Impact of Initial Moisture Content on the Drying Process of Wood Exposed to Infrared Radiation

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This article reports the results of temperature measurements carried out on 50-mm-thick Norway spruce (*Picea abies* [L.] Karst) wood samples exposed to infrared (IR) radiation. The varied property with respect to the optimization of the drying technology was the initial moisture content of samples. During the experiments, temperature profiles were registered on the surface and in the core of the samples under controlled technological conditions. Based on our osmotic approach, the variability in the curves was interpreted with respect to the stagnation temperature below the fiber saturation point (FSP). We conclude that the amount of liquid water necessary for osmosis must still be available locally in the core. With decreasing initial average moisture content, the time interval of the osmotic process also decreases. In this context our results support the hypothesis that the presence of free water in the wood tissue is necessary for the osmotic mechanism even if the average moisture content falls below the FSP.

Keywords: Infrared thermal treatment; Wood drying; Moisture content; Osmosis

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INTRODUCTION

Conventional wood drying technologies are based on the understanding of the drying mechanism of wood tissue. Through the understanding and description of the heat and mass transport processes in the drying wood on the macro- and microlevel, the appropriate adjustments of the technological parameters can be executed and the driving forces of the drying process thus can be accurately influenced. At the microscopic level, mechanisms cannot be examined at all or can only be examined partly, even with complex instruments. Therefore, when analyzing the drying mechanism, we rely on the results of macroscopic measurements. Based on the results of macroscopic measurements carried out on measuring equipment composed of simple elements, we gain insight into microscopic processes. This kind of mapping of the drying mechanism helps us to improve the quality of dried wood produced in the woodworking industry and also to increase the efficiency of the drying technologies.

Besides the commonly applied convective drying methods, infrared (IR) irradiation is also used either alone (Kollmann *et al.* 1967) or as part of complex drying processes (Valentino *et al.* 2002; Altun *et al.* 2011). In our earlier work (Cserta *et al.* 2011) the mechanism of wood drying using an IR heat transfer method was studied. The results indicated that the moisture transport mechanism could be considered as a semi-permeable membrane process with the moisture content as a dilute aqueous solution. We proposed that the moisture movement in wood is governed by osmotic effects based on a characteristic stagnation of the core temperature accompanied by a continuous decrease in moisture content. The initial moisture content of the samples was found to be one of the main parameters that had a significant effect on the dynamics of the drying.

In the present work, we consider the results of the temperature measurements on samples with varying initial moisture content with respect to the optimization of the drying technology. Because osmosis can only occur between liquid phases, it requires the presence of the continuous phase of liquid water. Due to the variability in the curves with respect to the stagnation temperature below the fiber saturation point, (FSP), as well, we conclude that the amount of liquid water necessary for osmosis must still be available locally in the core. When the initial moisture content decreases below the FSP, the time interval of the osmotic process also decreases. Our results are consistent with the presence of free water in the wood tissue below the FSP.

MATERIALS AND METHODS

The measurements were carried out in an IR furnace, as described earlier (Cserta *et al.* 2011; Cserta 2012). The actual output power of the radiators was varied during the irradiation process according to the set temperature using feedback from temperature sensors of the furnace. The combined nominal output power of the heating wires was 8 kW. The samples were exposed to continuous irradiation by a source of constant or gradually increased temperature. Temperature measurements were continuous using calibrated K-type thermocouples.

Freshly cut or pre-dried Norway spruce (*Picea abies* [L.] Karst) samples with varying geometry were exposed to identical IR irradiation. First, two sample types were examined: one with moisture content above the FSP (freshly cut) and one with below that. Because their temperature profiles showed significant differences, we added two extra sample types of 15 to 22% and 12 to 14% initial moisture content.

The process was monitored by measuring the temperature changes. Drill holes holding the sensors were positioned in the core and on the surface of the sample. These two measuring points enabled a depth-dependent description of the process.

The temperature changes of boards of 50×200×500 mm size were measured following the general practice of examining lumbers of approximately 20 to 50 mm thickness, *e.g.*, Awoyemi and Jones (2010); Gonzalez-Pena and Hale (2010); Ohmae and Makano (2009); Pang (2002); and Rozas *et al*. (2009). The boards were hung in a furnace and were irradiated without interruption for at least 200 min. All measurements were repeated at different irradiation intensities.

RESULTS

Temperature Measurements

Figure 1 demonstrates the temperature profiles of the samples with different initial moisture contents; the samples were exposed to radiation at 140 to 170 ºC for about 200 min.

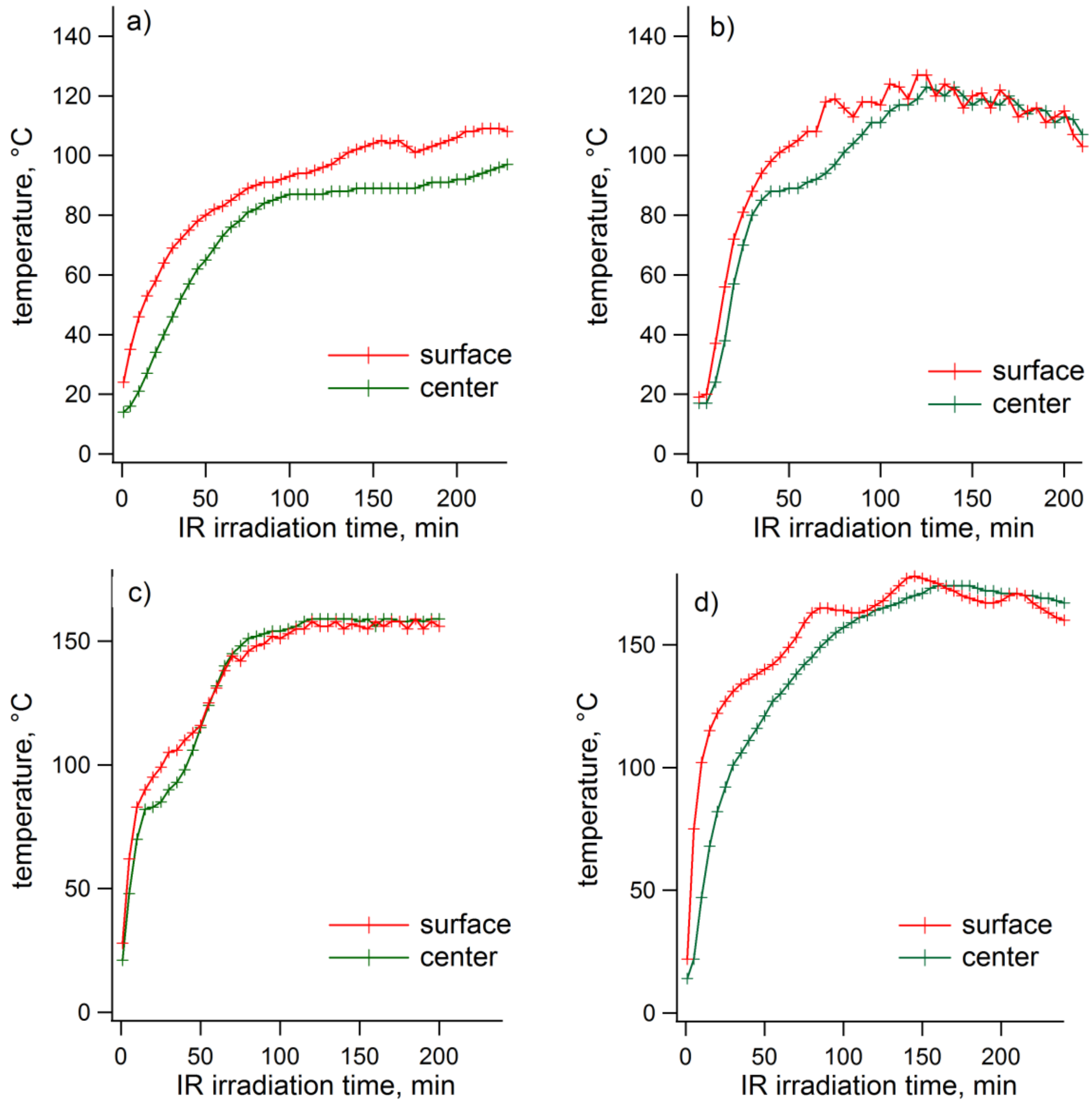

Fig. 1. Temperature profiles of freshly cut and pre-dried samples as a function of IR exposure time. (a) The initial moisture content of the sample was 45 to 60%. Maximum IR emitter temperature was set to 140 ºC; (b) The initial moisture content of the sample was 15 to 25%. Maximum IR emitter temperature was set to 140 ºC; (c) The initial moisture content of the sample was 15 to 18%. Maximum IR emitter temperature was set to 170 ºC; (d) The initial moisture content of the sample was 12 to 14%. Maximum IR emitter temperature was set to 170 ºC.

For the sample with the highest initial moisture content (Fig. 1a), the core temperature increased until reaching approximately 90 °C; it then stagnated for a time, and then it started to increase again. This interval was shortened and the stagnation was replaced by a relatively slow temperature increase with the initially dried sample with an initial moisture content of 15 to 22% (Fig. 1b). For the sample of 15 to 18% initial moisture content (Fig. 1c), this interval was reduced to a mere inflection point, while in the case of the sample of 12 to 14% moisture content (Fig. 1d), it disappeared completely. The surface temperature did not show this phenomenon in any of the experiments.

DISCUSSION

The effect of different technological adjustments and sample properties on the drying process can be interpreted in view of our osmotic approach. In the following, we examine the role of the initial moisture content.

The lack of a delay in the core temperature increase in the case of the initially dry sample (Fig. 1d) supports the assumption that the stagnation of the core temperature was highly influenced by the initial amount of liquid phase moisture content. It is clearly visible that the stagnation phase was shortened significantly with decreasing initial moisture content (Figs. 1a through 1d). In other words, there was a definite relationship between the initial moisture content and the duration of the core temperature stagnation produced by the osmotic vacuum.

Because osmosis may occur only between liquid phases, it requires the presence of liquid phase water on both sides of cell walls. There is variability in the curves with respect to the stagnation temperature below FSP; therefore, we conclude that the amount of liquid water necessary for osmosis must still be available locally in the core. By decreasing the initial moisture content below FSP, the time interval of the osmotic process decreases. These results are consistent with the presence of free water in the wood tissue, even below the FSP, which ensures the liquid medium necessary for the osmotic mechanism.

This conclusion coincides with previous research by Almeida *et al.* (2007) and Rozas *et al*. (2009), who claim that a region can exist in drying wood where the loss of bound water occurs when liquid (free) water is still available.

CONCLUSIONS

1. In the present work, Norway spruce samples of different initial moisture contents were exposed to IR radiation. Temperature was detected on the surface and in the core of the samples under controlled technological conditions. Based on the results, the appearance of liquid (free) water under FSP was predicted.

2. Because there is variability in the curves with respect to the stagnation temperature below FSP, we conclude that the amount of liquid water necessary for osmosis must still be available locally in the core. When the initial moisture content decreases below the FSP, the time interval of the osmotic process also decreases. The presence of free water in the wood tissue below the FSP is confirmed.

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REFERENCES CITED

Almeida, G., Gagne, S., and Hernandez, R. E. (2007). "An NMR study of water distribution in hardwoods at several equilibrium moisture contents," *Wood Sci. Technol.* 41(4), 293-307.

Altun, S., Yapici, F., and Korkmaz, Z. (2011). "Effects of vacuum drying with infrared heating on some properties of wood," *Forestry and Wood Technology* 73, 16-22.

Awoyemi, L., and Jones, I. P. (2010). "Anatomical explanations for the changes in properties of western red cedar (*Thuja plicata*) wood during heat treatment," *Wood Sci. Technol.* 45(2), 301-313.

Cserta, E., Hegedűs, G., and Németh, R. (2011). "Drying process in Norway spruce wood exposed to infrared radiation," *BioResources* 6(4), 4181-4189.

Cserta, E. (2012). "Drying process of wood using infrared radiation," PhD dissertation, The József Cziráki Doctoral School of Wood Sciences and Technologies, University of West Hungary, pp. 37-41.

Gonzalez-Pena, M. M., and Hale, M. D. C. (2011). "Rapid assessment of physical properties and chemical composition of thermally modified wood by mid-infrared spectroscopy," *Wood Sci. Technol.* 45(1), 83-102.

Kollmann, F. F. P., Schneider, A., and Böhner, G. (1967). "Investigations on the heating and drying of wood with infrared radiation," Wood Sci. Technol. 1(2), 149-160.

Ohmae, Y., and Makano, T. (2009). "Water absorption properties of bamboo in the longitudinal direction," *Wood Sci. Technol.* 43(5-6), 415-422.

Pang, S. (2002). "Investigation of effects of wood variability and rheological properties on lumber drying: Application of mathematical models," *Chem. Eng. J.* 86(1-2), 103-110.

Rozas, C., Tomaselli, I., and Zanoelo, E. F. (2009). "Internal mass transfer coefficient during drying of softwood (*Pinus elliottii* Engelm.) boards," *Wood Sci. Technol.* 43(5-6), 361-373.

Valentino, G. A., Leija, L., Riera, E., Rodríguez, G., and Gallego, J. A. (2002). "Wood drying by using high power ultrasound and infrared radiation," Proceedings of Forum Acousticum, Sevilla, Spain, September 16–20, 2002.

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