Continuous Drying of Lumber in a Microwave Vacuum Kiln

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ABSTRACT

At the moment the drying of hardwood in Germany is characterised by three main trends. Customers expect highest quality, producers must respond flexibly to market requirements and final edging and trimming is realised increasingly in sawmills. By means of the currently installed drying equipment it appears to be difficult to meet these demands without exceeding economical limitations because of inherent disadvantages of the technology. Drying of hardwood by use of heat and vent dryers takes up to several months. There is always a quality variation of the single boards within a stack. Monitoring of wood during the drying process is inadequate. Just about 50% of the dried wood are sold after final edging and trimming. The remaining part, dried at high costs, is used for steam production and other purposes.

The application of vacuum dryers shortens the process time but the disadvantages of stack processing are not avoidable. In addition they require more advanced and therefore more expensive equipment. High frequency radiation is used just as a supplement for convective heating up to now, without changing the configuration of the process.

Microwave drying at vacuum conditions appears to be suitable to meet the described demands. A continuous drying process which allows individual treatment of single boards can be configured. Because drying takes just a few minutes, fast reaction on customer orders is possible saving storage capacity. Single boards are accessible for measurement of relevant parameters. By integration of drying in the sawing process energy savings can be achieved because only the final dimensions need to be dried.

Experimental results obtained at pilot scale plant show the potential of vacuum-microwave drying. Special attention is paid to the advantages of the process in terms of continuous drying. A new laboratory vacuum-microwave kiln is presented.

INTRODUCTION

In Germany, hardwood is mainly dried in conventional heat and vent dryers. This technology has certain disadvantages that have negative effects on the processing of wood in sawmills:

a) Boards are stacked for drying. The properties of individual boards are not taken into consideration during the process. Process control relies on values of measurements taken at a few discrete places in the stack. Boards of a single load vary in their final quality parameters. This variation can be decreased by prolonging the process but will not vanish. For high quality demands a grading of the boards might be necessary.

b) The drying takes up to several months. Therefore fast reaction to changing market conditions is not possible. High storage capacities can help to avoid this problem but will cause additional costs.

c) Because of the discrete measurement of wood properties degradation due to drying can be detected only at the end of the process.

Hardwood sawmills must meet certain actual demands:

a) Customers expect higher quality of products. This includes absolute quality parameters and their variation.

b) Sawmills must respond flexibly to changing market conditions. Orders might depend on how fast companies can provide material.

c) Customers expect a higher diversity of final dimensions thus requiring to integrate further edging and trimming into the sawmill process.

The application of vacuum drying can reduce drying time. Avoiding the problem of different qualities of single boards within the stack is not possible. Furthermore it is important to consider the increasing problem of flow maldistribution under vacuum conditions. In the case of convective heat transfer investment and operating costs are higher than for conventional dryers. Therefore vacuum dryers could not displace conventional heat and vent dryers.

During the last years more attention was paid again to microwave drying of timber. After more extended research and publication in the 60's (*Egner 1964, Resch 1968*) work on this kind of drying was intensified in the 80's and 90's. Early research encountered several problems:

- imperfect microwave equipment of that time (inhomogeneous field distribution),
- missing equipment for measurement within the field,
- high energy cost.

The increased number of research projects in this technology is due to constant improvement of the equipment. There is a lot of progress in theoretical and practical issues.

Successful work to obtain a better theoretical understanding of microwave drying of timber was done by *Antti* (1999). The need for more research is obvious because there is still no larger industrial application.

On the other hand, there is an increasing number of small microwave applicators in joineries. Here boards are dried very fast to the desired final moisture content.

The disadvantages of conventional timber drying, the demands of the sawmill industry and the development of microwave technology give reason to consider a new technological approach. Microwave drying of timber under vacuum conditions appears to be suitable for continuous application. This principle is investigated. Results of experimental work carried out are presented here. Research issues for further investigations and possible ways for their solution are derived from these results. Chances of the new application are outlined. The experience drawn from the experiments was used to design a laboratoray vacuum-microwave kiln.

EXPERIMENTS

During a project on drying of food stuff a pilot scale vacuum-microwave drier was modified for the treatment of timber. Usually, bulk materials are dried continuously in the plant.

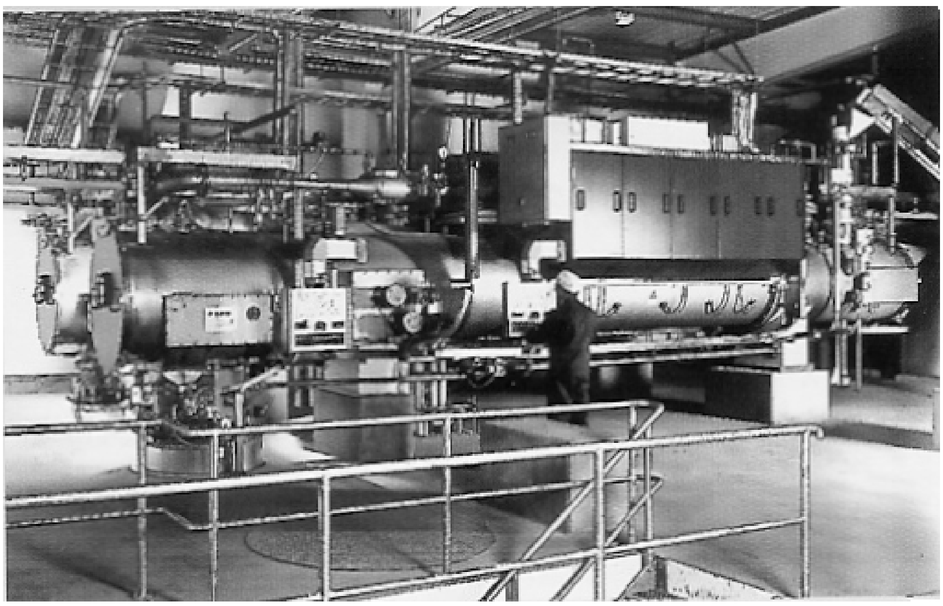


Figure 1. Industrial microwave-vacuum drier

Figure 1 shows such an industrial vacuum-microwave drier. The used pilot scale plant of similar configuration is divided into three sections. The first and last sections are used for material handling. Drying occurs in the middle section that is about 1 m long. The material is transported by a belt conveyor. Energy is provided by two magnetrons operating at a frequency of 2.45 GHz with a maximum power of 2000 W each.

By preselection power can be reduced to any value below. During operation it is possible to change the actual value manually or to control power input by means of the surface temperature of the dried material. Surface temperature is monitored online by means of a pyrometer. There is a permanent optical access to the drying section thus allowing observation of the material. Power not used for drying is reflected to the magnetrons and measured. The operational pressure can be varied from 30 to 200 mbar. Material surface temperature, microwave power, pressure and accumulated power are monitored by a control system and can be used for further evaluation.

First Experiment

First experiments were carried out to test the suitability of the system for drying timber. Materials used were predried beech, steamed beech and fresh-sawn oak. Samples had a size of 300mm x 100mm x 25mm. This size is suitable for the production of parquet. The single runs were performed with a conveyor speed of 20 m/h. Surface temperature of the samples was monitored online and limited to 60°C by control of magnetron power output. Initial moisture content, final moisture content and necessary drying time are shown in table 1. The drying times are in the range of few minutes instead of days or weeks for heat and vent drying or hours for microwave drying under atmospheric conditions.

Table 1. Results of first experiments

	Beech	Steamed beech	Oak
Initial MC	32 %	58 %	79 %
Final MC	8%	8 %	12 %
Drying time	~ 2 Min.	~ 4 Min.	~ 6 Min.

The samples showed no cracks or distortion induced by drying. Just the predried beech showed deformations in parts with heartwood. Colour changes could not be detected due to the absence of oxygen during the process. In addition, the temperature did not exceed 60°C. Figure 2 shows the oak sample after drying.

Second Experiment

To investigate necessary drying times for larger dimensions, in a second experiment boards of a size 1500mm x 200mm x 25mm were dried. Boards of this dimension could be used for flooring. Materials were beech and oak with an initial moisture content of about 40%. The final moisture content was about 10%.

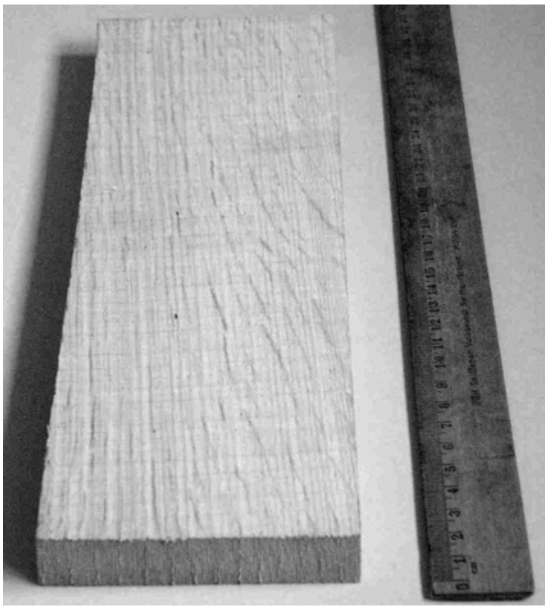


Figure 2. Oak sample after drying for 6min, radial annual growth rings

The runs showed again positive results similar to the smaller samples of the first experiment. Drying time was prolonged to about 10 min because of the larger amount of water to evaporate and the limited maximum power input. There were neither colour changes nor visually detectable cracks. Figure 3 shows one of the boards after drying.

If the energy consumption for a stack is calculated based on the experiments, the total amount is similar to the energy consumed by the fans during conventional heat and vent drying of hardwood. The energy consumption of the fans is in the range of 10 to 20 MWh for drying 50 m³ of oak and 6 to 12 MWh for 50 m³ of beech (*Seyfarth 2003*).

A 50 m³ load of timber consisting of boards with the dimensions of the second experiment would contain 6670 boards (50 m³ / (1,5m x 0,2m x 0,025 m)). A single board took 10 min at 4 kW microwave power equivalent to 0.667 kWh. Hence, to dry 50 m³, 4.45 MWh would be needed. Considering a realistic efficiency factor of 70 % for the magnetrons, this results in an electric energy consumption of 1.7 kWh per kg evaporated water, including the vacuum pump. The electric energy consumption of conventional kilns ranges from 1.1 to 2.25 kWh per kg evaporated water. Because the system used was not adapted to wood drying, the efficiency of energy input should be higher after a modification of the configuration.

The above calculation includes just the consumption of electric energy. The heating of conventional driers is often realised by burning of wood chips for steam generation. This energy could be saved or used for production of electric energy.

The overall operating costs for vacuum-microwave drying are comparable to the cost of conventional heat and vent drying. The rough cost estimation is based on the experience of the operator of the pilot plant. It also includes costs of wear-parts as a major part.

Third Experiment

Samples of pine, spruce and beech were dried to low final moisture contents, below 5%. The samples had an initial moisture content of about 80% for pine, 90% for spruce and 30% for beech. The size was 200mm x 150mm x 15mm. After drying, the samples were treated with vegetable oil to simulate a preservation treatment. One reason for this test was the observation of enlarged pores immediately after removal of samples from the vacuum vessel. This effect disappears after a few minutes. On the other hand, it was expected that water vapour generated in the wood will serve as a conveying medium for air that is present within the wood cells. This will cause very fast degassing of the wood. Because of Stefan-diffusion, air will always remain within the wood by use of other drying technologies. Complete degassing of the material should result in enhanced accessibility for preservation treatment. In contrast to the common pressure treatment with a minimum pressure of 8 bar the treatment was done under atmospheric pressure during the experiments. The vegetable oil penetrated the material without application of elevated pressure to a depth of about 1/3 for spruce and completely for beech. The oil was applied for 24h.

CURRENT RESEARCH PROJECT

The preliminary experiments are the basis for an ongoing research project funded by the German Society for Wood Research (DGfH). Subject of research are the following questions:

a) Which energy input is required for vacuum-microwave drying and which configuration is suitable for efficient energy absorption in the material? Because a single magnetron can not provide the energy for the complete drying process, a number of magnetrons must be installed. The necessary distances between single devices and applicable energy depending on moisture content, board dimension and wood species will be investigated.

b) What is the effect of vacuum-microwave drying on wood properties? Besides moisture and stress development other physical and chemical wood properties will be investigated.

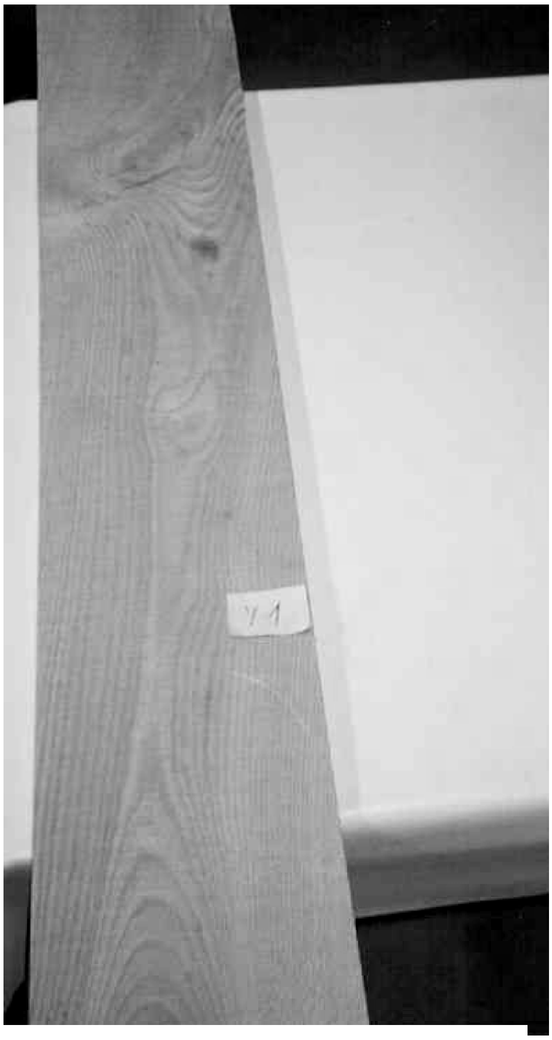


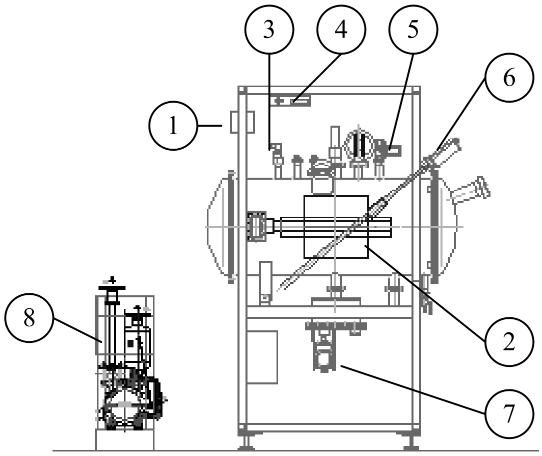
Figure 3. Oak board dried in the second experiment

LABORATORY VACUUM-MICROWAVE KILN

Based on the experience of the preliminary experiments, a laboratory vacuum-microwave kiln was designed. The system is manufactured by Püschner MicrowavePowerSystems, Germany. Figure 4 shows the outline of the kiln.

The kiln consists of a vacuum vessel with a volume of about 200 l. Energy is supplied by two 3 kW magnetrons operating at 2.45 GHz. There is a possibility to use different types of emitters. Pressure can be adjusted to values down to 33 mbar. Sample length is limited to 600mm.

For online weight measurement of samples, a load cell is integrated into the system. Temperature measurement can be done by fibre optic sensors and by means of an IR-camera. Additionally, the pressure measurement within the wood is possible.



1 pressure sensor
2 variable mounting
3 pressure transmitter
4 fibre optic temperature measurement (4 channels)
5 magnetic valve for pressure control
6 IR-camera 0 – 250 °C
7 load cell
8 vacuum pump

Figure 4. Laboratory vacuum-microwave kiln

CONCLUSION

Drying experiments were carried out using a vacuum-microwave pilot plant. The following statements can be derived from the experiments:

- Vacuum-microwave drying of hardwoods is considerably faster than conventional heat and vent drying – minutes instead of weeks or months.
- There was no discolouration or other damages caused by oxygen.
- There was no crack formation and deformation of the material.
- A continuous drying process could be used. Single boards are accessible for visual evaluation and sensor measurement.
- Operating costs are comparable to those of conventional heat and vent drying.
- Preservation treatment of the material was facilitated.

There are advantages of vacuum-microwave technology for an industrial application:

- Fast response on specific customer orders is possible.
- The equipment can be configured for a continuous drying process within the sawmill operation.
- The visual control of single boards can be achieved.
- Drying condition can be fitted to the requirements of individual boards.

The results of the experiments were used to design a new laboratory vacuum-microwave kiln.

ACKNOWLEDGEMENTS

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