RECENT UPGRADES TO DEHUMIDIFICATION KILNS TO DRY SOFTWOOD LUMBER

Sita Millar (Warren)
AMEC
Vancouver, BC, Canada

Dehumidification Lumber Dry Kiln Operation

The conventional lumber dry kiln dries by circulating humid 200+ deg. F air through lumber stacked with spacers to allow the airflow. The kiln controls manage the humidity of kiln atmosphere by venting hot humid air, which is replaced by ambient air, to match a schedule selected for the characteristics of the kiln load – species, dimensions and moisture content primarily. The typical kiln is heated by steam from natural gas or waste wood fired boiler.

The conventional kiln is fairly simple to operate and low cost: about $3 million for a 150,000 board foot capacity setup. However, the continuous venting of hot humid air is inefficient, using 2-3 times the heat of vaporization of the water extracted. This requires about 5000 cu.ft. of natural gas / thousand board feet of lumber, which currently costs about $45, more than labor or capital amortization, to dry lumber worth $250-$500.

These kilns are very common – the softwood industry in North America employs about 8000 lumber dry kilns of an average 150 Mbdft capacity. The total kiln dried softwood production in North America is in excess of 100 million Mbdf, with a wholesale value of $40 billion. Only a small proportion of softwood kilns operate by dehumidification.

Hardwood kiln numbers are greater, perhaps 10,000 in North America, although the amount of lumber produced is an order of magnitude less, because they are typically much smaller and their throughput a fraction of a softwood kiln as hardwood must be dried more slowly. A significant fraction are dehumidification kilns.

Figure 1 shows a simplified schematic of a dehumidification kiln. You will note that it is very similar to the familiar conventional lumber dry kiln. The kiln atmosphere is circulated through the kiln load by the primary circulation fans, heating the load and carrying away the evaporated moisture content.

You will note two major differences – there are no heating coils and no vents shown in this simplified picture. This is an over simplification, as many dehumidification kilns have direct fired air heaters or steam coils to bring the kiln and load up to temperature. During this heat-up phase and at other times in the drying schedule, the amount of moisture released may exceed the capacity of the dehumidification system, and venting may be required, so all dehumidification kiln have venting provisions, but these are not fundamental to the dehumidification kiln operation.

The dehumidification kiln dries wood in a closed system. The dehumidification system condenses the excess moisture in the kiln atmosphere to hold the desired wet bulb depression (relative humidity). The heat removed in condensing this moisture, plus the energy adsorbed by the dehumidification system motors, is returned to the kiln atmosphere by the heating coils. The process is identical to a home dehumidifier, air flows over a cold condensing coil followed by a heating coil, but in a dehumidification kiln the heat energy is not wasted, it is returned to the kiln atmosphere to heat the load and evaporate more moisture.

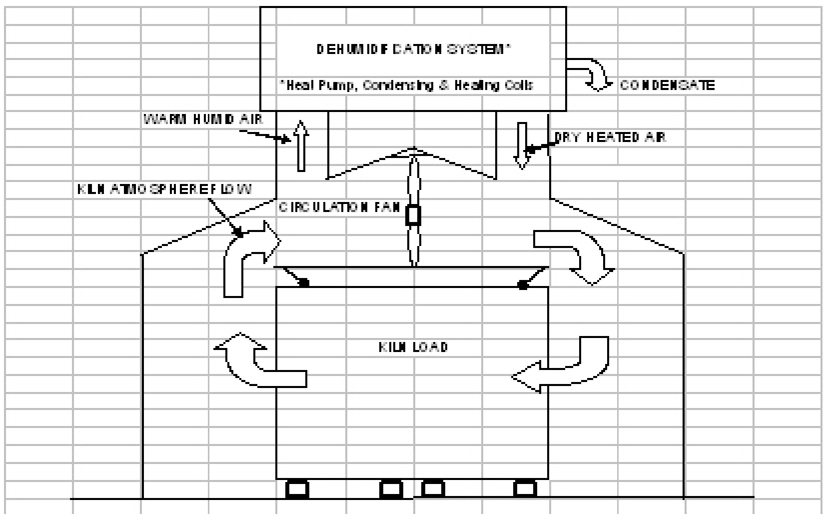

FIGURE 1. Simplified diagram of dehumidification lumber dry kiln.

The dehumidification system is not detailed here, but it basically consists of the condensing coil, the heating coil, and a heat pump that compresses and heats the working fluid, a specific compound or mixture of fluids that have thermodynamic properties suiting the application. The hot compressed fluid is cooled as it passes through the heating coil, releasing heat to the kiln atmosphere, and is then expanded, dropping the temperature enough to chill the condensing coil.

The original heat pump working fluids in HVAC applications, chlorofluorocarbons {CFC} (e.g., Freons™), have been replaced by more environmentally friendly HCFC (hydro-chloro-fluorocarbons), and these are also applied in dehumidification kilns, sometimes in proprietary blends with hydrocarbons or other compounds.

The dehumidification kiln's fundamental advantage compared to the conventional kiln is its energy efficiency. In a well designed and operated dehumidification kiln, through most of the schedule, there should be no venting of hot and humid kiln atmosphere. All of the energy captured in condensing the moisture removed from the kiln atmosphere is recycled back to the kiln atmosphere and the load.

In a conventional lumber dry kiln, all of the energy used to evaporate the charge moisture content is lost through the vents, plus the energy required to heat the air intake to replace the vented atmosphere and heat loss through the kilns walls, etc.

Dehumidification Lumber Dry Kiln: Expected Advantages

Dehumidification kilns provide other significant advantages in hardwood drying, and we expected to see these in evaluating their application to softwood drying. An early demonstration that this applies to softwood drying was the conversion of a 230 Mbdf hem-fir kiln to dehumidification at Cornett Lumber Co. at Central Point Oregon in 1987.

The history of the use of dehumidification kilns in drying difficult hardwood species, where the precision control and closed system meet high quality requirements, is said to carry over to softwood drying. Part of this may come from the lower drying temperature and temperature, but understanding this was part of or research agenda.

We had another question, in a closed cycle dehumidification kiln, what happens to the VOCs (volatile organic compounds) that wood releases in drying? In a conventional kiln, these are vented with the kiln atmosphere, a growing environmental concern in some jurisdictions. Might the bulk be condensed on the cooling coil, and end up conveniently captured in the condensate? If not condensable, do VOCs accumulate in the kiln to dangerous levels (as some feared)? Hardwood drying had no such problems, but this might surface in more rapid softwood drying.

Was the amount of VOC released lower at the lower operating temperature of a dehumidification kiln? This would be consistent with some laboratory findings.

Dehumidification Lumber Dry Kiln: Known Disadvantages

So, why are dehumidification kilns not commonly used? Why would anyone use a fundamentally less efficient type of kiln?

The first reason cited is always the cost of the dehumidification equipment, and a higher operation and maintenance cost as a result of the mechanical complexity. At least part of this disadvantage would be mitigated if the dehumidification kiln did not need a boiler for steam heat and conditioning, and we are told that modern heat pumps have greatly advanced in reliability and economy due to widespread adoption in the HVAC industry.

The second is differentials in energy costs. Conventional kilns get most of their energy from natural gas, or wood waste, until recently dirt cheap compared to the electricity that derives the dehumidification kiln heat pump. This is changing but will always depend on local factors, but the differential is expected to continue to narrow.

Commonly available heat pump working fluids break down above 160 ^{0}F, 40+ ^{0}F below the temperatures usually considered to be optimal for drying softwood lumber. Alternatives are available for high temperature processes, but are less well understood and available.

CFC and HCFC working fluids are costly and have environmental dangers as potent greenhouse gasses and in degrading the ozone layer. Restrictions on use of these fluids (manufacture of CFC's is banned) and the resultant need for care in maintenance are significant concerns.

Despite all these concerns, as the above pictures of dehumidification kiln installations and equipment in larger kilns shows, the size is not unreasonable and the complexity not overwhelming. With higher drying rates, the equipment must get larger, but the costs are helped by widespread use of heat pumps in industrial processes and air conditioning.

Above all, with rising energy costs and increasing demand for higher lumber quality, plus environmental concerns, this field deserved more investigation.

DH Kiln Field Trial: Description

So we embarked on a study of the potential for use of dehumidification kilns in high volume dimension lumber drying. This was to quantify the energy savings and determine the benefits in controlling environmental pollution. We wanted to understand the tradeoffs between dehumidification and conventional kilns, including the options to equip the latter with heat recovery units for improved energy efficiency and the application of regenerative thermal (or catalytic) oxidation to mitigate VOC emissions.

What changes might be needed to dehumidification equipment to suit the higher drying rate of dimension lumber? What is the optimal temperature for dehumidification drying of dimension lumber? What other process changes might be beneficial? Were suitable components (working fluid, pumps…) available? Our first stop was Custom Dry Kiln, who already had some dehumidification kiln installations at operations drying high value softwoods, installations of sizes in size range of dimension lumber kilns.

Together we found mills that were willing to allow us to conduct trials and collect information on their dehumidification kiln operation. While neither we nor the mills had the funds to measure all the parameters we would like to see, Custom Dry Kiln made a special flow meter to measure the condensate flow, which worked like a charm with few problems (once we got the bugs out) and we were given access to all available (and quite considerable) records of the kilns' operation.

The primary site had a complex of kilns (300 Mbdft capacity) serviced by a central machine house. We concentrated our investigation on one of the 50 Mbdft kilns, drying cedar lumber. Another site provided limited supplemental data on SPF drying. Extra data (moisture content samples, grading before & after) was collected on 3 loads, and we were able to collect samples of the kiln atmosphere (the number was constrained by the high cost of lab analysis of these samples – the world needs an accurate, robust instrument to measure VOC concentrations continuously in situ - and many samples of condensate throughout the drying schedule.

Full production, electrical production and natural gas usage records for the year prior to our trials enabled us to baseline the energy efficiency of the operation.

The typical drying schedule was 14 days (we saw longer and shorter) and we had to be present each day to collect samples, when and the kiln operation demanded. So we had plenty of opportunity to understand the details of the operation of a real dehumidification kiln. Much was learned on all sides. Figure 2 shows the 50 Mbdft kiln with the machinery house on the roof, the compressor bank serving all four kilns, and the process of collecting condensate samples.

FIGURE 2. Equipment at dehumidification kiln trial.

The scheduling of the first trial coincided with another commitment, so we lost a few days data. Nevertheless, the general picture is apparent. After a couple of days of heat up and steaming the dehumidification system was turned on, and a high flow of condensate was established. By the end of the week this fell off, similar to the drying rate of a conventional kiln, and maintained a much lower flow (Figure 3).

Note: DH kilns often use gas heat for heat up and initial drying stages, operating just like a conventional kiln. The higher energy consumption is offset against faster drying and increased productivity. Steaming, as here, may be used as a precaution against degrade due to moisture content variation within the load.

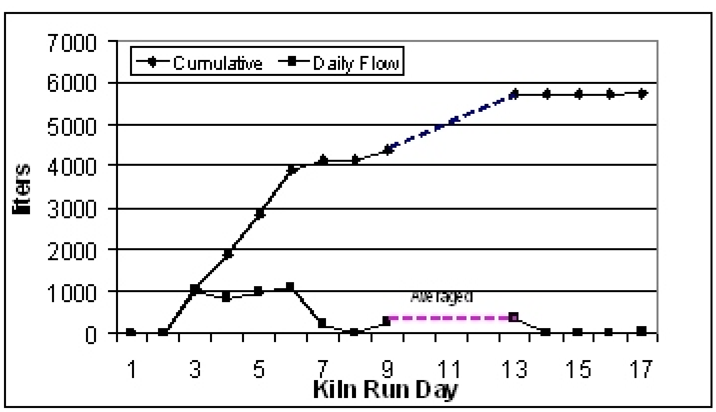

FIGURE 3. Condensate daily flow and cumulative amount for run #1.

Figure 4 shows the first measurements of speciated extractives concentration in dehumidification kiln condensate from drying Western redcedar. Total hexane levels were measured about 300 milligram/liter throughout the drying schedule, but in the speciated results only thujaplicans were significant and these fell off rapidly below 100 milligram/liter. This is typical of the atmospheric emissions profile measured in trials on conventional kilns.

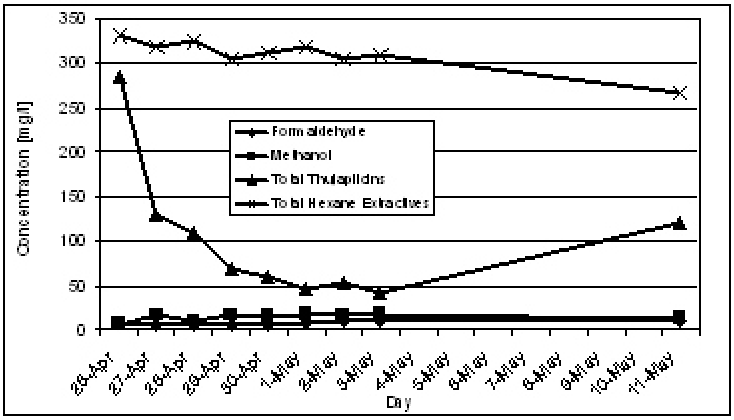

FIGURE 4. Extractives concentration in kiln condensate for run #1.

Further speciation of the extractives content reveals that isopropyl alcohol is the major component, with lower concentrations of thujaplicins. The concentration profile remains the same.

The results from the other two (shorter) drying trials were similar, although extractive concentrations were significantly lower.

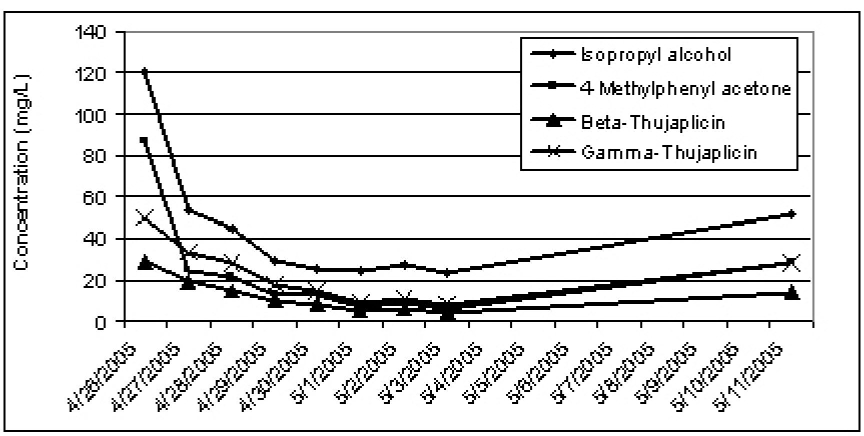

FIGURE 5. Extractives in condensate speciated by gas chromatography for run #1.

Power Consumption

The energy usage during this first trial was fairly constant, but all we could measure was the aggregate of all four kilns, the electrical use was not metered at the individual kiln level. Note that some electricity went to the electric boiler providing conditioning steam.

The estimated use by the 50 Mbdft kiln was about 1000 KW-Hr/day.

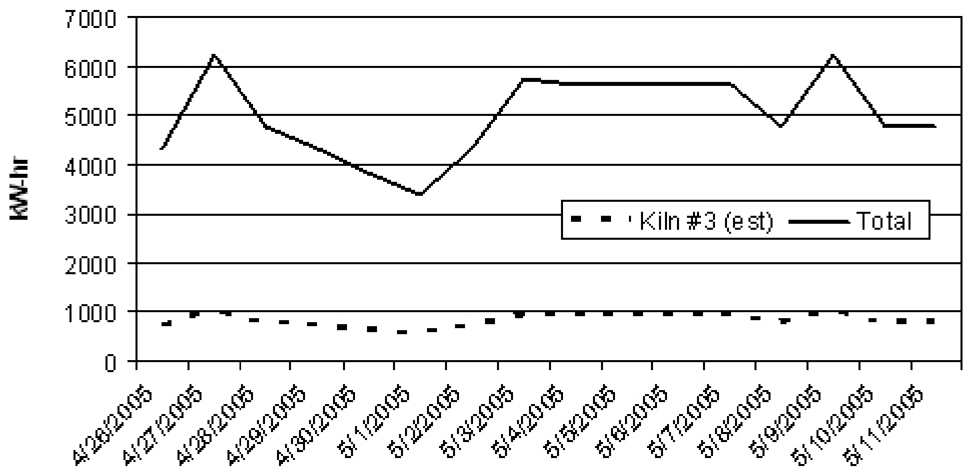

FIGURE 6. Electrical power use for trial #1. Data is for total usage by 4 dh kilns (300 mbft).

To get a better handle on the energy consumption of the dehumidification kiln complex, we were provided a full years records of both electrical power demand and natural gas consumption. The mill estimates that the kilns take 65% of the natural gas, thus more energy came from natural gas than electricity in drying an estimated 7.5 million board feet of cedar over the year. The indicated energy usage is thus 2.1 GJ/Mbdft, somewhat higher than expected.

However, note that the electrical usage is less than half of this, including the usage in generating steam. The excess energy is in the form of natural gas, used only in the heat-up when the kiln is operating essentially in a conventional mode with considerable venting.

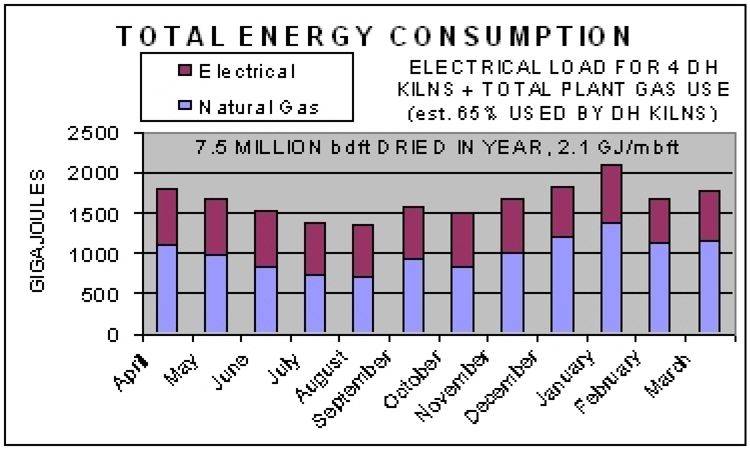

FIGURE 7. Energy use over a one year period.

What Did We Learn from These Trials?

The energy efficiency of dehumidification kilns is better than comparable results from conventional dry kilns, and especially so if adjusted for the prolonged careful drying used with the high value product dried in these kilns.

Half of the energy consumption was natural gas use during the heat-up and equalization, when the dehumidification system was not operating.

The results from the flow meter developed for these trials were excellent, the total condensate volume matched our estimate of the water removed from the lumber. Of course, we could not correct for the water added as steam during equalizing, or the compensating losses in venting, but the result was encouraging. The profile also looks as expected, high flow initially then tapering off.

The results presented here are unique in two aspects – these are the first measurements of extractive concentration in dehumidification kiln condensate while drying North American softwoods, and the first measurements of VOC released in drying Western red Cedar.

The VOC concentrations measured in the few kiln atmosphere samples obtained were surprisingly low, at 10 ppm, much lower than found in conventional kiln drying of other softwoods. The main constituent was methanol, and little of this was released to the atmosphere except during early venting.

The major extractives identified in the condensate were isopropyl alcohol, 4-methylphenyl acetone and various thujaplicins. Integrating the concentrations of extractive over the total condensate flow gave an estimated total release of 300 to 600 gm. for each thousand board feet, 1/10th of the atmospheric emissions of conventional kilns drying other softwoods.

However, private communication on results from laboratory drying of SPF from a Northwest mill showed similar low emissions

Upgrades to Dehumidification Kilns for Drying of Dimension Lumber

Based on these trials, we proposed the following design and operational updates to fully exploit the advantages of dehumidification drying:

1. It was noted that the airflow in the trial kiln was not very uniform, and this was attributed to distortions introduced by the separate dehumidification flow path. This would be unacceptable in high rate dimension lumber drying, so improved aerodynamic and system design is recommended.

2. The need for equalization, apparently a big energy consumer, could be reduced by sorting the loads for more uniform moisture content, where practical.

3. With increasing energy costs, more attention could be paid to minimizing heat losses, e.g., the ductwork forming the dehumidification flowpath could be better insulated.

4. The technology of high temperature heat pumps, e.g., high temperature working fluids, is common to many other industrial processes, esp. heat recovery. Collaboration to improve the capabilities, and our knowledge, of these systems is recommended.

5. Improved system designs could enable use of the heat pump during heat-up, when use of waste heat to boost the heat pump would pay big dividends.

6. Improved system and control designs could help to better balance the two primary demands: heat to evaporate the water in the wood and the heat extraction to condense the resultant humidity.

Acknowledgements

The work reported here could not have been accomplished without the encouragement and expert support of the following individuals: Dr. Brian O'Connor, Peter Harteveld, Dr. David Mackie, Paprican, Custom Dry Kiln Co., Ltd., AMEC.

Paprican performed all of the laboratory analysis reported. This is a complex demanding process, particularly the identification of the many (initially unknown) chemical species making up the volatile organic compounds released by wood as it is dried.

Custom Dry Kiln is a leading supplier of dehumidification kilns and dehumidification kiln equipment. They specialize in custom designs for high volume operations. AMEC is the world's largest engineering firm. It is headquartered in the U.K., but is a leading engineering consulting firm in North America. AMEC has long been a major supplier of engineering services to the international forests products industry, and also has a thriving environmental engineering practice.

<u>*Glossary:*</u>
dehumidification (DH); hydrochloroflourocarbon [HCFC]; chlorohydrocarbon [CFC]; heating, ventilating and air conditioning [HVAC]; hazardous organic pollutants (HAP); intellectual property (IP); regenerative thermal oxidization (RTO); regenerative catalytic oxidation (RCO); thousand board feet (Mbdf); volatile organic compounds (VOC)