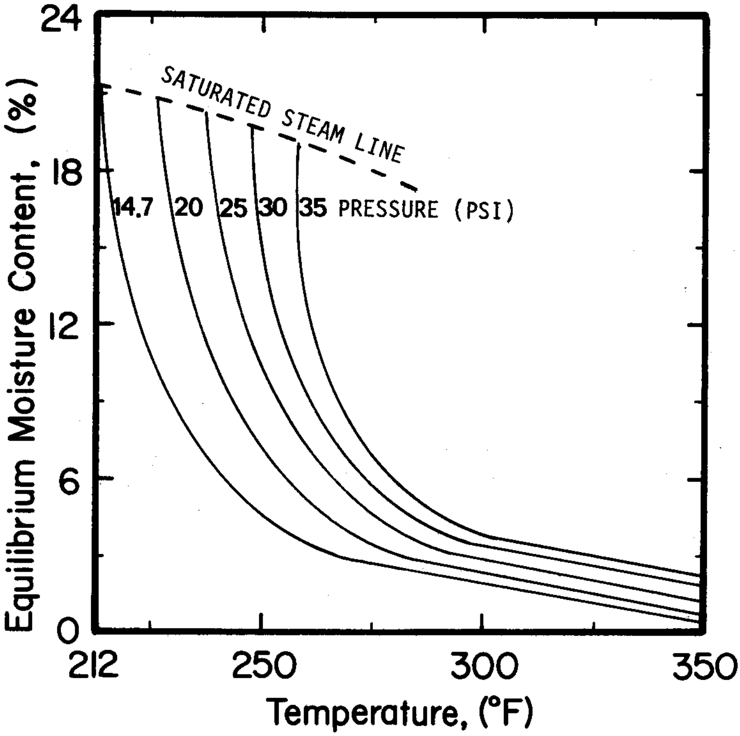
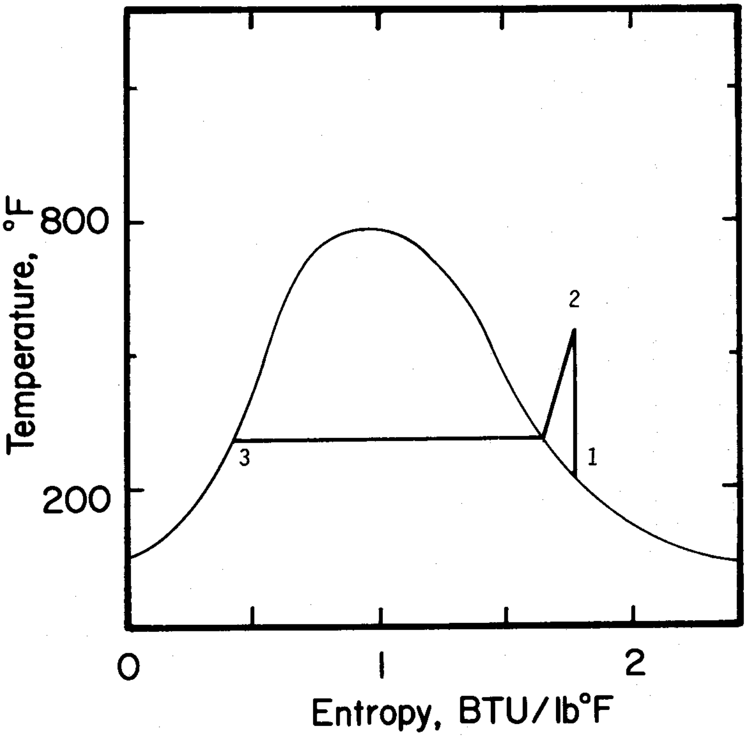


Figure 3. Equilibrium moisture content of wood versus temperature at various pressures (Rosen, 1983).



Point	Pressure psi	Temperature °F	Enthalpy BTU/lb	Entropy BTU/lb°F	State
1	14.7	212	1,151	1.758	Sat. Vapor
2	73.5	526	1,294	1.758	Super Heat
3	73.5	306	276	0.446	Sat. Liquid

Figure 4. Temperature entropy plot for vapor recompression heat recovery.

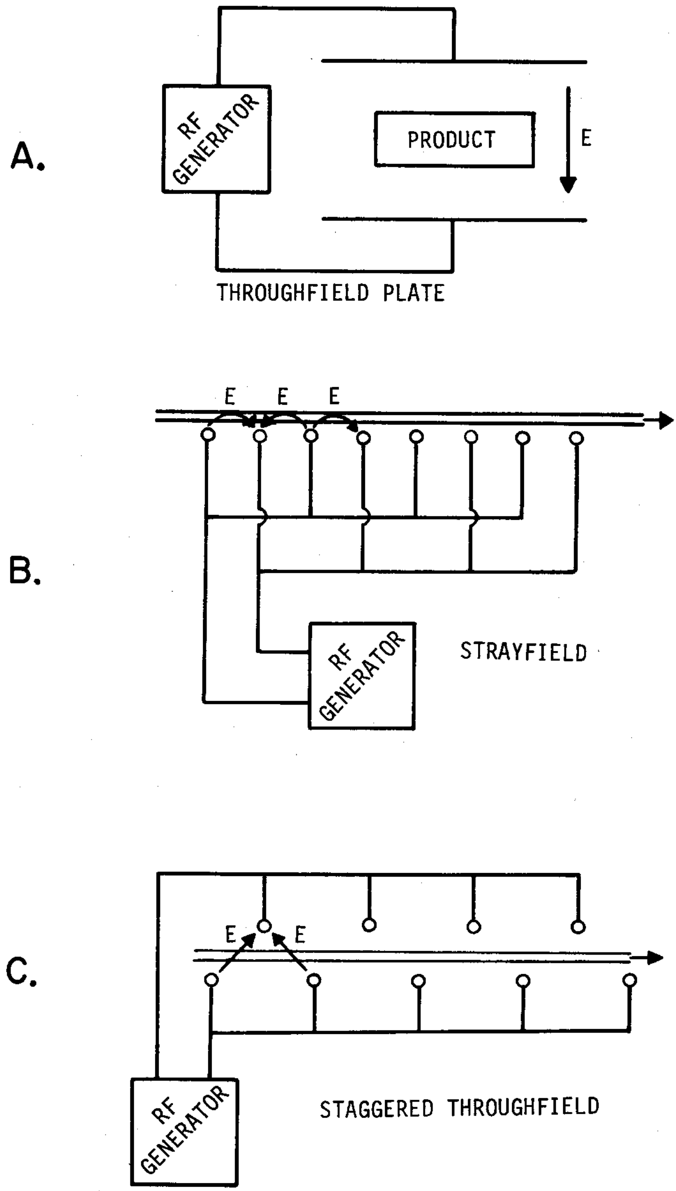


Figure 5. Various arrangements of radiofrequency electrodes used in industry.