CAE analysis and optimization of energy consumption and costs of wood drying with use of different drying techniques

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INTRODUCTION

What to do for optimal technical, technological and economical decision?
Obligatory evaluation and detail analyses of:
- time
- energy consumption
- cost
- wood quality.
The decision is not
- simple or
- the same for different cases.

Influencing the large number of variables:
- timber species,
- timber dimensions,
- initial and final moisture content,
- type and size of dryers,
- energy availability and its price,
- etc.

The aim of this study
- For different drying techniques set up the CAE simulation of:
  - Drying kinetics (drying curve, drying schedule, drying rate and time etc.)
  - Drying quality (target MC, MC gradient, defect, ....)
  - Energy consumption (total amount, specific energy consumption for kg of water or for m³, kind of energy and their proportion, etc.)
  - Costs of drying (influence of MC).
- To make a model for choosing the best combination of drying techniques
- To calculate the optimum MC_t at which change of drying techniques would bring the best results.

Verification of the model and the calculation of transition MC_t on the example of air pre-drying and kiln drying processes.
BASIC DATA

DRYING KINETICS AND ENERGY CONSUMPTION

COSTS

OPTIMIZATION

\[
\frac{\partial \text{Cost}}{\partial u} = \frac{\partial \text{Cost}}{\partial u}
\]

METHOD

Wood
- Species, (density, vol. shrinkage, FSP, drying coefficient)
- Dimensions (thickness)
- Drying characteristics (permeability, diffusivity)
- Initial MC
- Final MC

Environment conditions
- Temperature, Relative humidity
- Equilibrium moisture content

Wood:
- Environment conditions
- Lumber yard
- Package – lumber stack
- Drying chamber

Lumber yard
- Dimensions (pile spacing, roads, air circulation)
- Accessory equipment (stickers, roofs, footings etc.)

Package – lumber stack
- Dimensions (height, length, width)
- Sticker thickness
- Wood volume

Drying chamber
- Dimensions
- Kiln charge volume
- Construction – thermal isolation
- Heat and electric power installation

DRYING KINETICS AND ENERGY CONSUMPTION

Air drying
- Typical drying curve \( u(t) \)
- Drying time
- Drying rate \( - \frac{du}{dt}(t) \)
- Final moisture content \( u_f \)

Kiln drying
- Drying schedule \( (T, dT, Tv, u, \varphi) \)
- Drying time \( t(u) \)
- Heat and electric energy consumption \( E_i(t), \Sigma E_i(t) \)
- Specific energy demand
- Energy efficiency
Economic and Technical aspects on quality control for wood and wood products

### METHO

**Predrying**
- Drying suite
- Wood species
- Initial MC
- Thickness

**Calculation**
- Drying kinetics
- Final MC

**Results A**
- Drying kinetics of predrying
- Final MC

**Artificial drying with**
- Predrying (1)
- Final MC
- Kiln construction
- Wood volume

**Results B**
- Drying kinetics of artificial drying with predrying
- Energy consumption

**Results C**
- Drying kinetics of artificial drying
- Energy consumption

**Comparison**
- Energy consumption
- Drying time

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### Biotechnical Faculty University of Ljubljana

**LOG TRANSPORT**
- **LUG TANK**
- **LOG FARM**

**First Stage in Mill**
- **Preshrinkage**
- **Kleptogenesis**

**KLEURING**
- **KLEURING**
- **KLEURING**

**Final Stage in Mill**
- **KLEURING**
- **KLEURING**

**QUALITY DRIED WOOD**

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**Department for Wood Science and Technology**

**Resaw of**
- **Log**
- **Timber**

**Staning**
- **Kiln**

**Resaw of**
- **Stacking**
- **Sawing**

**Quality Dried Wood**

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### COSTS

#### Air drying
- Capital costs and amortization (ground and road preparation),
- Drying time
- Quantity of the wood on the yard
- Annual capacity of the yard
- Rate investment credit
- Insurance and taxes

#### Kiln drying
- Capital costs (ground preparation, technical and thermal characteristics of the kiln and conditioning chamber)
- Cost of maintenance
- Cost of labour and transport
- Energy costs (heat, electricity)
- Insurance and taxes

### OPTIMIZATION

**METHOD**

**BASIC DATA**

- Wood
  - Species, density, vol. shrinkage (FPD, drying coefficient)
  - Dimensions (thickness)
  - Drying characteristics (permeability, diffusivity)
  - Initial MC
  - Final MC
- Environment conditions
  - Temperature
  - Relative humidity
  - Equilibrium moisture content
- Drying chamber
  - Dimensions
  - Kiln charge volume
  - Construction – thermal isolation
  - Heat and electricity power installation
- Package – lumber stack
  - Dimensions (height, length, width)
  - Sticker thickness
  - Wood volume
- Lumber yard
  - Dimensions (pile spacing, roads, air circulation)
  - Accessory equipment

**DRYING KINETICS AND ENERGY CONSUMPTION**

- Influence of MC on air drying costs
- Influence of MC on kiln drying costs

**COSTS**

- Calculating transition MC
- Increase of kiln capacity
- Energy saving
- Cost saving

**OPTIMIZATION**

\[
\frac{\partial \text{Cost}_{\text{air}}}{\partial t} = \frac{\partial \text{Cost}_{\text{kiln}}}{\partial t}
\]
Comparison of drying costs between two different drying techniques

Costs of air drying

\[ \frac{d\text{Cost}_{\text{air}}}{du} = \frac{d\text{Cost}_{\text{kil}}}{} \]

\( MC_t = \text{transition moisture content} \)

METHOD

Species beech wood board \((Fagus sylvatica)\) Thickness 38 mm Initial MC fresh wood Fina MC EMC with environment condition Time 8 series - every month from December to July Samples 10 samples

Drying rate model

\[ \frac{\Delta u}{\Delta t} = \frac{a}{1 + e^{(-k(a - a_c))}} \]

Evaluation of drying process:

Drying time and drying rate Moisture content and MC gradient Casehardening Defects
KILN DRYING

Species: beech wood board (Fagus silvatica L)
Thickness: 38 mm
Initial MC: fresh wood (MC<sub>i</sub> = 78 ± 12%)
Final MC: MC<sub>f</sub> ≈ 8%
Samples: 13 samples
Time:
\[ t = \frac{1}{\alpha} \ln \left( \frac{MC_t}{MC_f} \right) \left( \frac{d}{25} \right) \left( \frac{65}{\varphi} \right) \]
Kiln: 8.5 m x 7.6 x 5.8 mm (V = 81.65 m<sup>3</sup>)

Evaluation of drying process:
- Drying time and drying rate
- Moisture content and MC gradient
- Casehardening
- Defects

RESULTS

AIR DRYING CURVES

Each curve represents average value of 10 boards.
Typical dependence of drying rate from wood moisture content for winter and spring drying period for 38 mm thick beech wood timber.

\[ \frac{\Delta u}{\Delta t} = \frac{a}{1 + e^{-(x-u)\times b}} \]

RESULTS

AIR DRYING RATE

<table>
<thead>
<tr>
<th>Period</th>
<th>Initial MC (u_i) [%]</th>
<th>Final MC (u_f) [%]</th>
<th>Max. drying rate [%/day]</th>
<th>U_i [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEC - APR</td>
<td>68.3</td>
<td>18.6</td>
<td>2.3</td>
<td>47.1</td>
</tr>
<tr>
<td>JAN - APR</td>
<td>87.0</td>
<td>17.8</td>
<td>1.4</td>
<td>37.0</td>
</tr>
<tr>
<td>FEB - MAY</td>
<td>80.7</td>
<td>17.9</td>
<td>2.1</td>
<td>44.7</td>
</tr>
<tr>
<td>MAR - JUN</td>
<td>74.4</td>
<td>18.8</td>
<td>2.4</td>
<td>40.1</td>
</tr>
<tr>
<td>APR - JUL</td>
<td>79.8</td>
<td>18.4</td>
<td>6.3</td>
<td>52.3</td>
</tr>
<tr>
<td>MAY - JUL</td>
<td>57.3</td>
<td>17.9</td>
<td>5.6</td>
<td>45.9</td>
</tr>
<tr>
<td>JUN - AVG</td>
<td>67.2</td>
<td>19.1</td>
<td>3.5</td>
<td>43.7</td>
</tr>
<tr>
<td>JUL - SEP</td>
<td>78.7</td>
<td>17.9</td>
<td>7.8</td>
<td>53.6</td>
</tr>
</tbody>
</table>

Influence of drying rate from wood moisture content from December to July.
Drying schedule (temperature $T$, relative humidity $\phi$, equilibrium moisture content $EMC$) and drying curve for 38 mm thick beech wood timber.

Increase of drying costs during air drying for eight series (DEC – JUL), for 38 mm thick beech wood timber.
RESULTS

TRANSITION MOISTURE CONTENT MCₜ

Calculated optimal transition moisture contents (MC) from air to kiln drying for eight drying periods for 38 mm thick beech wood timber.

RESULTS

DRYING TIME

Reduction of kiln drying time with use of air predrying from green condition to transition MC for eight drying periods for 38 mm thick beech wood timber.
**Energy Saving during Kiln Drying with Use of Air Predrying**

From green condition to transition MC for eight drying periods for 38 mm thick beech wood timber.

**Reduction of Costs for Kiln Drying with Use of Air Predrying**

From green condition to transition MC for eight drying periods for 38 mm thick beech wood timber.
CONCLUSIONS

With analyzing and comparing the costs of more drying processes we are able to predict the wood moisture content at which alteration from air to kiln drying would get the best results.

With this method we can predict:
- the potential energy savings,
- the lowering of kiln drying time and consequently rising of available kiln drying capacities
- the costs saving.

The model can be used for optimising the combination of any drying techniques.

Thank you for your attention!