

# CURRENT STATUS OF RADIO FREQUENCY/VACUUM DRYING

Robert L. Zwick, M.A.Sc., P.Eng.  
HeatWave Drying Systems Ltd.  
Castlegar, B.C.

Stavros Avramidis, Ph.D.  
University of British Columbia  
Vancouver, B.C.

A significant amount of research has focused on Radio Frequency/Vacuum drying over the last few years in western Canada. Earlier work had shown (Avramidis and Zwick, 1992) that RF/V drying appeared to be independent of product thickness, and that moisture migration occurred out the ends of the pieces. This resulted in a large research project put together by the Council of Forest Industries of B.C. (COFI) which set out to build a prototype commercial-scale RF/V kiln. In addition, a small laboratory-scale RF/V kiln was built to explore the fundamental physics of RF/V drying (Avramidis et al., 1994). The COFI project was completed in 1994 and a comprehensive report is now available on the project results (Zwick, 1995).

RF/V drying has certainly been researched for several years. The Japanese have performed excellent basic and applied research work into RF/V drying for almost 20 years (Kanagawa, 1977). In addition, Harris and Taras (1984) investigated some of the fundamental aspects of RF/V drying in North America. Although RF/V drying has not become commonplace in the North American market place, it is generating interest amongst the lumber industry (Milota and Wengert, 1995). The Japanese on the other hand, have fully adopted RF/V drying technology; with over 150 RF/V kilns installed in Japan. One may consider this as being unusual, based on the extremely high electricity costs in Japan vis a vis North American energy costs. Shown in Figures 1 & 2 are time lines on the activity that has been done on RF/V drying of wood products.

circa	
1974	PowerDry Corp
1976	US Patent approved for PowerDry RF/V technology
1977	Fuji Corp. building RF/V kilns
1978	Kangawa doing basic research in Japan
1984	Harris and Taras reported results of their investigation
1989	COFI/MB Research investigation at Kill Buck, NY; SUNY investigation at Kill Buck, NY
1990	COFI/MBR investigation completed
1991	Financing obtained for COFI RF/V kiln project
1992	COFI RF/V kiln project started

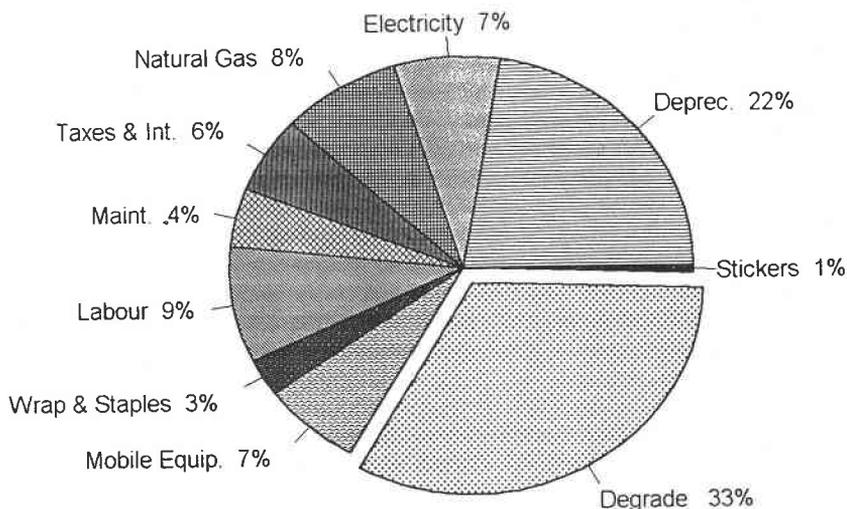
FIGURE 1. RF/V technology time line.

Jan. 1992	COFI RF/V kiln project started
July 1992	UBC laboratory RF/V kiln operating
Dec. 1993	COFI RF/V kiln started operation . After 10 runs, serious design deficiencies identified
Feb. 1994	RF/V kiln shut down after 47 runs. Marginal kiln schedule work done. Significant number of mechanical deficiencies addressed
Mar 1994	Computer simulations discover the reason for poor drying
May 1994	Redesigned, remanufactured and installed new electrodes
June 1994	RF/V kiln finally working properly, 8 more drying runs done: Hem-fir German windows, WRC 4"x 4", SPF trim blocks, D.fir 6"x RW timbers, Hemfir 6"x RW timbers, and Hemfir 4"x 4" baby squares
July 1994	Experimental program was stopped
Nov. 1994	Analysis of all data, final report finished for funding members
Nov. 1994	RF/V kiln shut down because tap water cannot be discharged
Mar. 1995	RF/V kiln sold to CanFor
Aug. 1995	RF/V kiln started with new environment discharge permit. Discussions with Fuji kilns - over 150 sold in Japan, 3 in N.A.
Feb. 1996	HeatWave Drying Systems incorporated, dedicated to the engineering and manufacturing of vacuum kilns
Present	Various investigations by CanFor, will be shut down in June

**FIGURE 2.** COFI RF/V kiln project time line.

The commercial viability of RF/V drying has been discussed in several recent papers. Smith et al (1996) gave a detailed economic analysis of RF/V drying for red oak squares. Recently, Avramidis and Zwick (1995) presented results from the COFI study. In both investigations, the RF/V drying process was shown to be economically viable in the case of products that had very long conventional dry kiln schedules. In general, the length of conventional dry kiln schedules are dependent on wood species, initial moisture content, product dimension, and product grade. RF/V drying schedules have much less dependency on product dimension and grade, but drying times are still strongly influenced by wood species (or specifically, wood permeability), and initial moisture content.

One of the biggest problems in establishing the economics of lumber drying, is to identify all the costs associated with drying and in particular, the cost of degrade. Shown in Figure 3, is a pie chart depicting the costs of drying high grade western hemlock, that also incorporates an estimate on the cost of degrade. An estimate of 7% by value of green lumber, was used as the degrade costs. This number was established by a COFI-commissioned study done by Carroll-Hatch International



**FIGURE 3.** Drying cost breakdown for conventional dried 4x4 clear hemlock. The estimated drying time is at least 28 days at a total cost of \$172/Mfbm.

(1991). Although limited data on degrade costs are available, other studies seemed to have confirmed that 7% degrade on clears in a conventional kiln was a realistic value (Zwick, 1995).

Shown below is a table that compiles the various investigations into drying degrade:

**TABLE 1:** Cost of degrade for dried in a conventional kiln

Description	% Value Degrade
Good Hemfir drying operation on merch lumber (from Carroll-Hatch, 1991)	5%
Hemfir drying operation on clear grades of lumber (final mc of 12%)	7%
Forintek SPF study (looking at over drying, based on value of dry lumber)	up to 11%
Forintek Hemfir study on baby squares (laboratory conditions)	4%
Dehumidifiers drying hemfir to a high target mc (resulting in >20% wets).	2% (est.)

Since the completion of the COFI RF/V kiln project, the prototype kiln was sold to Canfor Eburne Sawmills. The kiln has been used to investigate the RF/V drying of various products, and explore commercial opportunities with RF/V drying. For instance, Canfor has found that drying hemfir trim blocks in a RF/V resulted in a very high grade recovery, the lumber could be solid-packed going into the RF/V kiln, and the resulting RF/V-dried product all glued successfully at the fingerjoining plant.

Another opportunity uncovered by Canfor was an observation that the redrying of conventionally dried hemlock "wets" in a RF/V kiln, resulted in a dried product with an extremely uniform final moisture content and a near-perfect grade recovery (in excess of 99%). It is this opportunity that will be explored by the authors in this paper.

Improvement in grade recovery by redrying in a conventional kiln wet hemfir lumber was analyzed in detail by Milota and Wu (1995). In addition, their economic analysis indicated that redrying of wet lumber was a commercially viable option for a dry kiln operation. They also addressed the difficult topic of trying to quantify the impact over-drying has on grade recovery. Further work has to be done in this area, because of the limited research results available and the need for good numbers to do the economic analysis.

As discussed by Milota and Wu (1995), one of the main factors influencing degrade is over-dried lumber. Lumber in a kiln charge dried to a target moisture content, but with a large standard deviation, will have a portion of its population over-dried, and degraded - sometimes severely. This same lumber population may contain "wet" lumber that is at a moisture content too high to be acceptable to the customer. This is particularly true for drying hemfir and SPF, or when there is a final MC distribution with a large standard deviation due to poor drying practices.

Researchers have identified that there could be an economic opportunity to limit the amount of drying in a conventional kiln, thus ensuring a minimum amount of degrade. The option of presorting has been explored by Jamroz and Warren (1996). The other approach would be for one to accept a large population of wets, which could be subsequently dried in a conventional kiln (Milota et al., 1993, 1995) or in a RF/V kiln for full recovery. The economics of such a strategy with an RF/V kiln is currently being investigated.

Formulation of the problem to optimize the redrying strategy requires one to establish a Cost Objective Function (COF), and then determine what the minimum cost would be. This objective function can be solved by the variety of available management science techniques (Hillier and Lieberman, 1980).

The COF for drying is a function of:

$$\text{COF}_{\text{drying}} = \text{Fn (mobile equipment, wrap \& staples, labor, taxes \& interest payments, maintenance, natural gas (or other energy sources), electricity, stickers, depreciation, lumber degrade, plus a penalty cost on redrying wets)}$$

Establishing the feasibility of redrying requires one to focus on the degrade costs of the lumber dried in a conventional kiln. One approach for mathematically establishing degrade costs is to measure the value of green lumber before drying (based on the grade distribution) minus the value of lumber after it's been dried (based on the dried-lumber grade distribution, but still on the basis of green lumber values), divided by the original value of the green lumber. Quantifying degrade costs with this approach defuses the issue of trying to establish what the increase in value was for the dried lumber product, and is to a large extent independent to the vagaries of market prices or yearly inflation of costs. This non-parametric value is a function of final moisture content, measured from the population of conventionally dried wood. Milota and Wu (1995) proposed a linear cost function for degrade, based on the average moisture content of the lumber.

The next issue would be to identify a mathematical relationship of the final moisture content distribution, and to establish what percentage of that distribution are "wets". One such formulation was proposed by Zwick and Cook (1985). This work suggested that a three-parameter lognormal distribution characterizes the final moisture content distribution very well. This distribution has a location parameter (since the left-hand side of the tail is finite), a scale parameter and a shape parameter. The shape parameter, or second moment of the distribution, can be best characterized as a function of final moisture content since one always observes a decrease in standard deviation of the population as the lumber is dried to a progressively lower average moisture content.

Shown in Figure 4, is an example of two different log-normal distributions characterizing the final moisture content of conventionally dried hemfir lumber. After establishing what percentage of population exists as "wet" lumber, a penalty cost function can be applied against the "wets". This could then be incorporated into the COF. One could look at two different minimization strategies: accepting the "wets" as simply a cost of doing business; or to recover some value from the "wets" by redrying them. Certainly the value of the dried products plays a major role into what extent it is economically viable to redry the population of "wets".

## Conclusions

The redrying of "wets" in a RF/V kiln resulted in a minimal amount of rehandling, since the lumber did not have to be restickered. In the case of Canfor, the dressed lumber identified as being wet, was simply put into a sorting bin, restacked as a solid pile, run through the RF/V kiln, and then the package was shipped to the customer with no further processing by Canfor. The major product line done with such a RF/V redrying strategy was 3" hemfir German windows.

RF/V drying is still a commercial oddity, with some potential applications identified as a result of the COFI RF/V kiln project:

- timbers, large sections of lumber, and logs
- veneer (particularly decorative veneers and/or thick veneer)
- hardwoods (presently the most prevalent use of RF/V drying)

Recent Canfor investigations has shown that RF/V drying has the potential to be used on:

- drying of trim blocks for gluing/fingerjoining applications
- drying of "wets" from a conventional kiln charge; especially high-value wood

RF/V drying technology from the COFI project is only now being commercialized. HeatWave Drying Systems, Ltd. (Castlegar, B.C.) is a new company devoted to commercialize many of the above opportunities. A detailed mathematical cost analysis to establish the optimum redrying strategy is beyond the scope of this paper, but will be the subject of future discussions in this research area.

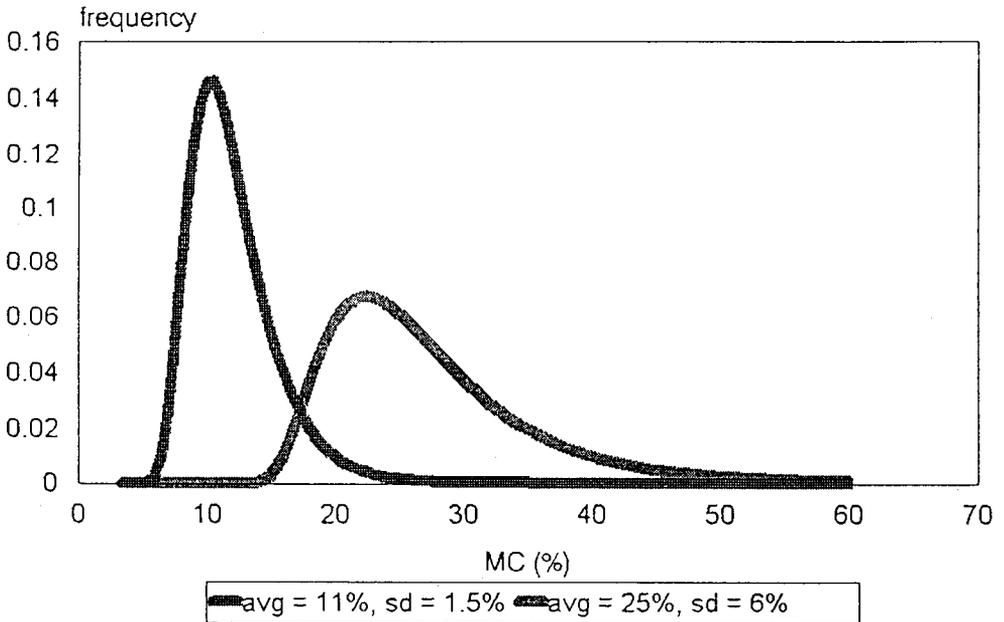


FIGURE 4. Moisture content distributions for hemfir dried to 2 different average moisture contents.

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