FOREWORD

The know-how in kiln drying of lumber is based on a few major theoretical concepts, like: Moisture Content of Wood, EMC (Equilibrium Moisture Content), Dry and Wet Bulb Temperature, etc. Most of these concepts have already been reviewed theoretically in other seminars or in the literature.

These concepts provide good starting points to understand the mechanism of drying but have to be seen in their practical application, to be fully comprehended. It is quite amazing to notice how some theoretical key-concepts are completely different when looked at under a practical point of view.

Of course, this applies both to the drying of Hardwoods and Softwoods.
FOREWORD

In this presentation we shall indicate with the letter T the more theoretical aspects. With the letter P the practical considerations.

MOISTURE CONTENT OF WOOD

We all know the definition of Moisture Content of Wood (oven-dry sampling):

\[
\text{MC} = \frac{\text{Weight of wet wood} - \text{weight of dry wood}}{\text{Weight of dry wood}} \times 100
\]

The importance of MC is of course relevant to the drying process, to recognize when to stop the process but also - during drying - when to modify the climate parameters (MC controlled schedules).

Few of us have a precise knowledge of how much this MC value varies in the kiln, varies through the thickness of a board, varies often along the length of a board too.

MC varies because wood is a living material and as all living phenomena it has to be studied statistically by sampling.
MOISTURE CONTENT MEASUREMENT

For most of us, the only way to measure MC precisely is OVEN-DRY sampling, but do we know that during oven-drying, not only water evaporates, but also some other substances, and this can sometime result in abnormal MC values (higher than real)?

If we use the oven-dry sampling method during drying (sample boards), this will mean positioning the sample boards, in places easy to reach during drying. These places are of course limited to the stacks near the plenums. Are we sure that these boards represent the whole load, or are we not measuring a Moisture Content value which shall be lower than average?

Most dry kilns use now the electrical method to assess MC during drying. Also here, there are some practical considerations to be made:

First of all, MC can be measured electrically with reliability only below FSP (approx. 30%).

Above that limit, MC values are just a rough estimations: the error increases normally together with MC.
MOISTURE CONTENT MEASUREMENT

During drying, moisture content is different through the thickness (Moisture Gradient), higher in the core and approaching EMC on the surface. When we plant a MC probe in the wood we can measure three (or more) different MC values:

- 1/2 thickness: core MC, maximum MC
- 1/3 thickness (according to some authors 1/5 thickness): average MC
- 1/6 thickness (according to EDG recommendation): surface MC

Planting at half the thickness, to the core, might be considered more cautious (higher temperature in the kiln when ALL wood is below a certain MC); planting at one-third might be considered more appropriate, being the average MC but is more risky (change of climate sooner).

Resistive measurement of MC requires that the whole system (cables, jacks, probes) is in spick and span shape.

This means that cables should not be joint/spliced when cut but rather shortened (the signal is extremely weak and should not be altered).

The jacks and probes must not be oxidised.

All terminals should be screwed tightly.

Reduction in MC reading caused by negligence can be conspicuous (20-30% less).
There are other considerations to be made regarding the resistive measurement of MC. The electrical behaviour (conductivity/resistance) of wood varies according to the anatomy of the species and the substances contained in the cells. For simplification sake, Nardi (and other kiln manufacturers) subdivide wood in four measurement classes (wood group). These classes (or temperature compensation curves) derive from thousands and thousands of samples. Yet, there are some species that do not follow these curves precisely.

Last but not least, the conductivity and resistance of many species containing silica crystals, but also simply reaction wood, is not perfectly known and can be the cause for wrong MC reading.

To conclude, we come to two common questions:

- is it better to use 6 or 12 MC (or more) probes in a kiln?
- where and how should I plant the probes?

As with all statistical sampling, the issue is not the number of samples but the way they are picked (random, not biased), especially if our aim is estimating the average MC accurately. Of course the higher the sample size, the smaller the error.

The fact is that monitoring a drying process, sometimes implies other targets, rather than simply aiming at an average MC. Example: I wish that no board is wetter than 12% or I want that the MC deviation (or spread) is the lowest possible.

In the former case, I will have to look for the wettest boards where to plant the electrodes, in the second case, I will try to use a method to make my sampling as random as possible.
MOISTURE CONTENT MEASUREMENT

Also the position of the nails (pins) in the board needs some considerations:

A recent research made by the Finnish VTT, found out that the pins can be inserted in the board in all possible ways, giving always (approximately) the same result: across the wood fibre, along the wood fibres, on the face of the board, on the side of the board, at 3cm distance, at 1m distance.

Take care and watch out if the same board contains radial (quatersawn) and tangential (backsawn) material: the tangential part will dry much faster, leading to an unrealistic MC reading.

AIR HUMIDITY

Another key-concept in drying is of course the humidity of the air: the moister the air, the slower the drying - the drier the air the faster the drying.

It is of greatest importance to measure the humidity of the air circulating in the kiln accurately: this is normally performed in the following ways:

- using a psychrometer (wet and dry bulb);
- using an EMC (Equilibrium Moisture Content) wafer
- using an electronic sensor

Mistakes in the air-humidity measurement can provoke drying defects. How can we be sure we are reading air humidity it correctly?
AIR HUMIDITY

Psychrometer

According to most, the only accurate way to measure relative humidity seems to be by the psychrometric method (difference between dry and wet bulb temperature, or psychrometric drop).

In practice, a psychrometer needs an air flow of at least 2 m/s and this is not always the case in the kiln especially if the psychrometer is not adequately exposed to the air-circulation. In some cases it is necessary to install a small accessory fan near the wet sock.

Another crucial point in a psychrometer, is the sock (wet bulb). It is quite difficult to have one that does not dry out and decomposes in time. This means: the wet bulb goes up, the psychrometric drop becomes narrow, signifying high air-humidity, and the vents stay permanently open. This all means: drying defects.

AIR HUMIDITY

EMC Wafer

It is a good for us that wood and other hygroscopic substances, containing cellulose, dry down to a certain MC when placed in warm air (temperature) at a certain moisture (relative humidity). This means that we have a constant relation between MC, temperature and relative humidity. This has all already been discussed in previous seminars.
AIR HUMIDITY

EMC Wafer

The uncertainties of the EMC wafer are related to the fact that cellulose wafers react exactly like wood and therefore is characterised by:

- hygroscopic inertia and
- hysteresis

This all means that, however thin, the wafer will take some minutes (around 15-20 minutes) to react to the warm, humid air (inertia) and that it will behave differently when drying or absorbing humidity (hysteresis).

All studies have shown that there is a good correspondence between electronically read EMC and the Relative Humidity of the air but only within a certain range: 25-85% (20-90% at best) R.H.

AIR HUMIDITY

Electronic sensors

It is quite "fashionable" nowadays to install electronic sensors in the control system for the measurement of the air-humidity. The value is immediately expressed as relative humidity, with no need to desume it from complicated transformations through psychrometric drop or Equilibrium Moisture Content.

There seem to be up to now only two major drawbacks:

- the rather high price
- the fact that these sensors are still rather fragile and need repeated calibration.
Temperature is of course one of the major parameters regulating the drying process. It is an indication of the level of energy (thermal) in the system: wood + air + kiln.

Temperature can be measured in a number of ways. The most important are:

- mercury thermometer (used sometimes for verification purposes)
- resistivity temperature devices RTD, such as PT100
- thermocouples

We normally measure the temperature of the air in the kiln, in more than one spot.

Wood temperature used to be measured only in vacuum kilns, especially in discontinuous drying of hardwoods. The temperature gradient between core and surface was one of the parameters requested in the control system.

Wood temperature in normal conventional kilns is especially important nowadays for the heat treatment of packaging materials according to the F.A.O. standard ISPM 15. Wood packaging material, to circulate around the globe, has to be sterilized from obnoxious nematodes and other living organisms by bringing the temperature in the core up to 56°C for 30 minutes.
TEMPERATURE

The temperature factor is of great importance for the electronic control of the kiln: it is closely connected and compensates the MC or EMC reading (in other words, the reading of the electronic conductivity in wood or in the EMC wafer changes according to the temperature of the material).

The electronic control units made by Nardi and most of the competitors too, compensate the MC readings via the air-temperature.

In most cases, as both temperatures are actually close to each other, this will allow a sufficiently accurate reading of MC and EMC.

It would be better however to investigate what happens more closely and see what happens in practice.

During the rise in temperature, the temperature of the wood will normally be lower (sometimes much lower) than the temperature of the air circulating in the kiln. Wood behaves in a similar way as the wet bulb of the psychrometer.

This means that there is less electricity flowing in the wood than expected and the control will display lower values.

As MC readings above fibre saturation point are in any case imprecise, this fact will probably not be noticed or be taken into consideration.
TEMPERATURE

During cooling, the temperature of the wood will normally be higher (sometimes much higher than the temperature of the air). Wood is a good heat insulator.

This means that there will be more electricity flowing than expected and the control will display a rise in MC parallel to the decrease in air-temperature.

If needs be, please always wait for some hours (24 hours) before measuring MC in wood taken out of the kiln.

Of course, when examining in practice the electronic measurement of temperature we cannot exclude that some errors are due to a poor calibration of the electronic equipment or even a true electronic fault.

Calibration should be performed at least twice a year. Most kiln supervisors have their own tricks to understand if an error in the measurement of temperature (or air-umidity) is real (actually taking place in the kiln) or is due to a faulty card (for example: swapping temperature cables).
AIR VENTILATION

The velocity of the air in a kiln is designed (number, size and power of the fans) according to well-established parameters: 1.5-2.0 m/s for hardwoods, 2.0-2.5 m/s for intermediate species, 3 m/s and more for softwoods.

The velocity depends on the balance between transport of water inside the lumber and its evaporation to the circulating air. This is of course dependent on the temperature (and humidity) of the environment.

The air moving through the lumber:
- brings the necessary heat (energy) to the wood
- carries away the water being evaporated
- creates the right pressure and depressure in the kiln, for venting to function correctly

Towards the end of drying, below FSP, when water moves by diffusion through the cell walls, less air circulation is requested (frequency converters).

The fact that the air-velocity in a kiln does not exceed the previous parameters (or range of parameters), does not have only a technological but also economical explanation: the faster the air flow, the higher the electricity costs.

At the same time, especially with refractory species, a ventilation which is too high, can upset the balance between evaporation and water transport, leading to immediate drying defects.
AIR VENTILATION

Last but not least: the theoretical figures for air-speed refer to a perfectly loaded kiln, which is hardly ever the case (see picture).

The situation seen in the picture is of course an exaggeration; but the ratio between boards and voids, which should normally be 2 : 1 is often closer to 1 : 1.

This means that the air-speed is much, much lower than expected.

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THE DRYING SCHEDULE

The drying schedule is subdivided into phases:
- heating or warm-up
- drying
- equalizing
- conditioning
- cooling
THE DRYING SCHEDULE

The drying schedule is normally dependant on:
- wood species
- thickness
- initial MC
- final MC
- quality requested

The drying schedule is usually organised in steps, processing the right climate sequence according to the decreasing moisture content in wood.

It is sometimes simplified, using the gradient method. In this case the climate remains at a fixed ratio: MC / EMC.

The climate parameters usually depend on the MC of the wood (the lower the MC, the higher the temperature and the lower the relative humidity).

We sometimes make a general simplification where the climate sequence is fixed according to time (24 hours at 40°C, 24 hours at 50°C, etc.).
THE DRYING SCHEDULE

The drying schedule for hardwoods is usually MC-dependent.

The following practical considerations have then to be made:

- what MC am I going to consider? the average? the highest (max) value?

We have to examine the initial MC spread and decide according to our final aim (quality, duration, etc.).

If we dry according to the maximum value, we shall be sure most of the boards will be have the right final moisture content (or be even drier), but the process could last more than expected.

If we dry according to the average value, we might go faster than expected due to a more aggressive climate and ruin the material.

<table>
<thead>
<tr>
<th>Nardi 1</th>
<th>Nardi 2</th>
<th>Nardi 3</th>
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<tbody>
<tr>
<td>MC</td>
<td>Temp.°</td>
<td>EMC%</td>
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<td>50-55</td>
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Initial MC  | 40%  | 16%  | 16.30%
Final MC   | 12%  | 10.70%| 12%
Duration   | 9 days| 7 days| 3 days
THE DRYING SCHEDULE

The drying schedule is usually provided by our company directly, either through automatically generated programmes, or by processing customized schedules (normally based on the existing literature + experience).

It is quite normal however for the customers to optimise their schedules. Some customers also receive, directly or indirectly, schedules used in other neighbouring sawmills. This all means that hardly ever the schedules used in a sawmill are the same as the ones originally processed or provided by the kiln manufacturer.

But... how does the kiln react to the schedule and the drying control.

A poorly maintained kiln, even if controlled by a sophisticated control (example: P.I.D.) system, is rarely able to translate the requested (SET) parameters into reality (REAL).

Maintenance is important!
THE DRYING SCHEDULE

And how does the wood react to the drying schedules?

Is the wood already pre-dried?
Is it case-hardened? What is the end-quality that we are looking for?

For all particular cases, a special adaptation of the schedule has to be foreseen.

<table>
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<th>MC (%)</th>
<th>Tem.°C</th>
<th>ETMC%</th>
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CONCLUSIONS

In these few slides, we have tried to point out the difference between theory and praxis in kiln drying.

It is normal for unskilled operators to take for granted, or follow too closely, an instruction issued by the manufacturer. These instructions have instead to be interpreted and adapted to reality.

Unfortunately some systems - especially the ones that are fully automatised - make it difficult for the operator to adapt THEORY to PRACTICE.

At Nardi we normally try to avoid this but we need the help of the customers to get to know his actual requirements. Together, we then make the right adjustments (schedules, control parameters, etc.) to fine-tune his plant and achieve the best drying results.
THANK YOU FOR YOUR ATTENTION!