

EFFECTS OF ULTRASOUND ON WOOD VACUUM DRYING CHARACTERISTICS

Zhengbin HE

Beijing Forestry University - College of Materials Science and Technology - Key Laboratory of Beijing for Wood Science and Technology
Address: P.O. Box 979, Beijing Forestry University, 35 Qinghua East Road, Haidian district, Beijing, 100083, P.R. China
E-mail: he050914409@126.com

Zijian ZHAO

Beijing Forestry University - College of Materials Science and Technology - Key Laboratory of Beijing for Wood Science and Technology
Address: P.O. Box 979, Beijing Forestry University, 35 Qinghua East Road, Haidian district, Beijing, 100083, P.R. China
E-mail: zhaozijian427@163.com

Fei YANG

Beijing Forestry University - College of Materials Science and Technology - Key Laboratory of Beijing for Wood Science and Technology
Address: P.O. Box 979, Beijing Forestry University, 35 Qinghua East Road, Haidian district, Beijing, 100083, P.R. China
E-mail: yf19890525@163.com

Songlin YI

Beijing Forestry University - College of Materials Science and Technology - Key Laboratory of Beijing for Wood Science and Technology
Address: P.O. Box 979, Beijing Forestry University, 35 Qinghua East Road, Haidian district, Beijing, 100083, P.R. China
E-mail: ysonglin@126.com

Abstract:

Ultrasound was examined as an alternative way to assist wood vacuum drying in this paper. Drying tests were carried out at three absolute pressure levels at 25°C to determine the effects of ultrasound and absolute pressure levels on the drying characteristics. A microscopic analysis was also carried out to visualize the formation of microchannels and view any other changes to wood tissue structure that occurred. Results showed that ultrasound could improve wood temperatures during the drying process, and the final temperatures increased with decreasing absolute pressure levels. The temperature decreased with increasing ultrasound propagation distance. Ultrasonic waves also could create microchannels within the tissue of wood samples. For the ultrasound-vacuum combined dried samples, there were some ruptures and small holes on the wall of vessel; some pits were abscission, extracts in wood ray cells were removed, and pits on parenchyma were punctured. These changes provide the passageways for water leaving from wood, and thus improve the drying rates and decrease the drying time.

Key words: *ultrasonic drying; temperature distribution; microstructure; vacuum drying.*

INTRODUCTION

Wood drying is one of the most important steps in wood product manufacturing. The drying process consumes roughly 40-70% of the total energy in the entire wood products manufacturing process. (Zhang and Liu 2006). However, currently-used conventional drying methods are time consuming and energy consumption, some even result in significant quality problems, and reduce the value of the wood products (Anon 1997).

Power ultrasound is a novel technology in material drying, and it is considered an alternative to other energy sources, since it is an efficient non-thermal alternative to increase drying rate without significantly heating up of the material (Cohen and Yang 1995). When ultrasound power is applied in porous material, ultrasound waves will cause rapid series of alternative compressions and expansions, in a way similar to a sponge when it is squeezed and released repeatedly (De la Fuente *et al.* 2006). The forces generated by this mechanical mechanism could be higher than the surface tension, which maintains the moisture inside the capillaries of the material. And the forces also could remove strongly attached moisture in material. As a result, moisture could be easily removed from the material (Azoubel *et al.* 2010). In addition, pressure variations, oscillating velocities, and microstreaming generated by ultrasound affecting the solid-gas interfaces may reduce boundary layer thickness and, therefore, improve the water transfer rate from the solid surface to the air medium (Gallego-Juárez 1998).

In recent years, ultrasound has been implemented as an alternative method for drying material, and the results have shown that this method can greatly reduce the overall processing time (Aversa *et al.* 2011, Mothibe *et al.* 2011, Jangam 2011), increase the mass transfer rate (Cárcel *et al.* 2011, García-Pérez *et al.* 2011, Zhao and Chen 2011), increase wood specific permeability coefficient (Takashi 2010), and increase the effective water diffusivity (Bantle and Eikevik 2011, Fernandes and Rodrigues 2008). However, few reports so far have addressed the application of ultrasound to vacuum drying of wood. In this work, the temperature distribution inside wood samples during the drying process was investigated, and a microscopic analysis was also carried out to explain why ultrasound-vacuum combined drying could significantly improve the drying rates.

MATERIALS AND METHODS

Material and Equipment

Chinese Catalpa wood (*Lignum Catalpae Ovatae*) provided by Chengde Rongxing Furniture Co., Ltd, Hunan, China, was taken as specimen. The dimension of the test specimens was 400mm long by 100mm wide by 60mm thick with the initial moisture content of 95%.

A schematic of the experimental set-up of ultrasound vacuum drying system is presented in Fig. 1. Pressure controller, vacuum pump and pressure meter could control the pressure with the accuracy of ± 0.002 MPa automatically, the absolute pressure ranges from 0.096MPa to 0.1MPa (ambient pressure); Data acquisition system (including temperature sensor made of TP100 thermocouple, data routing inspection and computer) record temperatures inside wood specimens automatically during the drying process; The electronic generator driving the ultrasonic transducer is composed of an impedance matching unit, a power amplifier, and a resonant frequency control system, this system is specifically developed to keep the power applied constantly at the resonant frequency of the transducer during the process, the ultrasonic generator has a maximum power capacity of about 1200W and with the frequency of 20, 28, 40kHz respectively. The ultrasonic transducer is connect to the ultrasonic generator with corresponding power and frequency levels, it also contacts directly with wood to avoid ultrasonic energy attenuation; The gas valve recovered the vacuum condition in drying chamber to the ambient pressure whenever the chamber needed opening. The air velocity was controlled by PWM (pulse width modulation) and measured with a hot-wire anemometer in order to do the test at a constant velocity of 1m/s. The temperature monitor controlled the temperature according to pre-set values. The heat generator consisted of two sets of heat generators. The highest temperature that could be selected was 200°C.

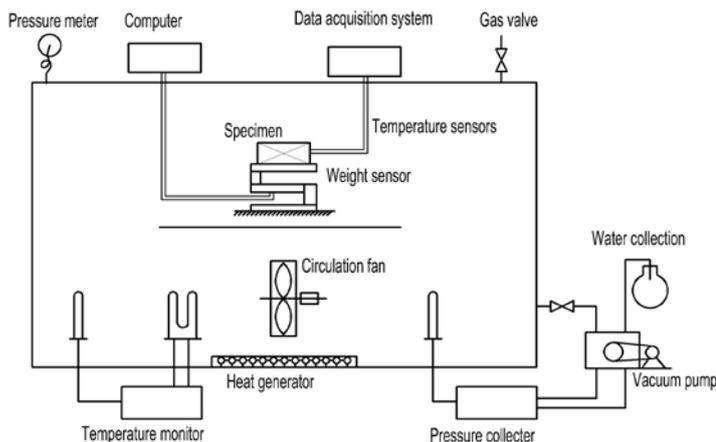


Fig. 1

Schematic of the experimental set-up of the ultrasound-vacuum dryer.

METHODS AND PROCEDURES

The experiment was carried out at various absolute pressure levels. The temperature distribution inside samples during the drying process was investigated. And scanning electronic microscopy was used to characterize the wood structure changes before and after drying.

Vacuum drying procedure

The drying temperature was held constant at 25°C (ambient temperature), and the absolute pressure levels were 0.03, 0.06 and 0.1MPa respectively. Ultrasonic frequency level was held at 20kHz constantly and ultrasonic power was held at 100W. Thermocouple locations and identification letters was shown in Fig. 2. In each experiment unit, the temperature value acquisition process finished when temperatures inside samples became constant.

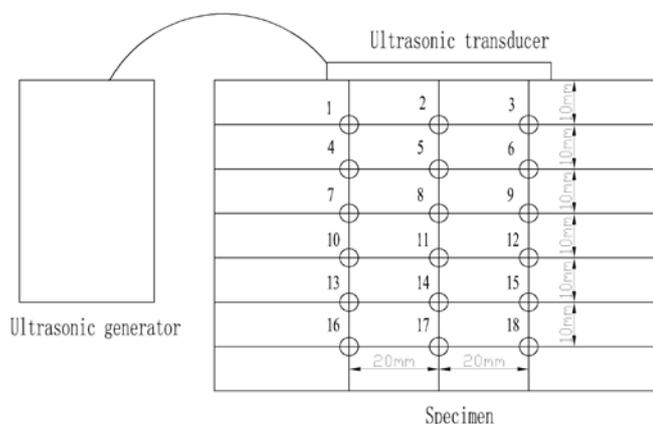


Fig. 2

Thermocouple locations and identification letters.

Electron microscope scanning

A sample was selected randomly from each experiment unit and cut into cubes with the dimension of 5mm per side for microscopic image analysis using a scanning electron microscope (SEM, Hitachi S-3400N II, Tokyo, Japan).

RESULTS AND DISCUSSION

Temperature distribution

In order to evaluate or investigate the effects of ultrasound and the absolute pressure levels on the ultrasound-vacuum combined drying characteristics, the temperature distribution nephogram at different conditions are presented in Fig. 3 - 5.

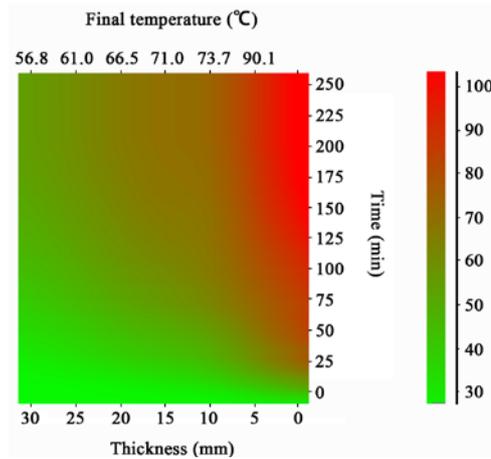


Fig. 3

Wood temperature distribution nephogram at 0.03Mpa.

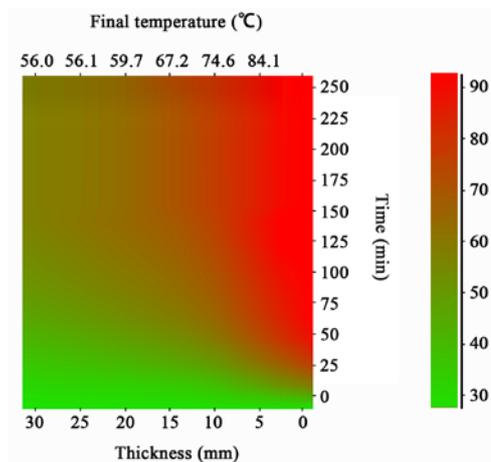


Fig. 4

Wood temperature distribution nephogram at 0.06Mpa.

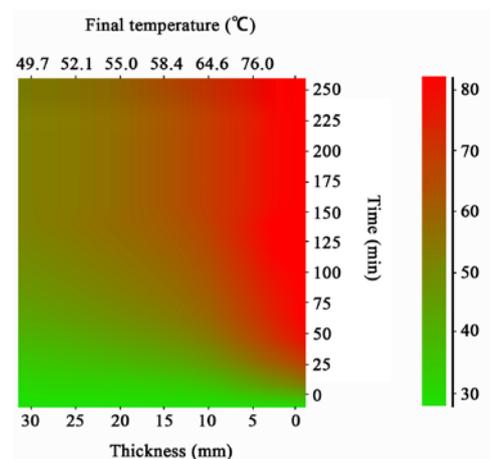


Fig. 5

Wood temperature distribution nephogram at 0.1Mpa.

It is found that the temperatures inside samples became constant ultimately, and the final temperatures increased with decreasing absolute pressure levels. When the drying processes were carried out at 0.03, 0.06 and 0.1MPa respectively, the highest final temperatures were 100°C, 90°C and 80°C respectively. Temperatures of samples carried out at lower absolute pressure levels were higher than those carried out at

higher absolute pressure levels. Furthermore, the reduced temperatures were observed from 100°C to 56.8°C at absolute pressure level of 0.03MPa, from 90°C to 56.0°C at 0.06MPa and from 80°C to 49.7°C at 0.1MPa when the distance from wood surface increased from 0mm to 30mm. That mainly because ultrasound wave is one kind of mechanical waves in the elastic medium. When it propagates in the medium, particles of the medium subject to the mechanical action, some of the mechanical energy was translated into heat (Yang 2009). What's more, when ultrasound travels across a medium, cavitation bubbles are generated, the bubbles can also grow and collapse and generate very high local temperatures and pressures (Soria and Villamiel 2010). As a result, ultrasound-vacuum combined drying could improve wood temperatures and therefore shorten the drying time.

ELECTRON MICROSCOPIC ANALYSIS

In terms of microstructure, there are generally three kinds of cells present in hardwoods, namely, vessels, fibres and ray cells including parenchyma (Desch and Dinwoodie 1996). The intervacular pits in the longitudinal walls are the communication paths for lateral flow between adjacent vessels, and the parenchyma is that for transverse direction in ray cells.

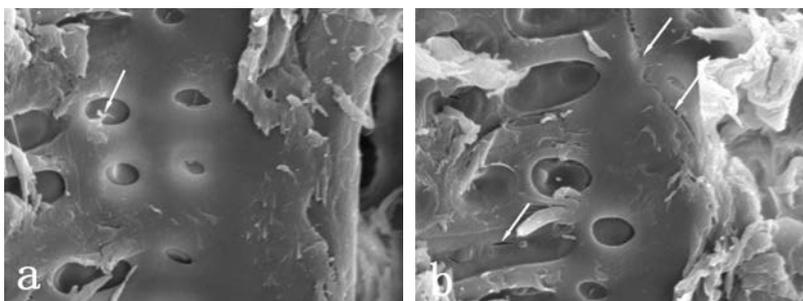


Fig. 6

Photomicrograph of wood vessel wall (1000×): (a) Without ultrasound; (b) Dried by ultrasound.

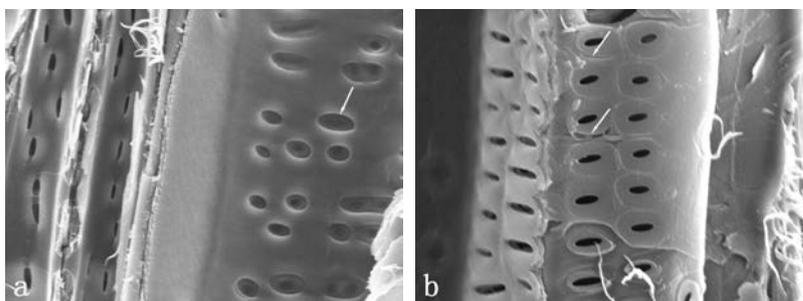


Fig. 7

Photomicrograph of wood pits (1000×): (a) Without ultrasound; (b) Dried by ultrasound.

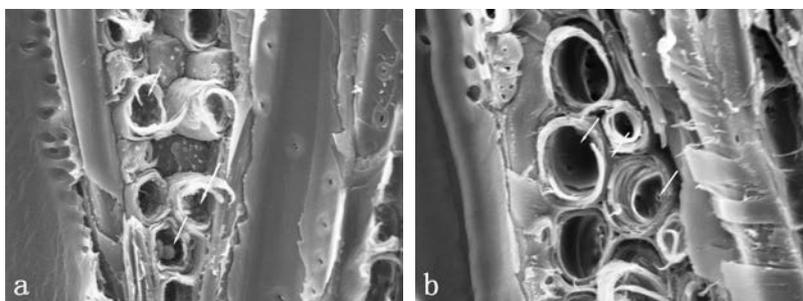


Fig. 8

Photomicrograph of wood extracts (1000×): (a) Without ultrasound; (b) Dried by ultrasound.

Scanning electron microscopy (SEM) micrographs indicated that, the ultrasound-vacuum combined drying method had significant influence on the sample tissue structure (Fig. 6 - 8). Compared with samples dried without ultrasound (Fig. 6a, 7a and 8a), for the ultrasound-vacuum combined dried ones, there were some ruptures and small holes on the wall of vessel (Fig. 6b), some pits were abscission (Fig. 7b). And

extracts in wood ray cells were removed (Fig. 8b), pits on parenchyma were also punctured (Fig. 8b). Therefore, ultrasonic waves could promote cavitation and induce the formation of microchannels within the tissue of wood samples, which also could be found in many existing researches (Stojanovic and Silva 2006, Garcia-Noguera *et al.* 2010). These changes provided passageways for water leaving from wood, and thus improved the drying rates and decreased the drying time. The reason could be that when wood suffered from ultrasound, ultrasonic waves squeezed and released repeatedly and created microscopic channels in porous materials (De la Fuente 2006). Moreover, ultrasound cavitation could generate a microjet that hits the solid (Mason 1998), the microjets hitting the solid surface may produce an injection of fluid inside the solid (Mason and Cordemans 1996) and created microchannels in material.

What's more, through wood microstructure was broken by ultrasound, the strength of wood samples was not changed, for the reason that wood fibres was the strength and mechanical support of wood (Panshin and de Zeeuw 1970) and ultrasound only broke the structure of pits and removed the extracts. It will not affect wood physical characteristics (mechanical strength), and it is a good way to improve wood permeability and shorten the drying time.

CONCLUSIONS

Ultrasound could improve wood temperatures during the drying process, and the final temperatures of wood increased with decreasing absolute pressure levels. When the drying process were carried out at 0.03, 0.06 and 0.1MPa, respectively, the highest final temperatures were 100°C, 90°C and 80°C respectively. The temperature decreased with increasing ultrasound propagation distance. The reduced temperatures were observed from 100°C to 56.8°C at absolute pressure level of 0.03 MPa, from 90°C to 56.0°C at 0.06MPa and from 80°C to 49.7°C at 0.1MPa.

What's more, ultrasonic waves could promote cavitation and induce the formation of microchannels within the tissue of wood samples. Compared with samples dried without ultrasound, for the ultrasound-vacuum combined dried ones, there were some ruptures and small holes on the wall of vessel; some pits were abscission, extract in wood ray cells were removed, and pits on parenchyma were punctured. These changes provide the passageways for water leaving from wood, and thus improve the drying rates and decrease the drying time.

From a general point of view, the effects produced by ultrasound during ultrasound-vacuum combined drying process could increase sample temperature and create microstructure in wood tissue, as a result, this drying methods could greatly reduce the overall processing time, increase the mass transfer rate, increase wood specific permeability coefficient and increase the effective water diffusivity.

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