Sorption Behaviour of Microwave Dried Wood

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ABSTRACT

In preliminary experiments samples of beech, pine and spruce were vacuum-microwave dried. After drying, these samples were stored under room climate for several weeks. The measurement of the equilibrium moisture content showed unexpected high values ranging from 13% up to 21%.

To verify these results and to find possible causes for this behaviour beech was dried using different methods. Methods applied were vacuum-microwave drying, microwave drying under atmospheric pressure and conventional drying. Sorption isotherms of the sample material were determined in a climate chamber and by means of salt solutions. Vacuum-microwave dried wood showed slightly higher values of equilibrium moisture content than wood dried by a conventional kiln schedule or atmospheric microwave. Apparently the level of specific power input is decisive for this deviation. The high equilibrium moisture content of the previous experiments was not found. The highest values observed were about 8% for 50%rh and 20°C.

INTRODUCTION

Wood usually is dried to a final moisture content that is close to the equilibrium moisture content under application conditions. The equilibrium moisture content varies with relative humidity of surrounding medias and temperature. Changes will effect for example dimensional stability because of swelling and shrinkage and resistance to decay of the wood.

The equilibrium moisture content can be described by sorption isotherms. For practical purposes a diagram from Keylwerth can be used that originates from data for spruce. These data are also applicable for other wood species (Kollmann 1951). To calculate sorption isotherms different mathematical models are available for example the approach by Hailwood/Horrobin (1946) in addition with coefficients by Simpson (1973).

During experiments on vacuum-microwave drying of wood, samples of pine, spruce and beech were investigated. The samples had an initial moisture content of about 80% for pine, 90% for spruce and 30% for beech. They were dried to levels below 5%. For a dimension of 200mm x 150mm x 15mm power of up to 4000W was applied by two magnetrons. The absolute pressure was 40 mbar.

The samples were stored under room climate (about 20°C, 50%rh) for several weeks. Measurement of equilibrium moisture content gave unexpected high values of 16 – 19.5% for spruce, 15.5 – 19% for pine and 13 – 21% for beech. Reference samples dried and stored under the same climate showed values of 8 – 10% which is in good agreement with literature values (Kollmann 1951).

Equilibrium moisture content higher than 20% would cause a risk of decay by fungi. In addition, steeper sorption isotherms could cause stronger dimension changes under application conditions. In literature on microwave drying of wood no evidence was found that the application of microwaves can cause a modification of wood in terms of increased content.
hygroscopicy (Egner 1964, Resch 1968, Antti 1999). Therefore an investigation was conducted to verify the obtained results and to find possible causes for a deviation from the expected behaviour.

MATERIALS AND METHODS

Beech wood with an initial moisture content of 73.5% was dried. The methods applied were vacuum-microwave drying (VMW), microwave drying under atmospheric pressure (MW) and a conventional drying schedule in a climate chamber (DS). Table 1 shows the experimental schedule.

Table 1. Experimental schedule

<table>
<thead>
<tr>
<th></th>
<th>VMW</th>
<th>MW</th>
<th>DS</th>
</tr>
</thead>
<tbody>
<tr>
<td>high power</td>
<td>low power</td>
<td></td>
<td></td>
</tr>
<tr>
<td>high final</td>
<td>4000 W</td>
<td>2000 W</td>
<td></td>
</tr>
<tr>
<td>moisture</td>
<td>X &gt; 12%</td>
<td>X &gt; 12%</td>
<td>X &gt; 12%</td>
</tr>
<tr>
<td>content</td>
<td>X &gt; 12%</td>
<td>X &lt; 12%</td>
<td>X = 8%</td>
</tr>
<tr>
<td>low final</td>
<td>4000 W</td>
<td>2000 W</td>
<td></td>
</tr>
<tr>
<td>moisture</td>
<td>X &lt; 12%</td>
<td>X &lt; 12%</td>
<td></td>
</tr>
</tbody>
</table>

Vacuum-Microwave Drying (VMW)

A pilot scale plant was used for vacuum-microwave drying. The facility was provided by the company ZIFRU GmbH in Zittau, Germany. The vacuum vessel consists of three sections. The microwaves are applied in the middle section that is 1m in length. The material is transported by a conveyor. The system is equipped with two magnetrons providing a maximum of 4000 W operating at a frequency of 2.45 GHz. For the experiments an absolute pressure of 40 mbar was applied that corresponds with a boiling temperature of water of 29°C. It was possible to measure the surface temperature of the material at a single position and to set a temperature limit to automatically reduce the power applied.

The samples used had a size of 200mm x 150mm x 15mm. They were cut from 17 boards of 1m length. 15 runs were performed, each run consisting of four samples. The power levels given in table 1 were the emitted power of the magnetrons. It was not possible to tune the system to full energy absorption during the whole drying process. But the major part of energy was absorbed by the material at the beginning of the single runs.

After test runs the number of passages through the microwave section was used to obtain a certain range of final moisture content. Figure 1 shows the final moisture contents of all runs and their division into classes.

Microwave Drying (atmospheric) (MW)

A laboratory scale microwave oven LabWave 9000 (CEM GmbH, Germany) was used for microwave drying under atmospheric pressure. The maximum power of the oven is 650 W. A reduced power level can be adjusted by reducing the application time within a time interval. Because of the limited load cell and dimension of the oven sample dimensions used were 200mm x 55mm x 15mm. Single samples were dried in difference to VMW.

![Figure 1. Final moisture content of VMW drying runs](image-url)
To avoid damaging of the material applied power levels were 325W and 162.5W time-averaged. The resulting final moisture contents were about 4% and 8% with the higher moisture content differing from the original experimental schedule. Overall 20 samples were dried.

**Climate Chamber Drying Tests (DS)**

Reference samples were dried in a climate chamber Feutron KPK 600 (Feutron Klimasimulation GmbH, Germany). The drying schedule used was set up by means of the former East German standard TGL 21503. The target moisture content was 8%. The drying time was 150.5 h. 10 samples were dried.

**Determination of Sorption Isotherms**

The temperature chosen for sorption experiments was 20°C. For the determination of the sorption isotherms at least three cubic samples with an edge length of 15 mm were cut from each dried sample (overall 180 samples). Prior to the sorption experiments all samples were oven dried to determine the dry mass and to have the same starting conditions.

For the sorption experiments two methods were used. Samples were stored in a climate chamber at different levels of relative air humidity for one week. The chosen air humidity’s were 20%, 60% and 80%. The time period of one week was chosen to get fast results. It was expected to have the highest sorption rates at the beginning of the experiments similar to experiments by *Time* (2002). At least trends for differences between the applied drying methods should be visible from this experiments.

A second charge of fewer samples (about 25) per humidity was stored in glass vessels over different saturated salt solutions (*Lide 1999*) at a temperature of 20±2°C for three weeks. The used salts and the corresponding relative air humidity’s are shown in table 2.

**Table 2.** Salts and corresponding air humidity’s used

<table>
<thead>
<tr>
<th>Salt</th>
<th>Relative humidity [%]</th>
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</thead>
<tbody>
<tr>
<td>MgCl₂</td>
<td>33.0</td>
</tr>
<tr>
<td>Mg(NO₃)₂</td>
<td>54.4</td>
</tr>
<tr>
<td>KCl</td>
<td>85.1</td>
</tr>
<tr>
<td>KH₂PO₄</td>
<td>96.0</td>
</tr>
</tbody>
</table>

**RESULTS AND DISCUSSION**

Figures 2 and 3 show the results of the sorption
experiments in the climate chamber. Apparently one week was not enough time to establish the sorption isotherm. All measured values are below that of Keylwerth.

Figure 2\(^1\) shows the values for the VMW dried material averaged by groups. The lowest MC were measured for the combination low power and low final MC. The values are about 0.5% lower for all humidity's. The other groups are very similar except for 80%rH where high power and low MC content result in about 0.5% higher MC for sorption.

Figure 3 shows the comparison of all drying methods applied. Values of VMW and MW are averaged by the power level. The highest MC were measured for VMW with the biggest difference to the reference samples of 1% at 80%rH. Values for the reference and MW are very similar. The highest MC for the VMW and MW samples were measured by application of the high power level. For VMW the specific power was significantly higher than for MW.

Figure 4 shows the MC of samples stored in glass vessels. After three weeks all values are still below those of Keylwerth. Because of the shape of the curves it is obvious that equilibrium moisture is not reached for all relative humidity’s. MW dried samples show the lowest MC. The values for VMW samples are higher than those for reference at high relative humidity’s. For VMW and MW higher power level applied means higher MC.

Apparently the specific power applied to the sample has influence on the sorption behaviour. For all samples of VMW and MW drying higher specific power means higher moisture content. Chemical modification is known to decrease the hygroscopicity of wood by inactivation of hydrogen bonds of the cellulose molecules (Chauhan 2001). An increase in free hydrogen bonds caused by high energy input appears to be improbable. More likely is an influence on the microstructure of the wood that might cause better accessibility for water vapour.

CONCLUSION

No significant difference in moisture content was found for different drying methods applied. Vacuum-microwave dried material shows slightly increased values. The difference is about 1% for high relative humidity. Apparently the specific power applied is decisive for the height of deviation. Results from preliminary experiments with equilibrium moisture content up to 20% could not be verified.

\(^1\) X... moisture content, φ... relative air humidity

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