

CONTINUOUS LUMBER DRYING BY APPLYING A SEQUENCE OF DIFFERENT DRYING METHODS WITHIN A SINGLE PROCESS

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Abstract:

A drying concept for sawn wood by a continuous drying of the boards in a sequence is introduced. The advantage of this concept is, that different drying methods may be applied within a specific stage of the whole drying process. Thus a significant acceleration of the whole drying process can be expected compared to the conventional batch drying. Furthermore every single board can be moisture monitored and can be put backwards in the case of lagging behind the drying schedule. A process model is introduced and the potential of improvements concerning a reduction of the drying time, reduction of energy input and improvement in the drying quality are evaluated.

Key words: continuous drying of lumber; combination of drying technologies; accelerated drying process.

INTRODUCTION

Drying of lumber is a necessary process step between the sawing process and the secondary processing of lumber or the direct use of timber in various applications. The current state of the art of wood drying is batch-drying where the lumber has to be laboriously stacked with stickers before putting the stacks into the kiln dryer (Trübswetter 2006). Stacking and the drying process itself are very cost-intensive so that wood drying is a major contribution to the production costs of lumber. Currently various efforts are made in order to reduce drying costs by a better energy management and to achieve a better kiln-drying performance (Welling *et al.* 2003, Anon. 2011b, Anon. 2012). There are also continuous drying chambers but they still use the lumber stacks, which are put batchwise into the drying kiln (Anon. 2011a). Stack drying allows a limited moisture monitoring of the lumber, as only a few measuring points can be set within a stack. Therefore a continuous monitoring of all boards during the process is not possible which accounts for a slower (drying with caution) drying rate theoretically achievable.

There are a few publications available only on the logistic kiln-drying management connected to a production management system in the mill. Such overview is given by Rindler (2011) who discusses a heuristic approach which generates an optimal kiln allocation plan taking into account stacking and placement restrictions. Based on a discussion on Rindler's work, a drying concept such as a continuous drying of the boards in a sequence is proposed as an alternative approach to conventional batch drying. Therefore, different approved technologies of lumber drying should be combined in a continuous drying process for solid spruce wood. Conventional condensation drying, high temperature drying, high frequency vacuum drying, infrared drying and air-jet drying combined in an individual arrangement should accelerate the drying progress in dependence of the individual board moisture content.

The purpose of this study is to establish a basis for a model, which allocates the most efficiently sequential arrangement of drying technologies to each board with its individual moisture content.

STATE OF THE ART AND METHODOLOGICAL APPROACH

The conventional wood drying process based on fresh air/exhaust moist air exchange is well documented in the various literature, theoretically and in practical application as well (e.g. Pratt 1974, Langrish *et al.* 1993, Keey *et al.* 2000, Trübswetter 2006, Perré 2007, Teischinger 2012). Very important sources of knowledge are comprehensive documentations of former wood drying conferences such as the compilation of Fortuin (2003) and the COST action E 15 "Advances in drying of wood" (Anon. 2004). In his dissertation Fortuin (2003) provides a very detailed and comprehensive documentation on the application of mathematical models describing the conventional drying process by convective heat transfer.

The conventional kiln drying process based on fresh air/exhaust moist air exchange in a batch chamber has several advantages and disadvantages as compiled in the various handbooks on wood drying (Trübswetter 2006, Teischinger 2012).

One of the main disadvantages of this system is: building up stacks with stickers before putting the stacks into the drying chamber, which is work-consuming in the production process, batch drying is a discontinuous process (or quasi discontinuous process in the case of a drying tunnel), comparatively slow process based on convective heat exchange. Due to the "open" fresh air/exhaust air system the energy balance is not very beneficial even by applying heat recovering systems.

Easy handling and controlling the system, the use of comparatively cheap low temperature heat from combustion of by-products (e.g.: bark, sawdust) and wood waste material as an energy source account for the benefit of the system. Different drying processes such as the dehumidification process, radiofrequency or microwave drying are primarily based on electricity as an energy source, which is much more expensive than heat from a plant-internal combustion process. A detailed study on the energy balance and energy costs of the conventional drying process and the dehumidification process was given by Teischinger (1980), Ressel (1986) and Tretau (2008) analyzed the energy consumption of various drying processes and introduces an energy management system.

Various other drying technologies for wood (including veneer) such as e.g.: radio-frequency (high frequency) drying, air-jet drying are described in detail in distinct literature such as Fessel (1964), Kröll (1978), Resch (2009).

When comparing different drying processes besides drying time and energy consumption the drying quality has to be taken into consideration as well. A good means to assess drying quality is the current EN-standard EN 14298 "sawn timber – Assessment of the drying quality".

Based on these findings, it becomes clear that there is a trade-off concerning the economics of the drying process between the various drying processes (including the different energy sources) and the drying time which is related to each process. It is obvious that electrical energy input in order to evaporate the moisture in the wood is very expensive compared to heat from the combustion process. As most of the lumber drying is a batchwise stack drying, one process applied to a specific stack cannot be changed during the whole drying process due to the surrounding infrastructure of the kiln. Furthermore, infrared radiation, radio-frequency energy cannot be transferred to a single lumber board when stacked to a pile.

WORKING HYPOTHESIS – ACCELERATING THE PROCESS BY SPECIFIC DRYING STEPS

One of the approaches in this study is to analyze the best possible progress of drying of a fresh cut sample board of spruce with a distinct thickness (40 mm) concerning the different drying technologies, which could be applied in different stages of the drying process. The cost-effective conventional convection drying process could be the predominant process, but during specific stages of the drying process, other technologies, such as the high temperature drying, high frequency vacuum drying, infrared drying, and air-jet drying may be applied in this study. According to Fig. 1 they would only be applied for a specific period in order to accelerate the drying process, but to keep the costs of electrical energy input as low as possible.

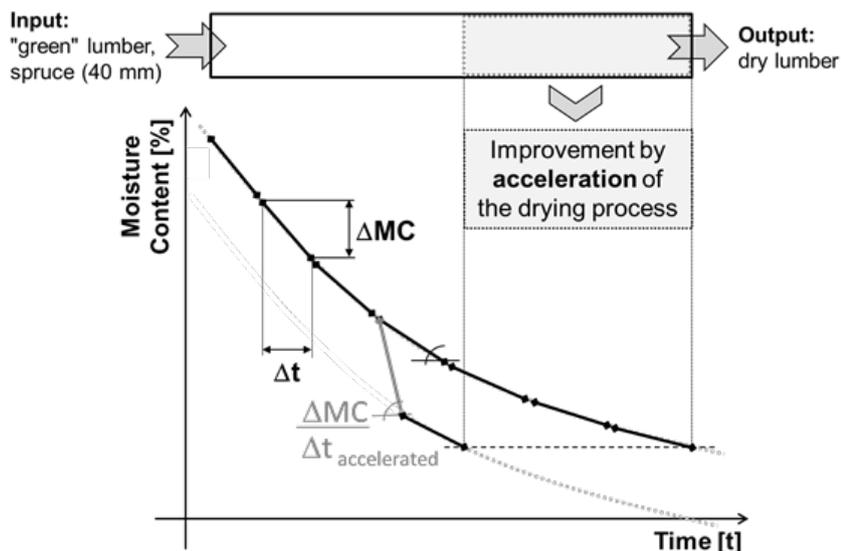


Fig. 1

Typical drying rate of a conventional convection drying. As a hypothesis high frequency vacuum, infrared or air-jet drying at a certain moisture content could give an accelerating impulse to reduce the drying time.

One of the prerequisites for applying different drying technologies within one process is to change from batch-wise stack-drying to a continuous “sequence-drying” of the boards. Similar to veneer drying, where the sheets are conveyed in one veneer layer through a chamber (there can be several distinct layers within one chamber), a sequence of lumber boards should be conveyed through a chamber where each board can be measured and monitored concerning its specific moisture content. Along the conveyed sequence of boards different drying technologies may be applied as shown in Fig. 2. The following drying technologies have been taken into account:

- Conventional convection drying
- High temperature drying
- High frequency vacuum drying
- Infrared drying
- Air-jet drying

MATERIALS AND METHODS

A model sample board of spruce with a thickness of 40mm and an initial moisture content of >50% and a final moisture content of 10% was used in order to characterize the various drying rates of the different technologies shown in Fig. 2 and explained in the following.

The conventional convection drying experiments run in a laboratory convection kiln dryer equipped with an electronic humidity and temperature sensor and was operated by a computer aided process control (Fig. 2). One “standard” and one “accelerated” drying schedule was controlled in dependence of the wood moisture content by means of screwed in electrodes. The settings for the standard drying were shown in Fig. 3a and for the accelerated drying in Fig. 3b.



Fig. 2
Laboratory convection kiln dryer.

HF[%]	Temp	TG	UGL
60%	43°C	3,2	9,4
35%	44°C	3,2	9,4
30%	47°C	3,3	9,0
25%	52°C	3,2	7,8
20%	55°C	2,9	6,8
15%	58°C	2,6	5,8
10%	62°C	2,1	4,7
8%	65°C	1,9	4,3

HF[%]	Temp	TG	UGL
60%	63°C	4,1	7,4
35%	64°C	4,1	7,4
30%	67°C	4,3	7,0
25%	72°C	4,3	5,8
20%	75°C	4,2	4,8
15%	78°C	3,9	3,8
10%	82°C	3,7	2,7
8%	85°C	3,5	2,3

a)

b)

Fig. 3

Settings of the drying temperature (Temp), drying gradient (TG) and equilibrium moisture content (UGL) in dependence of the wood moisture (HF) of the standard (2a) and the accelerated (2b) drying schedule.

The high temperature drying was processed by superheated steam in a laboratory tube furnace (Fig. 4). The thermal energy was supplied by electric heating coils. Two high temperature dryings were processed, one at 110°C and 78% relative humidity (RH) for 44 hours and another one at 120°C and 63% RH for 22.5 hours to reach final moisture content.



Fig. 4
Laboratory tube furnace.

An in-house designed high frequency vacuum dryer was used for the dryings (Fig. 5). The principal components were the vacuum chamber, condenser and a generator. The drying process of the high frequency vacuum technology is based on a reduced boiling point of water due to the low pressure inside the

vacuum chamber and the heating of the water dipoles in the wood due to the electromagnetic waves. The process control worked by means of the ratio of the wood temperature to the boiling point of water (T/T_s), which was kept above 1 throughout the dryings for drying 1 and 2 (Table 1).



Fig. 5
Frequency vacuum dryer

Table 1

Settings of the high frequency vacuum drying 1 and 2

Settings	Drying 1	Drying 2
Drying temperature [°C]	47.6	46.8
Boiling temperature [°C]	40	47.7
Pressure / Vacuum [mbar]	73.9	174
Ratio T/T_s	119	108
Drying time from 80 to 12% MC [hours]	38.5	96

For the infrared drying a laboratory fresh/exhaust air chamber equipped with two infrared ceramic heaters (2000W) was used (Fig. 6). Drying temperature on the wood surface was 150°C and in the core 85°C for 18.5 hours, until final MC of 12% was reached.



Fig. 6
Laboratory fresh/exhaust air chamber equipped with two infrared ceramic heaters.

For the air-jet drying again a laboratory fresh/exhaust air chamber was used, equipped with nozzles (diameter of 1mm) in pipes (diameter of 10mm) with a distance of 10mm (Fig. 7). Heated air with an temperature of 75°C and an relative humidity of 25% flowed at a distance of 30mm and a flow velocity between 20-25m/s on the board surface. On the board surface drying temperatures of 70°C and in the board core of 65°C was reached. The drying time from 80% to 12% MC was 23.5 hours.



Fig. 7

Laboratory fresh/exhaust air chamber with air-jet equipment.

These drying technologies and schedules lead to a series of drying curves (Fig. 8) which are the bases for a further modelling the best combination of different technologies to be applied in a specific stage of the process. The technological implementation and transition to combine these presented methods in one continuous drying process is not shown here. This study primarily focuses on the combination of the most accelerated drying technologies in dependence of the wood moisture content and drying step.

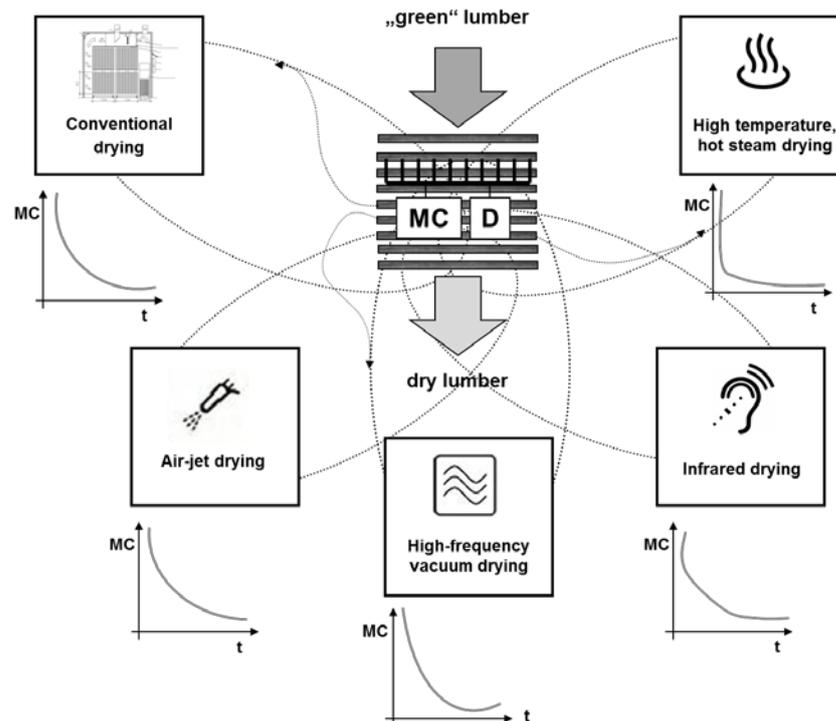


Fig. 8

When drying a conveyed sequence of boards, different drying technologies can be applied along the whole drying process.

RESULTS AND DISCUSSION

As a first result the various drying characteristics for the model board due to the different technologies applied, are given in Fig. 9. The severe high frequency vacuum drying, high temperature drying at 120°C, infrared drying and air-jet drying have shown from >50% to 20% a comparable drying rate. The drying rate below 20% MC for the high temperature at 120°C is the highest. The infrared and the air-jet drying have shown comparable drying rates. Both conventional convection dryings and the mild high frequency vacuum drying as well as the high temperature drying at 110°C indicated clear differences in regard of their drying rates from the very beginning (Fig. 9).

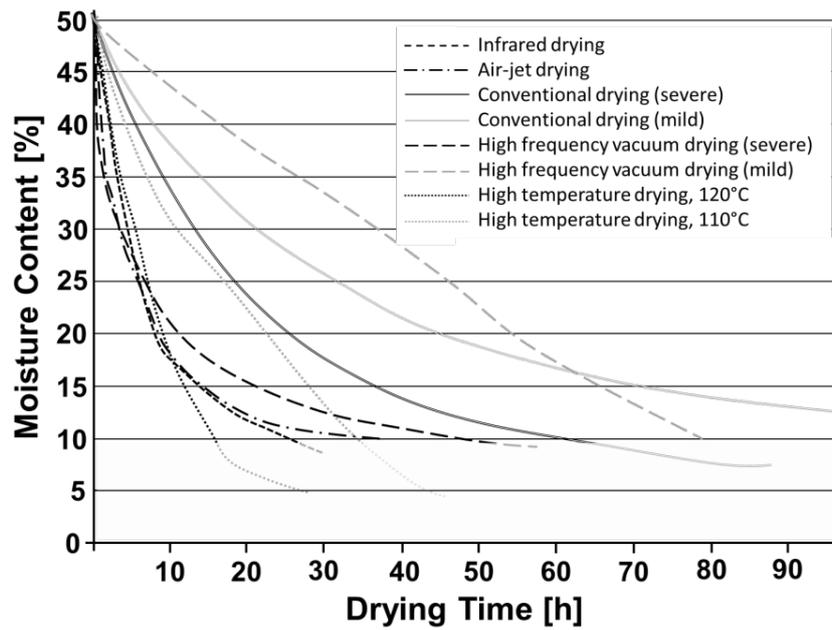


Fig. 9

Compilation of the various drying characteristics of the model sample (spruce, thickness 40mm) as a basis for the drying model in order to find the best possible combination of drying technologies.

Fig. 10 provides a first impression on the idea of combining different drying technologies within one drying process. The drying curve (characteristic) of a conventional drying according to Fig. 9 is superimposed with a curve of high temperature drying. Considering the drying rate and the overall drying costs, which are assumed to be lowest at the conventional drying, the process starts with a conventional drying stage and is followed by high temperature drying (specific models and variations are to be developed currently and an evaluation of these combinations of different drying technologies will be the next step for further investigations).

These results are based on drying experiments of spruce wood (40mm) and cannot be automatically transferred to other wood species and dimensions. Therefore more experimental work is necessary in regard of the influence of species and dimensions.

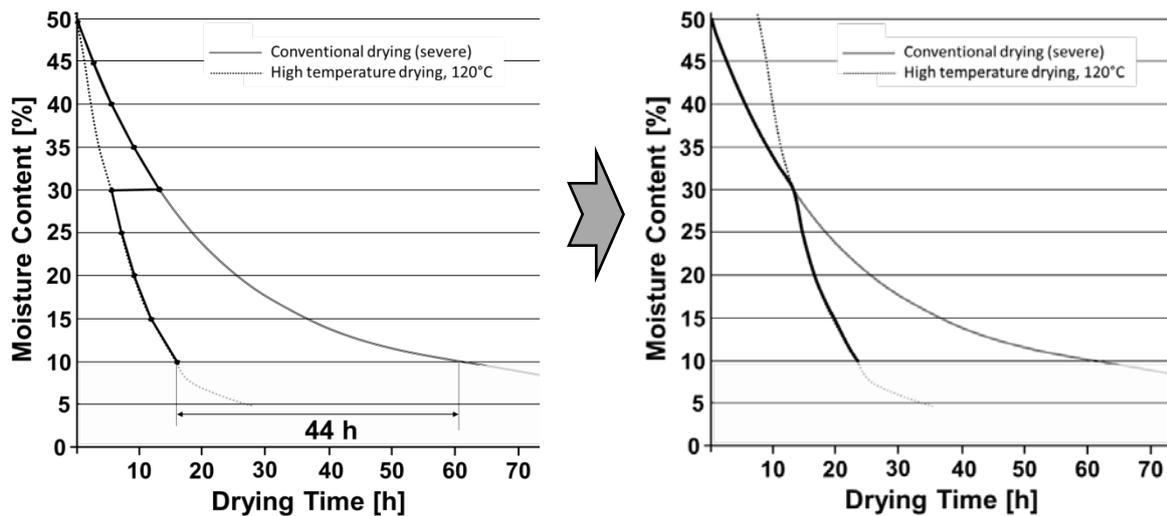


Fig. 10

Example of the idea of combining different drying technologies within one drying process. As shown in the left diagram a two-step drying process (first conventional followed by high temperature drying) can save 44 hours or 73% of the expected drying time of conventional drying.

SUMMARY

The working hypothesis of combining different drying technologies within one continuous single drying process could be accepted. The current approach is a theoretical idea of a continuous sequence drying system for boards, but a specific transfer into a practical application is not considered at this stage. The first results have shown, that for spruce wood with a thickness of 40mm the combination of conventional and high temperature drying at 120°C could have an accelerating impulse operated with proportional expenses. If the expenses were not considered, but only the drying rate, another combination(s) are possible. Based on a characterization of different drying technologies applied to a model board of spruce, the various characteristics (drying curves) can be superimposed during different stages of the drying process. So the fastest or practical feasible, but not the cheapest path can be elaborated. Currently a model is to be developed for a trade-off analysis of drying time and specific costs of the various drying technologies. A further modeling should be a decision tool to find a proper combination of technologies with respect to drying time and drying costs.

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