Drying Softwood in a Vacuum Dryer
— A Comparison of Drying Results in a Vacuum Dryer and a Conventional Kiln
Björn Hedlund

DRYING SOFTWOOD IN A VACUUM DRYER – A COMPARISON OF DRYING RESULTS IN A VACUUM DRYER AND A CONVENTIONAL KILN

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ABSTRACT

Drying quality of 75 x 150 mm Pinus Silvestris lumber dried in a DWT vacuum dryer and a
conventional drying kiln was compared in a joint venture project by The Technical Research
Centre in Finland (VTT) and The Swedish Institute for Wood Technology Research (TRÄTEK).
The basic data from the study has been reevaluated at Stora Teknik on behalf of TRÄTEK.

Two drying tests were made in the DWT dryer with drying programmes suggested by DWT to
average moisture contents of 17 % in 105 h and 9.6 % in 209 h. The conventional kiln used a
schedule that is frequently used in Scandinavia (Tratek's / Malmquist M3). The conventional kiln
dried the wood in 180 h to an average moisture content of 23.8 %.

Drying climate was registered by electronical thermometers in addition to the control systems of
both the dryers. Condensed water and energy consumption in the DWT dryer were measured.

Average moisture content, moisture gradient within the planks, standard deviation and
systematical variation of moisture content between the planks were measured by dry sample
tests after drying. Drying packages were weighed before and after drying. Remaining tension was
measured by means of prong tests. Drying checks and quality degrade due to drying was
determined by visual inspection.

The average final moisture content of the DWT drying tests was 17 % and 9.6 % with standard
deviations of 2.8 % and 2.2 % respectively. The conventional kiln showed a final moisture content
of 23.8 % and a standard deviation of 4.5 %.

Approximately 21 % of the wood dried in the conventional kiln and of the wood dried to 17 % in the
DWT dryer was degraded due to drying defects, the degrading was mainly due to checking. The
degrade of the wood dried to 9.6 % in the DWT dryer was approximately 10 %.

The energy consumption of the DWT dryer was very low, 240 kWh/m³ wood to 9.6 %, which is
less than 3600 kJ/kg extracted water.
INTRODUCTION

Vacuum drying of softwood has fairly recently been introduced in Sweden and Finland. A comparative study of drying quality in a DWT dryer and a conventional drying conventional kiln was conducted in Finland during 1990 in order to study the suitability of the process for softwood.

The study was a joint venture of The Technical Research Centre in Finland (VTT) and The Swedish Institute for Wood Research (Trätek). The results of the study have previously been reported by Holger Forsén at VTT in 1990 [Forsén, 1990].

The report by Forsén has been used as a basis for a new analysis of the basic material of the study made at Stora Teknik i Falun on behalf of Trätek. All basic data have been supplied by Holger Forsén at VTT and Björn Esping and Anders Samuelsson at Trätek.

The vacuum drying tests were carried out at AB Päras Oy in Kronoby, Finland and the reference kiln drying test at Oy Wisa Forest AB in Jacobstad, Finland.

PROCEDURE

2.1 WOOD MATERIAL

The wood was 75 x 150 mm high quality Pinus Silvestris planks. The quality of the planks was mainly class I - IV according to the Scandinavian rules for sorting of sawn lumber from fir and spruce [Sortering, 1982]. From each log one plank was sorted to the conventional kiln and one to the vacuum drying tests. Prior to the drying test average moisture content, density and weight of each drying load was determined.

2.2 DWT DRYING TESTS

The DWT dryer had a diameter of 2.6 m and a length of 18 m. The wood was loaded on 3 drying trucks with 2 packages on each. Each drying package was 13 planks high and 6 planks wide, which gave a distance across the drying package exceeding 1.8 m. Stickers were 28 mm thick, giving a package height of 1.34 m. The fans are placed above the drying loads and dimensioned to give a flow of between 15 m/s to 20 m/s with 19 mm stickers. The fans do not reverse the flow during the drying process.

Climate was measured by one pressure probe and two temperature probes. Signals from resistance moisture probes were used in the drying tests to measure moisture content of the wood and control the drying schedule according to the DWT system. An effect of the system is that the exact drying schedules were not known prior to the test. Table 1. shows the resulting drying schedules of the two tests.
Table 1. Resulting drying schedules of DWT drying tests.

<table>
<thead>
<tr>
<th>Process</th>
<th>Drying to 17 %</th>
<th></th>
<th>Drying to 9.6 %</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Temp.</td>
<td>RH</td>
<td>Period</td>
<td>Temp.</td>
</tr>
<tr>
<td></td>
<td>ºC</td>
<td>(%)</td>
<td>(h:min)</td>
<td>ºC</td>
</tr>
<tr>
<td>Preliminary vacuum</td>
<td>--</td>
<td>--</td>
<td>0:51</td>
<td>--</td>
</tr>
<tr>
<td>Heating</td>
<td>65</td>
<td>90</td>
<td>7:54</td>
<td>65</td>
</tr>
<tr>
<td>Step 1</td>
<td>65</td>
<td>72</td>
<td>42:42</td>
<td>65</td>
</tr>
<tr>
<td>Step 2</td>
<td>65</td>
<td>65</td>
<td>28:49</td>
<td>70</td>
</tr>
<tr>
<td>Step 3</td>
<td>70</td>
<td>50</td>
<td>5:37</td>
<td>75</td>
</tr>
<tr>
<td>Step 4</td>
<td>70</td>
<td>40</td>
<td>4:33</td>
<td>75</td>
</tr>
<tr>
<td>Conditioning</td>
<td>70</td>
<td>60</td>
<td>15:00</td>
<td>70</td>
</tr>
<tr>
<td>Total process time</td>
<td>105:26</td>
<td></td>
<td></td>
<td>209:25</td>
</tr>
</tbody>
</table>

Condensed water and energy consumption of the dryer were measured. In addition to the measuring system of the dryer, temperature on the pressure side and suction side of the dryer packages were measured with wireless thermoprobes. The vacuum dried wood had been stored approximately a week after sawing.

2.3 CONVENTIONAL KILN DRYING TEST

The drying packages were 30 planks high and 10 planks wide. The drying conventional kiln had 4 drying packages in each load giving a total distance across the packages of more than 6 m. Two packages were used in the study, one outer package and one centre package. Air velocities, dry and wet bulb temperatures were measured across the drying packages during the drying process.

A drying schedule based on Trätek's / Malmqvist's drying model M3 (unpublished) was programmed in the conventional kiln. Control parameters in the schedule were wet bulb temperature 50 ºC, density 450 kg/m³, air velocity 3.5 m/s and reversing fans every 2 hours, see figure 1.
2.4 ESTABLISHING DRYING QUALITY

Test samples for moisture content and moisture gradient were taken in the cross section of the drying packages according to a fixed pattern. The main part of the samples were taken from the root end or top end of the planks, with the exception of a small number of control samples taken at the resistance moisture probes.

Relative moisture content gradient was calculated from the maximum moisture content among six slices cut from a plank's cross section and the average moisture content of the plank according to the following formula:

$$ \text{Relative gradient} = \frac{\text{maximum moisture content} - \text{average moisture content}}{\text{average moisture content}} \times 100 $$

Length of the planks and drying checks were measured with a mechanical check length meter. Average of relative surface check length was calculated.

All planks were sorted visually by personnel from VTT and from 5 different sawmills in Finland and Sweden. Degrade due to drying defects were established and the value loss due to drying defects estimated.
RESULTS

Degrade due to drying defects, average checking and moisture content average and standard deviation of the drying tests are shown in Table 2.

Table 2. Drying results.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>DWT 17%</th>
<th>DWT 9.6%</th>
<th>Conv. kiln</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drying checks sapwood side</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>average</td>
<td>30.0%</td>
<td>13.3%</td>
<td>22.7%</td>
</tr>
<tr>
<td>number of pieces</td>
<td>393 pcs</td>
<td>468 pcs</td>
<td>536 pcs</td>
</tr>
<tr>
<td>% w. checks</td>
<td>84%</td>
<td>61%</td>
<td>75%</td>
</tr>
<tr>
<td>Moisture content</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>average</td>
<td>17.0%</td>
<td>9.6%</td>
<td>23.8%</td>
</tr>
<tr>
<td>standard deviation</td>
<td>2.8%</td>
<td>2.2%</td>
<td>4.5%</td>
</tr>
<tr>
<td>number of pieces</td>
<td>88 pcs</td>
<td>85 pcs</td>
<td>79 pcs</td>
</tr>
<tr>
<td>Relative moisture content gradient</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>average</td>
<td>26%</td>
<td>23%</td>
<td>15%</td>
</tr>
<tr>
<td>Degrade due to drying defects^1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I - IV to V - VI</td>
<td>20.8%</td>
<td>9.7%</td>
<td>20.7%</td>
</tr>
</tbody>
</table>

1) The moisture content of the wood dried to 9.6 % show a difference between the average moisture content of the root and top end of the planks.
   \[U_{\text{top average}} = 8.1\%, \ U_{\text{top stand. dev.}} = 1.1\%\]
   \[U_{\text{root average}} = 11.2\%, \ U_{\text{root stand. dev.}} = 1.8\%\]

2) According to the Scandinavian rules for sorting of sawn lumber from fir and spruce [Sortering, 1982].

3.1 DENSITY AND DRYING QUALITY

The final moisture content of the wood dried to 9.6 % in the DWT dryer showed a weak correlation to the density of the wood, \( r = 0.4 \). See figure 2. No significant correlation between density and final moisture content could be detected in the wood dried in the DWT dryer to 17 % or in the conventional kiln dryer.
Density and final moisture content of planks dried in DWT dryer to average moisture content of 9.6 %, $r = 0.4$.

3.2 SYSTEMATIC VARIATION OF DRYING RESULTS

A systematic variation of the drying result in the DWT dryer could be expected due to the fact that the flow of steam not is reversed during the drying process. At the same time differences between the outer planks and the inner planks in the conventional kiln could be expected due to the great distance across the drying packages along the air flow direction.

The moisture content of the bottom layers of the wood dried to 17 % in the DWT dryer are slightly lower than the top layers. This is probably caused by a higher steam velocity in the lower part of the package, a higher velocity caused by the placement of the fans and the curvature of the dryer wall. The wood dried to 9.6 % do not show this effect, instead a difference in moisture content due to different density between the top and root end of the planks is seen. See figure 3.

Figure 3. Average moisture content at different wood layers. At 17 % final moisture content a significant dependence of the level in the dryer on moisture content can be detected.
The wood dried to 17% moisture content also show a lower moisture content in the inner end of the dryer compared to the outer end (door end). This difference cannot be seen in the wood dried to 9.6% final moisture content. See figure 4.

![Figure 4](image)

**Figure 4.** Average moisture content for each pair of drying packages. The wood dried in the DWT dryer to an average of 17% show a lower moisture content in the inner end than the outer end of the dryer.

No significant difference in moisture content can be detected between the pressure side and the suction side of the drying packages in the DWT dryer. The samples from the top end of the planks show a significantly lower moisture content than those from the root end. See figure 5.

![Figure 5](image)

**Figure 5.** Final moisture content across the drying packages in the DWT dryer. The wood show a significantly lower moisture content in the samples taken from the top end of the planks, but no difference between the pressure side and suction side.
Planks in the centre of the conventional kiln dryer showed a slightly higher final moisture content than the outer planks.

The relative moisture gradient after drying was high in the wood dried in the DWT dryer, 23 % at 9.6 % final moisture content and 26 % at 17 %. The wood dried in the conventional kiln dryer had a relative moisture gradient of 15 %.

3.4 CHECKING

The wood dried in the conventional kiln and the wood dried to 17 % in the DWT dryer showed severe checking, average checking on the sapwood side of 23.2 % and 30.0 % of the plank length respectively. One reason for the severe checking was a high density of the wood, average density of the vacuum dried wood was 465 kg/ m³ (dry mass / volume at 17 %). The checking in the conventional kiln dryer was probably also affected by an insufficient fan capacity for the depth of the load, which led to a rapid drying of the wood in the inner parts of the packages late in the drying schedule [Forsén, 1990].

The wood dried in the DWT dryer showed a higher degree of checking in the planks closest to the pressure side of the drying packages compared to the planks farther back in the package. See figure 6.

![Figure 6. Average share of drying checks across the drying package. Planks dried in DWT dryer to 9.6 %.

Degrate due to drying defects was high in the wood dried in the conventional kiln and in the DWT dryer to 17 %; both tests showed degrade rates of approximately 21 % from higher to lower quality. The wood dried to 8 % in the DWT dryer had a significantly higher drying quality, with a degrade rate of 10 %.
3.5 DWT CLIMATE CONTROL SYSTEM

The control system for the drying process in the DWT dryer used resistance moisture meter probes to determine when the dryer should go from one drying step to another.

A comparison of the resistance probes measurements of the moisture content with the average moisture content of the wood in the dryer calculated from the amount of condensed water indicate that the moisture meter probes not give an accurate measurement of the moisture content before it has reached levels well below the fiber saturation point, see figure 7.

![Figure 7](image)

Figure 7. Comparison between average moisture content calculated from the amount of condensed water and from the readings of the resistance moisture probes. The corresponding drying schedule is shown.

The readings of the resistance probes dropped rapidly from well above to well below fiber saturation point. One effect of this is that the drying schedule tend to pass through the drying steps corresponding to these moisture levels as rapidly and then stop the drying programme.

This short drying period at the end of the drying schedule can be one of the reasons that the standard deviation of the moisture content as well as the moisture gradient were fairly high when the drying ended.

3.6 ENERGY CONSUMPTION

The total energy consumption of the DWT dryer was very low compared to conventional kilns. The energy consumption per liter water is lower than those reported earlier, approximately 4700 kJ/kg extracted water for 78 mm spruce planks dried from 54-56 % to 6 % [Weber, 1991].

The consumption of electricity in the DWT dryer is strongly dependent of the drying time, which indicate that the fans have been running at maximum power during the whole drying process.
The measured energy consumption of the DWT dryer at the tests and values of normal energy consumption of conventional kiln dryers in Sweden and Finland are shown in table 3.

Table 3. Energy consumption of the DWT dryer and normal values for conventional kilns.

<table>
<thead>
<tr>
<th>Dryer</th>
<th>Heat (kWh/m³)</th>
<th>Electricity (kWh/m³)</th>
<th>Total (kWh/m³)</th>
<th>(kJ/kg water)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DWT to 17%</td>
<td>75</td>
<td>90</td>
<td>165</td>
<td>2664</td>
</tr>
<tr>
<td>DWT to 9.6%</td>
<td>66</td>
<td>174</td>
<td>240</td>
<td>3564</td>
</tr>
<tr>
<td>Conv. kiln to 18%</td>
<td>280</td>
<td>28</td>
<td>308</td>
<td>5110</td>
</tr>
<tr>
<td>to 8%</td>
<td>400</td>
<td>45</td>
<td>445</td>
<td>6106</td>
</tr>
</tbody>
</table>

The higher heat consumption at the DWT drying test to 17% compared to the drying test to 9.6% is surprising but can possibly have been caused by the lower temperature used, 70 °C maximum compared to 75 °C [Forsén, 1990].

4 CONCLUSIONS

The drying qualities in the tests were not acceptable. The severe degrade of the wood was mainly due to checking. The checking was partly caused by a high density of the test material and should be possible to reduce with drying schedules adopted to high density wood.

The DWT dryer has given as good or better drying results than the conventional reference kiln. The main problems with the DWT dryer were the high moisture content variation and steep moisture gradient. Both these problems were probably caused by the fast ending of the drying schedule caused by the system with resistance moisture probes controlling the schedule. Higher drying temperature seems to both give better drying quality and lower energy consumption in the vacuum dryer.

The energy consumption of the DWT dryer has been shown to be very low compared to conventional kilns although the DWT dryer requires a higher share of electrical power.

REFERENCES

SORTERING av sågat virke av furu och gran. AB Svensk Trävarutidning, Stockholm 1982.
Sammanfattning


Två provtorkningar genomfördes i vakuumtorken med torkningsscheman föreslagna av DWT, från rätt ner till medelfuktkvot 17 % på 105 timmar respektive medelfuktkvot 9,6 % på 209 timmar. I kammartorken användes ett torkschema enligt Trätek/Malmquist M3. Torktid 180 timmar till medelfuktkvot 23,8 %. Klimatet under torkningen registrerades med elektroniska termometrar som komplement till torkarnas egna mätsystem. I vakuumtorken registrerades även kondensatavgång och energiförbrukning under hela torkloppet. Fukt kvotens medelvärde, gradienten inom plankorna, standardavvikelse och systematiska variationer mellan plankorna mättes på uttagna prover efter torkningen med torrviktsmetoden. Virkespaketen vägdes före och efter torkning. Restspänningar mättes med gaffelprov. Torksprikkor och nedklassning på grund av torkningsskador bestämdes visuellt dels enligt ”Gröna boken” av VTTs personal, dels av en grupp översorterare från finska och svenska sågverk enligt sågverkens egna kriterier.

Fukt kvotens standardavvikelse mellan olika plankor var 2,8 % för virket torkat till medelfukt kvot 17 % respektive 2,2 % för virket torkat till 9,6 % i vakuumtorken. Motsvarande värde var 4,5 % för virket torkat till 23,8 % i kammatorken. Nedklassningen var hög för det kammatorkade virket och virket torkat till 17 % i vakuumtorken, omkring 21 %. För virket torkat till 9,6 % i vakuumtorken var nedklassningen lägre, omkring 10 %.

För kammatorken kan nedklassningen förklaras dels av att virkets densitet var högre än vad som antagits, dels av att torkens fläktkapacitet var för låg med hänsyn till blåsdjupet. Nedklassningen av det kammatorkade virket kan i sin tur ha orsakats av att torkets kapacitet ej varit tidstyrt utan istället styrt med islagna stift för fukt kvotsmätning. Systemet med stift har lett till en hastig övergång till ett hårt torkklimat samt att torrviktsmetoden avslutats för tidigt med hög sprickbildung, fuktkvotspridning och -gradient som följd.

Den totala energiförbrukningen vid vakuumtorkningen var låg, omkring 240 kWh/m³ ner till 9,6 % vilket motsvarar mindre än 3600 kJ/kg avgivet vatten. Detta kan jämföras med omkring 6000 kJ/kg vatten för torkning ner till 8 % i konventionella kammatorkar. Vakuumtorken förbrukade dock mer energi än konventionella torkar vilket delvis förklaras med att fläktarna gått på fullvarv hela torkloppet.

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