Bulletin of the *Transilvania* University of Braşov
Series II: Forestry • Wood Industry • Agricultural Food Engineering • Vol. 9 (58) No.1 - 2016

CONSIDERATIONS UPON THE DRYING OF OAK LUMBER

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Abstract: *Oak is one of the most valuable home-grown wood species which are used in furniture manufacturing, but also one of the most difficult to dry. Severe drying defects, such as checks, collapse, distortion and discoloration, are quite frequent and may cause significant material losses. In order to assist wood-processing enterprises in optimizing this drying process, the authors have gathered some of the most relevant information on drying time, energy consumption and drying quality when applying various drying techniques to various oak wood species. Some recommendations based on the authors' own experimental research with the conventional drying of oak lumber are also presented.*

Key words: *oak wood, drying techniques, drying time, drying quality, energy consumption.*

1. Introduction

The causes of all drying difficulties of oak can be related to its structure since oak belongs to the category of ring-porous wood species. The high differences in density within an annual ring (between early wood and late wood) cause variable shrinkage which facilitates checking. The structure of oak wood is mainly composed of very dense fibre zones, in which water can migrate at a slower pace. Additionally, especially in heartwood, the presence of tyloses blocking the cell lumens, reduces further wood permeability. Another important feature of oak wood is the very large medullary rays, which are low-resistance anatomic elements, and thus fragile to tensile stresses. The parenchyma cells are inclined to collapse during drying and the chemical composition (mainly due to the high amount of tanning substances) creates discolorations.

Therefore, the most common problems with oak drying are the long drying times, tendency to checking, risk of collapse, deformations and discolorations. The ways of preventing them are often contradictory: (1) low temperatures, combined with high relative air humidities prevent checking, but lead to very long drying times and expose the timber to fungal attack and discoloration (2) high temperatures allow the shortening of the drying time and energy savings, but have a negative effect on drying quality. This is why a compromise has to be found, and the present level of scientific and

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technological knowledge allows us several options. But before choosing one or the other alternative, the user should be aware that no drying method is perfect and the decision on a prevailing criterium (high quality or short drying time) should be taken in advance.

2. Objective

The main objective of this paper is a review of the most popular techniques applied so far to dry oak lumber, along with their performances in terms of drying time, energy consumption and drying quality. The main benefit will be a better support for wood-processing industries in taking better documented decisions when choosing a particular drying technique.

3. Characteristics of Different Techniques Applied for Oak Drying

Conventional heat-and-vent kilning is not the most suited way of drying oak wood and this is because even with optimized and strictly observed drying schedules, the drying times are still very long. Drying 25 mm thick lumbers from green state to 8% moisture content (MC) may take up to 35 days [5]. With increasing thickness, the drying time may go up to 3 months. The drying above fibre saturation point (from green down to ca. 30%) is often considered to be economically inefficient because during this period, the temperature is limited to maximum 30°C [13] or 41.1°C [5],in order to avoid checking. However, pre-drying in an open yard may take up to one year or even more and can lead to serious casehardening, which requires a longer warming-up period with high wet-bulb values at the beginning of kiln-drying, to soften the wood surface again.

The total specific energy consumption during conventional kiln drying is evaluated at 560-700 kWh/m^3 or 2.7-4.0 kWh/kg$_{evap.water}$ [3, 10]. When drying pre-dried lumber (from 30% initial MC), the energy consumption may be reduced to half.

Dehumidification by condensation maintains the same disadvantages as conventional drying (long times, poor quality), but at lower energy consumptions. With this technique, the average specific energy consumption is evaluated at 120–380 kWh/m^3 depending on wood thickness [6], respectively 1.3 - 1.6 kWh/kg$_{evap.water}$ [3], [9]. The reduction of the drying costs compared to conventional kiln drying mostly depends on the desired final moisture content: the drying rate becomes very slow when drying below 15% MC, which stretches the drying time. Another big disadvantage of condensation drying is that it is not possible to correct casehardening, which is a frequent defect in oak lumber kept for a longer period of time in the open yard for pre-drying.

According to recent advances in drying research, the most suitable technique for drying oak lumber is considered to be **vacuum drying**. Studies performed worldwide show that, for valuable species, such as oak, vacuum drying leads to a better economic efficiency than drying at atmospheric pressure, although it requires higher investment costs and also higher energy consumptions.

The major advantages of vacuum drying are:

- lower drying times, due to the fact that a pressure gradient is generated inside the wood, which accelerates the internal moisture migration;
- less checking, due to the fact that at low pressures water boils at lower temperatures and thus both water migration and evaporation occur at a low temperature, protecting the wood (similarly with mild schedules);

- reduced risk of discoloration, due to the absence of oxygen.

The main problem with vacuum drying is the fact that vacuum is a poor heat conductor, which generates the need for high energy supply in order to provide an adequate heat transfer. Heavy maintenance costs of corrosion to metallic kiln parts have also to be taken into consideration when choosing any variant of the vacuum drying technique.

Superheated steam vacuum drying (SSV) is a convective drying method, similar to conventional drying, but due to the low pressure (ca. 0,01MPa), the medium inside the kiln is transformed at quite low temperatures (50-60°C) into superheated steam. Air speeds of 20-40 m/s [1] have to be provided, in order to achieve uniform heat transfer.

The high cost of the kiln itself (ca. three times more than a conventional dryer [1]), has discouraged so far Romanian entrepreneurs to invest in SSV kilns, but feasibility studies show remarkable advantages of this technique when drying oak lumber, especially with regard to drying time and quality.

Table 1 presents a synthesis of the most relevant experimental results regarding the drying times obtained by vacuum drying in superheated steam for various oak species and grades [1, 2], [11,12].

According to a study performed on 25 mm thick red oak (*Quercus rubra*) lumber [10], the thermal energy consumption of an SSV kiln is 82% lower than that of a conventional kiln, while the electrical power consumption is 60% higher. With values ranging between 1.9 and 2.3 $kWh/kg_{evap.water}$ [2], [10], the total specific energy consumption of a SSV kiln is 1.5-1.8 times lower than that of a conventional kiln. Drying times are 2.5 - 3 times shorter than in the case of conventional drying even when drying wood from green state [1, 10]. Additionally, the drying quality improves significantly: checks and discoloration may be completely avoided. The prong tests revealed severe internal stress at the end of conventional drying, which made conditioning necessary, but there was no such need with SSV drying, thus demonstrating the potential of this technique to produce stress-free lumber.

However, compared to common oak (*Quercus robur* L.), red oak is regarded as much easier to dry without degrade.

Drying performance of SSV drying when applied to oak lumber Table 1

Reference	Species	Thickness [mm]	Initial MC [%]	Final MC [%]	Drying time [h]
Brunner, 1999 [1]	European oak (*Quercus robur*)	27	40	8	120
		27	80	8	288
		52	40	8	216
		52	80	8	624
		65	40	8	360
		65	80	8	960
Guilman, 1996 [2]	European oak (*Quercus robur*)	27	50	10	230
		54	100	10	560
Tremblay *et al.*, 2001 [11]	Red oak (*Quercus rubra*)	50	63.3	7.8	684
Tremblay *et al.*, 2001 [12]	White oak (*Quercus alba*)	50	53.1	14.5	519

A comparative calculation of drying costs [4] revealed that for 54 mm thick oak lumber, SSV drying becomes more efficient than conventional drying at annual capacities over 500 m^3/year and even more efficient than condensation drying if the annual capacity exceeds 1000 m^3/year. When operating with large capacities, the drying costs may sink below 100 euro/m^3 [1], [10].

High frequency / vacuum drying (**HFV**) provides the best results with regard to quality, but is also the most expensive technology. Due to the characteristic of HF heating to induce a temperature gradient oriented from inside the wood to the surface and to heat up first the moistest parts, this technique ensures incontestable advantages [7]:

- ability to dry freshly cut wood;
- loading is possible without stickers;
- heating of wood occurs in minutes and is fairly uniform, if well stacked;
- drying stresses are small or not existent, so checking rarely develops;
- short drying times (ca. 15 days for 25mm thick oak lumber from 50% to 8%)[8];
- wood retains its natural colour.

Due to the high (exclusively electric) energy consumption, this technique has been barely applied in Europe, but for companies producing their own electricity, HFV drying is with certainty an alternative which can be employed to their advantage, considering that such quality can not be achieved by any other drying technique, and for sure, not in such short times.

Vacuum-press drying and **microwave drying** did not lead to satisfactory results in industrial approaches and are not considered suitable for oak lumber drying.

4. Optimisation of Conventional Drying of Oak (*Quercus robur* L.)

Similarly with other wood species, air temperature and equilibrium moisture content (EMC) are the main parameters of the drying schedule. With oak wood, the basic rules which are to be observed during conventional drying are:

● temperature should not exceed 30-40°C until wood reaches the critical moisture content of 27% [13]; simultaneously, the EMC has to be maintained as high as possible, at approximately 18% relative humidity and the air velocity may go as high as 2 m/s [14];

● as soon as the wood moisture content has decreased below 27%, temperature can be raised to 60°C (even 70°C for up to 40mm thick timber) and the drying gradient (ratio between wood moisture content and EMC) should be *DG*=1.5; the air flow speed should not exceed 1.3-1.8 m/s in the stack during this drying stage [5];

● equalisation and conditioning at the end of the process are compulsory in order to achieve a uniform distribution of the moisture content across the timber thickness and to relieve the internal stresses [14]. This should be performed by decreasing the temperature to 50°C, while spraying until the EMC increases up to 10-12%.

Figure 1 presents a drying schedule conducted according to the above mentioned recommendations in a conventional kiln within the Thermal Treatment Laboratory of the Wood Engineering Faculty in Brasov. The 2m^3 capacity kiln was loaded with 40 mm thick oak (*Quercus robur* L.) lumber, with an initial moisture content of 50%. The process lasted 700 h and the quality control at the end of the process revealed only a small amount of surface checks, no internal checks and no discoloration.

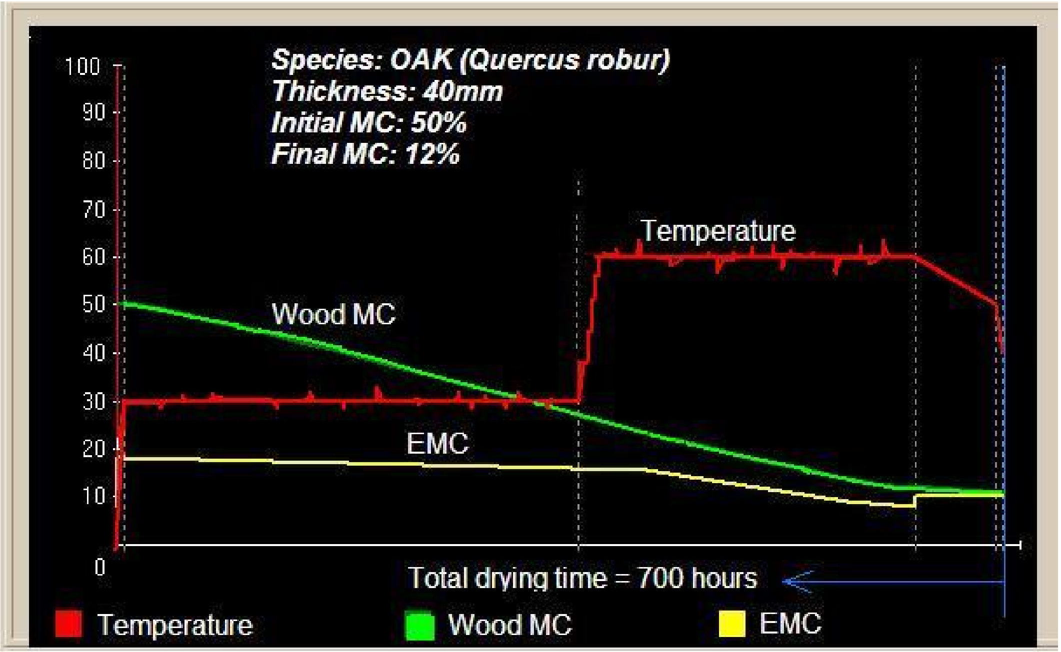

Fig. 1. *Experimental drying schedule for conventional drying of oak lumber*

5. Conclusions

There are well proven reasons why oak wood is hard to dry. The authors tried within this paper to formulate some recommendations concerning what can be done to improve the drying quality of this species. Several options concerning the most suitable drying techniques, as well as an optimized schedule for conventional drying were presented for this purpose.

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