COMMERCIAL RFV KILN DRYING - RECENT SUCCESSES

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Heat-and-vent kilns require considerable amounts of energy, a major portion of which is released into the atmosphere through ventilation and due to their relatively small capacity and the required long drying times in order to achieve acceptable-enough high quality lumber, they constitute a classic "bottle-neck" production problem.

Radio frequency (RF) heating is a commercial operation that has found many applications over the last fifty years in various industrial production units, and in many cases has replaced the less efficient and economic conventional methods. One of these operations is the drying of materials that contain large quantities of water, such as agricultural grains, ceramics, foodstuffs, textiles, paper products and wood.

When an RF field is combined with vacuum, temperature and pressure gradients develop in both the longitudinal and transverse lumber directions. Moisture is driven out rapidly in both liquid and gas phase during the initial stages of drying. These gradients also increase the rate of bound water diffusion at moisture contents below the fiber saturation point. With careful control, the drying process can be accelerated without the quality of the dried lumber being seriously affected. Furthermore, leveling out of uneven moisture content distribution in the lumber has also been credited to the RF drying method.

Before the 1990s, some studies on the RF/air and RF/V drying of wood had been carried out mostly with hardwoods and a few softwoods. The RF/V studies were carried out with an earlier generation commercial dryer manufactured in the US circa 1970's (Harris and Tarras 1984; Lee and Harris 1984; Waengert and Lamb 1982). The results of those studies were quite good concerning drying times and final wood quality, but it was even then quite clear that much more work was needed to understand the process and then design better and more efficient hardware for large production volumes of high quality fiber, and optimized drying schedules for various wood species, timber thickness and cross-sectional shapes. Thus, a major research initiative started at the University of British Columbia (Avramidis and Zwick 1996) in collaboration with the local forest products industry and the support of the Canadian federal government in 1989 parts of which are still ongoing. It is the objective of this paper to briefly discuss the current successes experienced with a new RFV dry kiln technology located in Castlegar, British Columbia.

Radio Frequency/Vacuum Drying Principles

During RFV drying, wood is placed inside a vacuum chamber (Figure 1) with an applicator (between two metal electrode plates). As the electromagnetic waves penetrate green wood, thermal energy is generated. The intensity of this heating does not depend on the dimensions of the lumber or wood thermal conductivity. This volumetric heating is the most important feature that distinguishes RF from other heating methods, such as conventional kiln drying in which thermal energy is supplied through convective heat transfer (Figure 2).

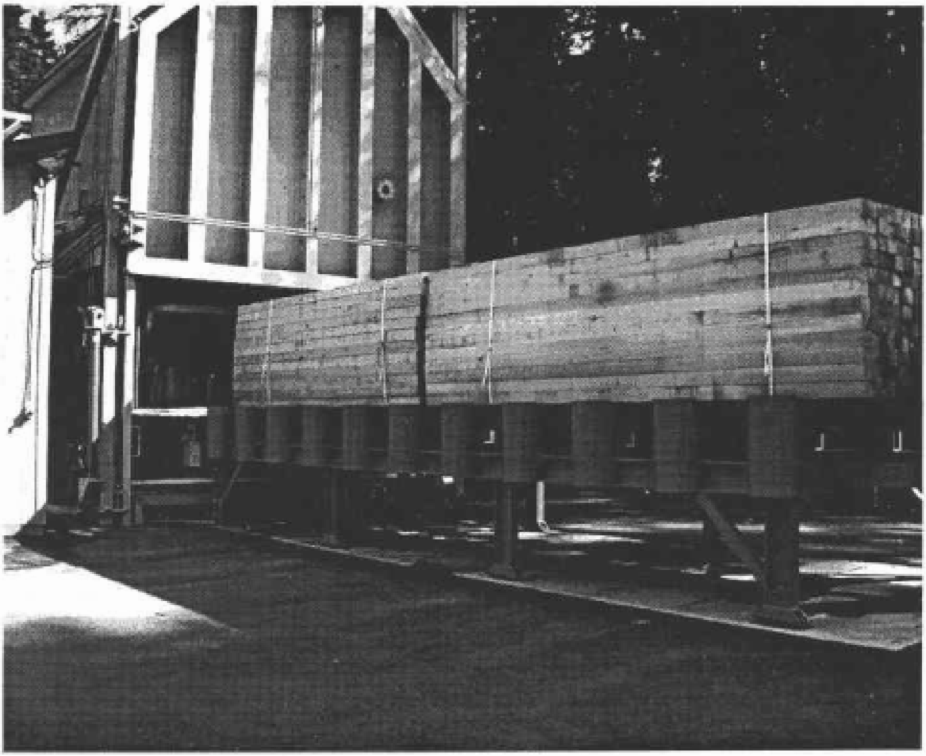


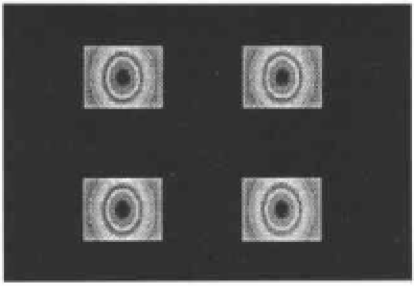
FIGURE 1. Picture of RFV kiln .

The reduction of pressure inside a vacuum chamber reduces the boiling point of water. This method is commonly called radio frequency vacuum (RFV) drying and the principal attraction is that the drying process temperature can be considerably lower than that used in kiln conventional drying, thus reducing the occurrence of drying defects combined with the considerably faster drying times.

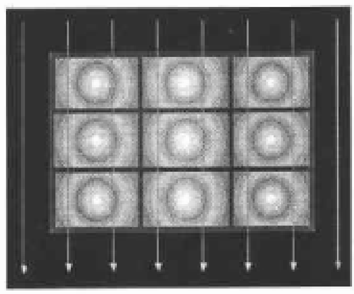
RF heating is considered as volumetric heat transfer where thermal energy is produced simultaneously throughout a pile of lumber placed in an electromagnetic field. Because of this phenomenon, there are no steep temperature profiles formed and transfer of moisture from the center areas towards the surface of wood begins immediately upon exposure to the field. There is no need for heating elements (non-contact process) between each layer or lumber stickering, thus reducing handling costs. Furthermore, the rate of heating is a function of the electric field and the lumber dielectric characteristics and not the thickness of individual pieces of lumber.

In RFV drying, because of the simultaneous heat generation within the body of a drying piece of lumber and the piling method (no stickers), the temperature and moisture gradients develop from the center to the surface. Furthermore, because of the high vapor pressures reached in a very short time throughout, free water in both liquid and vapor phase is "pushed" primarily along the longitudinal direction of the wood (path of least resistance) which happens to be the length of a piece of lumber, and where bulk flow is very fast due to very high longitudinal permeability coefficients since longitudinal-to-transverse permeability ratio of over 10,000 (assuming zero grain angle). As a result,

RF Is A FUNDAMENTALLY Different Mode Of Heat Transfer



Heating from the "OUTSIDE IN" is characteristic to conductive, convective, microwave and radiative heat transfer.



RF uniformly heats the wood from the surface to the core and is characterized as volumetric heat transfer.

FIGURE 2. Heat transfer modes.

most of the moisture at levels above the fiber saturation point flows lengthwise and exits from the end surfaces of the lumber (Avramidis and Zwick 1992). Below the fiber saturation point, moisture transfer by inter-gas and bound diffusion is still faster compared to conventional drying because the respective coefficients are still much greater in the longitudinal than in the transverse direction (longitudinal-to-transverse ratio of diffusion coefficients range between 2 and 100) (Siau 1984).

This simplified mass transfer mechanism description is in reality much more complicated if variables such as natural wood variability in moisture content, permeability, shrinkage, and fiber deviations, just to name a few, within and between pieces of lumber are taken into consideration.

The new generation commercial RF/V dryer

The chamber is made of coated mild steel and has a rectangular cross section. It can accommodate a timber load of 1.5m high, 2.5m wide and 10m long. The dryer has a patented material handling system to allow for easy and quick loading of the lumber packages. In addition, there is a patented RF connection system that eliminates the need to physically attach the electrode to complete the electrical connection (as opposed to earlier systems).

There are two horizontal aluminum electrodes, namely the ground electrode (bottom) and the "hot" electrode (top). There is a compression loading system on the top electrode capable of supplying 1100 kN (250,000 lb) onto the wood packages.

The vacuum system can lower the ambient pressure to about 2.66 kPa (0.4 psi) and the RF power is provided by a proprietary amplifier designed to a rated output of 150 kW. Since the load capacity was about 30m^3, this type of RF dryer had the "30.150" designation which allows for a maximum power density of 5 kW/m^3. The power amplifier technology allows the system to determine the average moisture content of the kiln charge, known as an "end point" detection feature, which is another patented innovation. Power amplifier technology allows for absolute control of the RF power, thereby eliminating the risks of the drying degrade know as internal honeycomb; something that has been commonly associated with earlier RFV drying technology.

This new dryer has been extensively used since the beginning of this year with various wood species and timber sizes. The new dryer has performed remarkably well compared to older-style RF generators using oscillator designs with the most striking effect being the reduction of energy use by about 40-50% (down to as low as 1.38 kWh/kg of water removed).

Testing of the "30.150" dryer continues with the drying of hardwood (temperate and tropical) species, utility poles and logs, and other wood products such as veneer and trim-ends.

Recent commercial RFV kiln drying successes – SOFTWOOD TIMBERS

The short RFV drying times of thick lumber (> 105 mm or 4" thick) in comparison to conventional or Superheated Steam Vacuum (SSV) kiln drying times translates to one of the more immediate opportunities for the lumber manufacturer. The results from recent drying runs at the commercial RFV kiln are shown in Table 1.

TABLE 1 – Timber drying economics in a 50 m^3 RFV kiln.

	4" D.fir 45% - 17%	**12" D.Fir Timbers** 45% - 17%	**12" Spruce Timbers** 35% - 17%	**12" Hemlock Timbers** 45% - 17%
RF into wood	75 kW	38 kW	75 kW	75 kW
Drying Time	67 hrs	134 hrs	38 hrs	60 hrs
Processing Rate	172 Mfbm/mo	76 Mfbm/mo	305 Mfbm/mo	191 Mfbm/mo
Total Electricity per Charge	10,000 kWh	13,400 kWh	5,760 kWh	8,960 kWh
Energy Cost @ 4.5¢/kWh	$454	$605	$259	$403
$ / Mfbm	$23.77	$31.70	$13.58	$21.13

It must be emphasized that these drying times are not absolute. RFV drying in many respects can be considered a new technology and RFV kiln schedule development work is still ongoing. Therefore, further improvements exist with drying times, RFV kiln productivity, and drying costs.

In addition to the impressive drying times, quality improvements have also been excellent. Timbers containing heart center (i.e., pith) exhibit no V-checking defects and timber distortion amounted to less than 15% of the pieces. In addition, there is an approximate 30% reduction in shrinkage compared to what is found in conventional kiln drying technologies.

The key defect that limits drying times for timbers is internal honeycomb. It is a result of the internal temperature and pressure conditions that are so high; the steam escapes the easiest path. Normally moisture movement for RFV drying is out the ends of the boards but if the internal pressure is too high, wood fibers rupture to allow the steam to escape. Uncontrolled heating causes internal honeycomb, which is a difficult defect to detect externally. Unless identified by the trained eye, it can only be found after resawing the lumber. Power amplifiers found in this new technology guarantees absolute RF power control and eliminate internal honeycomb defects from RFV drying.

Internal honeycomb can be controlled during RFV drying by taking into consideration 3 parameters:

- Power density (kW/m^3) or how much RF power is put in per cubic volume of wood.
- Wood permeability where for example, wood that is more "treatable" can accept a higher power density, i.e., white vs. red oak, SYP vs. D.fir.
- Lumber cross-section dimensions, where internal temperature and pressure conditions are higher with thicker lumber for the same RF power density and wood permeability.

Recent Commercial RFV Kiln Drying Successes –
RE-DRYING LUMBER or Q-Sift

One of the most significant opportunities uncovered with recent drying investigations is the RFV re-drying of lumber. The length of time for RFV drying is dependent not only on the RF power density, but the amount of water to remove from the kiln charge of wood. For an equivalent power density, removal of minimal percentage in moisture content results in substantially reduced drying times. RF heating is selective only with water content. This fundamentally different aspect of heat transfer can be exploited with an operating strategy discussed at the end of this paper, which can potentially revolutionize how wood is processed and dried in large lumber manufacturing installations. Table 2 is a comparison in drying times for various products at the same power density but with different amounts of water to remove.

Recent Commercial RFV Kiln Drying Successes – TRIM ENDS

Not requiring stickering of lumber creates an obvious opportunity for drying small pieces of lumber, namely trim ends. In this application, trim ends can be solid-stacked and dried thereby considerably reducing piece-handling operating costs. In addition, the type of drying conditions found in an RFV kiln results in no end-checks as opposed to more conventional methods of drying trim ends. Fingerjoined lumber recovery is therefore considerably higher. The commercial RFV kiln is at a fingerjoining facility where there were no incidents of glue failure or reduced strength characteristics of the

TABLE 2 – Re-dry economics in a 50 m3 RFV kiln.

	HemFir 22% - 17%	**SPF** 22% - 17%	**SYP** 22% - 17%	**Red Oak 4/4 or 8/4** 15% - 8%
RF into wood	150 kW	150 kW	150 kW	150 kW
Drying Time	5 hrs	5 hrs	7 hrs	13 hrs
Processing Rate	2.3 MMfbm/mo	2.3 MMfbm/mo	1.9 MMfbm/mo	970 Mfbm/mo
Total Electricity per Charge	1,300 kWh	1,300 kWh	1,700 kWh	3,200 kWh
Energy Cost @ 4.5¢/kWh	$60	$60	$75	$143
$ / Mfbm	$3.14	$3.14	$3.93	$7.48

fingerjoined boards as a result of the RFV kiln. Drying of green trim ends also is possible but RFV drying times are considerably longer due to the increased amount of water to remove (refer to the previous "Re-Drying" section). Table 3 provides a description of drying costs for trim ends.

TABLE 3 – Trim block drying economics in a 50 m3 RFV kiln.

	SPF Trim Ends 19% - 14%	**HemFir Clear Blocks** 16% - 10%	**SPF Green Trim Ends** 35% - 15%	**Aspen Trim Blocks** 50% - 10%
RF into wood	150 kW	150 kW	250 kW	250 kW
Drying Time	5 hrs	6 hrs	13 hrs	26 hrs
Processing Rate	3.0 MMfbm/mo	1.9 MMfbm/mo	1.2 MMfbm/mo	477 Mfbm/mo
Total Electricity per Charge	1,330 kWh	1,600 kWh	4,900 kWh	9,800 kWh
Energy Cost @ 4.5¢/kWh	$60	$72	$221	$442
$ / Mfbm	$2.42	$3.77	$11.57	$23.14

Recent Commercial RFV Kiln Drying Successes – VENEER

One of the more commercially accepted applications of RFV drying with the older 1970's - type of technology has been with green hardwood veneer. The veneer sheets can be solid-stacked and since the wood products are relatively thin in thickness, RF power density and internal honeycomb have not been issues with the older RF oscillator technology.

However, RF oscillators have a tendency to operate with great difficulty on wood at moisture contents less than 15%. Energy efficiency decreases and drying times unnecessarily increase. This is not the case with RF power amplifier technology. In addition, RF power amplifier technology allows RFV kilns to reach higher power densities compared to RF oscillators.

Grade recovery is extremely high with RFV veneer drying which justifies the operating and capital cost of RFV kilns for decorative green hardwood veneers. In the case of commodity plywood veneer, RFV re-drying is more suitable for this application. Below is a table that outlines veneer drying costs and times:

TABLE 4 – Veneer drying economics in a 50 m3 RFV kiln

	SPF 12% - 8%	**HemFir** 12% - 8%	**Aspen** 50% - 8%	**Red Oak** 70% - 8%
RF into wood	150 kW	150 kW	250 kW	250 kW
Drying Time	5 hrs	5 hrs	27 hrs	68 hrs
Processing Rate	1.9 MMft2/mo	1.9 MMft2/mo	305 Mft2/mo	114 Mft2/mo
Total Electricity per Charge	1,100 kWh	1,100 kWh	10,300 kWh	25,860 kWh
Energy Cost @ 4.5¢/kWh	$48	$48	$464	$1,164
$ / Mft^2	$0.30	$0.30	$2.91	$7.31

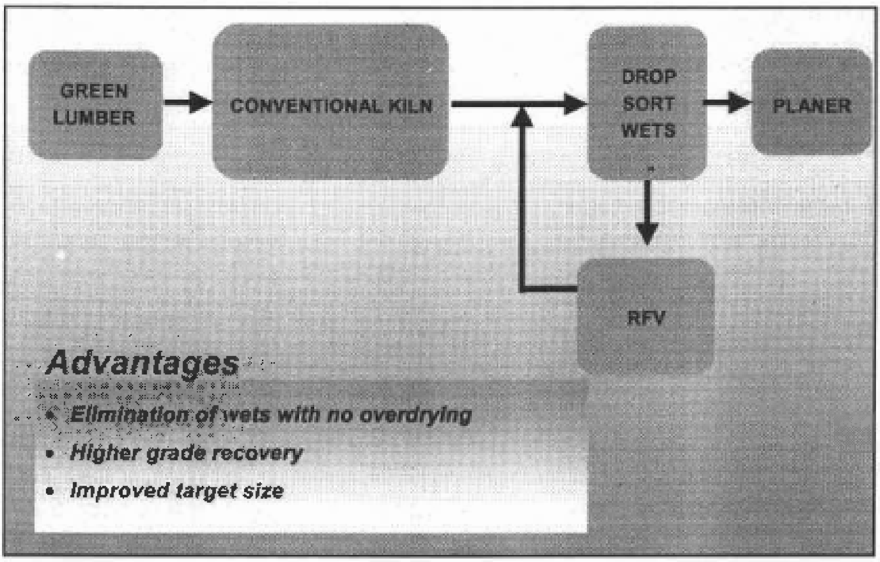
Q-Sift

One opportunity that RFV drying has to offer is making the process known as Q-Sift® viable. Milota revisited the issue of "post-drying" hemfir lumber (Milota and Wu 1995), a topic which was discussed at WDKA meetings over twenty years ago. As discussed in the re-dry section above, RFV drying times are very short, kiln productivity is very high, and commercial demonstrations are showing that RFV re-dry degrade is very low; especially when compared to re-drying by conventional methods.

One RFV kiln used for redry applications can process in the order of 2 million board feet of wets every month. This is considerably more than what a sawmill generates but what if there is now an economical solution to re-dry wet wood, what if one could generate more wets? Enough to keep a RFV kiln on a monthly basis?

For a 150 MMfbm/yr (354,000 m^3/yr) sawmill, one RFV kiln can be kept at full capacity by intentionally generating roughly 20% wet lumber through the conventional kilns. This also reduces drying times in the conventional kiln by 20%, thereby increasing the effective conventional kiln capacity at the sawmill as well! As discussed by and experienced in commercial trials at Castlegar, grade recovery substantially increases.

FIGURE 3. Q-Sift operating strategy.



Paybacks for a $2 million Q-Sift installation for a hemfir mill producing to the Japanese market are in the order 8 months (primarily because the price for "wet" lumber is so heavily discounted). For an ALS producer to the North American lumber market, paybacks are in the order of 12 months.

There is now a solution to the hemlock-drying problem as it relates to wet wood, grade recovery and drying times!

Conclusions

A newly developed commercial RFV drying technology has recently been showing that it is reliable, inexpensive to operate, highly productive for many applications, and has a broad range of applications. Not only does the specialty added-value manufacturer (timbers, hardwoods, etc.) now have a solution to many of their drying woes, studies have conclusively demonstrated there are also very strong paybacks for the conventional "2x4" lumber producer. Sawmills with a "wets" kin drying problem now have an economical solution based on integrating RFV kilns into an overall kiln drying strategy.

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