Drying Parawood with Superheated Steam

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Abstract: A superheated steam dryer (SSD) was used to dry the parawood. The average moisture content and temperatures in the dryer vs. elapsed drying time were experimentally investigated. It was found that the superheated steam could increase the potential of the conventional hot air drying. By using a SSD at the superheated steam temperature of 110 °C with volumetric flow rate of 125 $m^3 min^{-1}$ for parawood's thickness of about 30 mm, the moisture content of the parawood could be reduced from 40% (d.b.) to about 9.75% (d.b.) within 35 hrs while the conventional hot air dryer required the drying time of approximately 8-16 days. The physical structure of the parawood was also investigated by a prong test. The quality of dried parawood was not found to be different from those dried with the hot air drying method.

Keywords: Superheated steam drying, parawood

INTRODUCTION

Over the years, the application of superheated steam for drying have been studied by a number of researchers[1-11]. However there are few studies applying the superheated steam with the wood drying. To the best knowledge of authors, up to now, there has been only two works carried out by Pang and Pearson[10] and Defo et al.[11], dealing with the application of superheated steam drying for wood.

Pang and Pearson[10] conducted an experiment to dry radiate pine timber by using superheated steam under vacuum and at various pressures. Experiments consisted of two parts. In the first one, softwood timber was dried in a superheated steam kiln. Drying rates, steam temperature across the stack and wood temperature were measured. In the second one, experimental studies were performed to investigate the applications of the superheated steam drying at ultra-high temperatures. The experimental results showed that the ultra-high temperature drying saved more energy and could reduce the drying time by a factor of 5 to 10. The pressurized steam conditioning was proven to be a method to decrease twist of the dried timer.

Defo et al.[11] developed a two-dimensional mathematical model for vacuum-contact drying of wood using superheated steam. The heat and mass transfer equations were based on the water potential concept whereas the pressure equation was formulated considering unsteady-state mass conservation of dry air. The convective heat and mass transfer coefficients were determined from the test conducted with sugar maple sapwood in a laboratory vacuum kiln. The average air velocity was 2.5 m s $^{-1}$ and the dry-bulb temperature varied between 60 and 66°C. The ambient pressure varied from 15 to 11 kPa. The simulation results elucidated that heat and mass transfer coefficients were dependent on the moisture content.

As described above, information on drying wood with superheated steam is still limited. In order to have fully understanding of the wood drying process using superheated steam, more experimental studies on this issue should be done. In the present study, the main concern is to experimentally study the use of superheated steam in drying parawood. The drying characteristics in terms of average moisture content vs. elapsed drying time and temperatures in the dryer vs. elapsed drying time were investigated. The effects of superheated steam temperature, flow delivery and wood thickness on the drying kinetics were investigated and compared. The quality of the product after drying was discussed.

MATERIALS AND METHODS

The experiment was conducted at the Department of Mechanical Engineering, KMUTT. Schematic diagram of the experimental apparatus is shown in Fig. 1. The main principle is to blow superheated steam into the temperature-controlled drying chamber.

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Table 1: Detailed information of the dryer and experimental conditions

Drying chamber size	1.5 m × 1.5 m × 1.5 m
Boiler capacity	Maximum steam production 9 kg hr^{-1}, Maximum pressure 9 bar
Effective volume in drying chamber	Maximum capacity 1.2 m^3
Size of parawood	25 mm × 75 mm × 1000 mm
	30 mm × 75 mm × 1000 mm
	50 mm × 75 mm × 1000 mm
Electrical heater	Maximum power 5 kW.
Drying temperature	110° C, 120 ° C
Motor for blower	1 Hp. 220 volt.
Volumetric flow rate induced by blower	55 m^3 min^{-1}, 90 m^3 min^{-1}, 125 m^3 min^{-1}
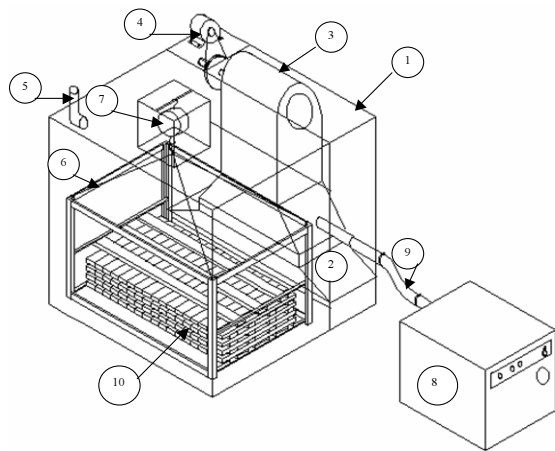
1. Drying chamber   6. Wood supporting frame
2. Hood   7. Balance
3. Blower   8. Boiler
4. Blower motor   9. Steam pipe
5. Exhaust pipe   10. Parawood
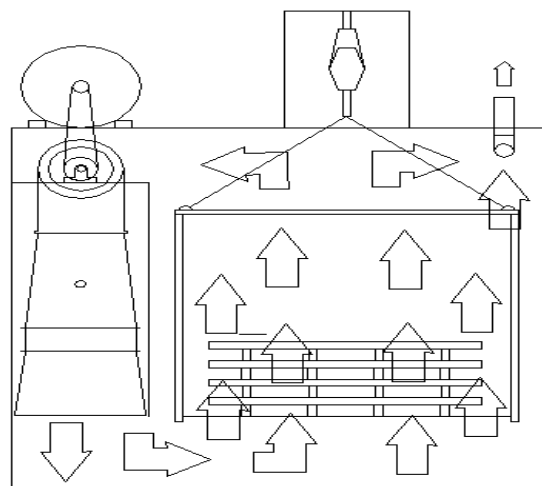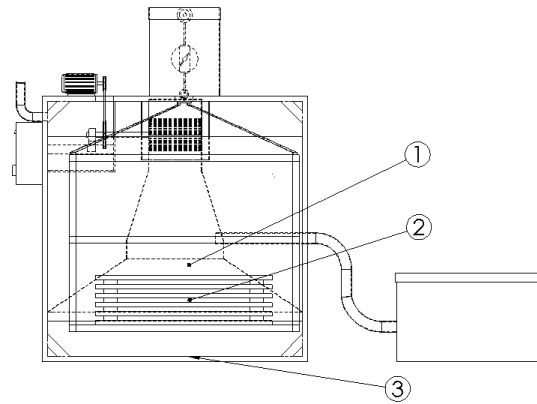
Fig. 1: Schematic diagram of the experimental apparatus

Fig. 2: Schematic diagram of the steam flow direction

1 Controlled temperature
2 Wood bed temperature
3 Supplied steam temperature

Fig. 3: Temperature measuring points

Detailed information of the dryer is shown in Table 1. A blower was used for the steam propulsion. Steam sucked in by the blower was fanned through layers of wood, which lowered its temperature. This steam was mixed with the superheated steam generated from the boiler and passed through the reheater to make its temperature higher than the controlled temperature. Finally, the mixed steam was blown back into the drying chamber. Schematic diagram of steam flow directions is shown in Fig. 2. The drying procedure continued until the wood's final moisture content is below 12%. Positions of temperature readings are shown in Fig. 3.

RESULTS AND DISCUSSION

Effect of temperature of superheated steam: Figure 4 shows a relationship between wood's moisture content and elapsed drying time, at the controlled drying temperatures of 120°C and 110°C. At the beginning, superheated steam blown into the drying chamber which had lower temperature had caused condensation - some occurred on the wood and some occurred around the chamber wall. This was evident from the higher weight of wood which signified the higher moisture content. After a while, the moisture content of wood decreased back to the same level as the initial value and continued decreasing gradually. It was also evident that the drying rate increased with increasing drying temperature. At the temperature of 120°C, it took about 25 hrs to reduce moisture content from 38% to 9.7%. On the contrary, at the temperature of 110°C, it took up to 35 hrs to reduce the moisture content from 40% to 10%. However, more cracks were found after drying at
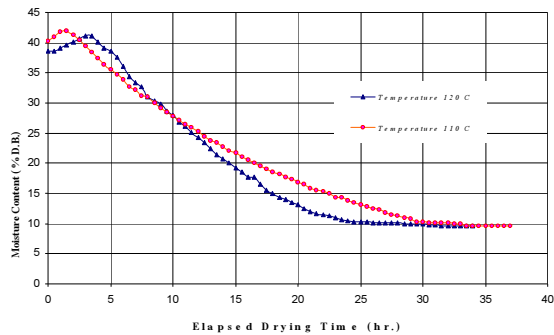
Fig. 4: Plot of average moisture content against time at various temperatures, (Flow rate=125 m^3/min, thickness=30 mm)
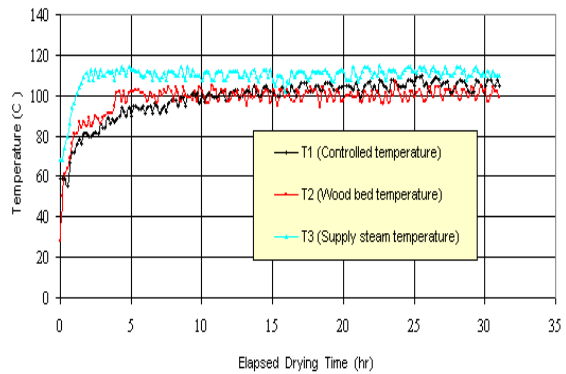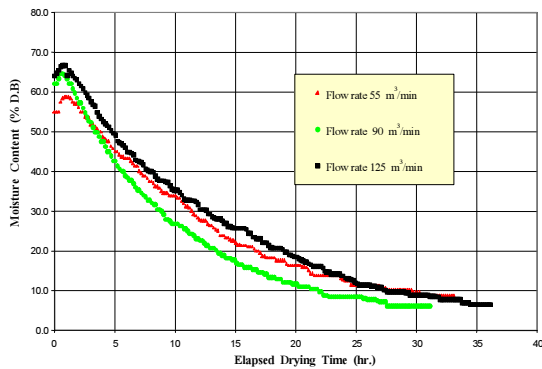

Fig. 5: Plot of average moisture content against time at various flow rates, (Temperature=110 °C, thickness=30 mm)

Fig. 6: Plot of temperature against time for wood thickness of 25 mm at flow rate of 55 m^3/min

higher temperature. This may be because at the temperature of 120°C, the atmospheric pressure would cause about 50% of relative humidity in the drying
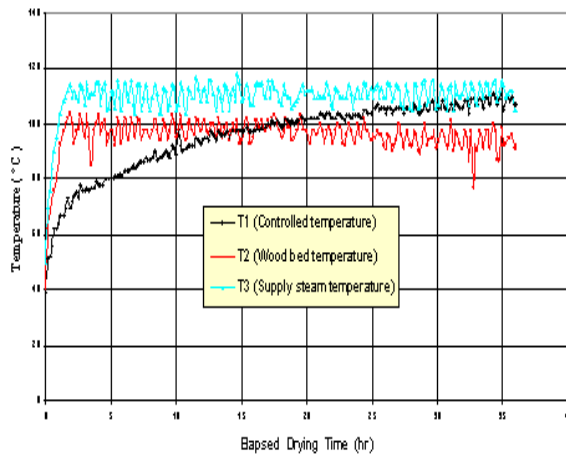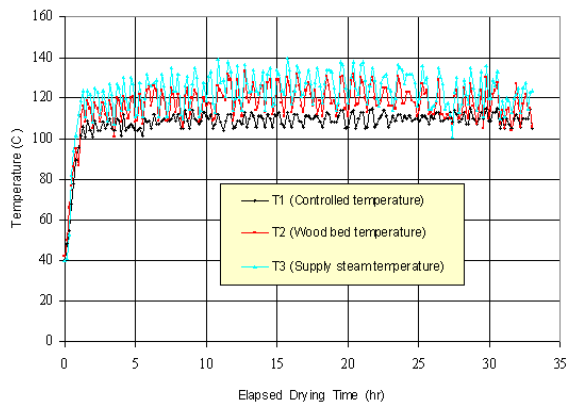

Fig. 7: Plot of temperature against time for wood thickness of 25 mm at flow rate of 90 m^3/min

Fig. 8: Plot of temperature against time for wood thickness of 25 mm at flow rate of 125 m^3/min

chamber, whereas at the temperature of 110°C, the atmospheric pressure would cause about 70% of relative humidity.

Effect of flow delivery from the blower: The temperature of 110°C was thus selected for the next experiment. The study about effect of volumetric flow rate was done by varying speed of motor driving blower. This enabled the volumetric flow rate to be varied from 55 – 125 m^3 min^{-1}. Results of the experiment shown in Fig. 5 revealed that, at the blower delivery of 90 m^3 min^{-1}, the moisture content decreased quicker than at the flow rate of 55 m^3 min^{-1} and 125 m^3 min^{-1}. Figures 6, 7 and 8 also showed that the time constant value was 2 hrs at the flow rate of 55 m^3 min^{-1}, 13 hrs at the flow rate of 90 m^3 min^{-1} and 20 hrs at the flow rate of 125 m^3 min^{-1}. Considered the changing temperature in the drying chamber, it was found that at
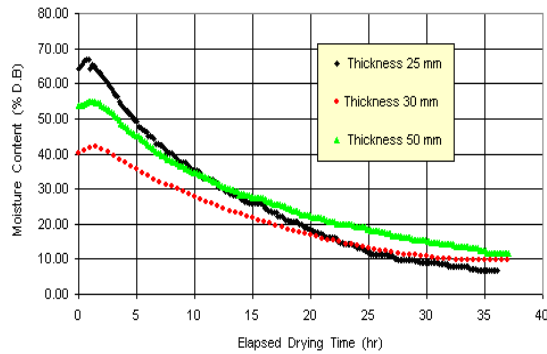
Fig. 9: Plot of moisture content against time at controlled temperature of 110 °C, flow rate of 55 m³/min for various wood thicknesses

Fig. 10: Photograph of parawood after the prong test

higher time constant, wood temperature would be low, which resulted in higher quality of dried wood. Hence, it could be seen that the volumetric flow rate in drying would better be 125 m³ min⁻¹.

Effect of wood's thickness: As shown in Fig. 9, at the blower delivery of 125 m³ min⁻¹, it was found that the wood of 25mm thickness yielded maximum moisture content reduction – from 64% to 10% within 26 hrs. The wood of 30mm and 50mm thickness yielded similar reduction rate. In the wood of 30mm thickness, moisture content reduced from 40% to 10% within 31 hrs, whereas in the wood of 50mm thickness, moisture content reduced from 52% to 10% within 36 hrs. Concerning the physical structure of the dried wood, the wood of 25mm thickness was found to be more damaged (bent, crooked and cracked) than the wood of 30-50mm thickness.
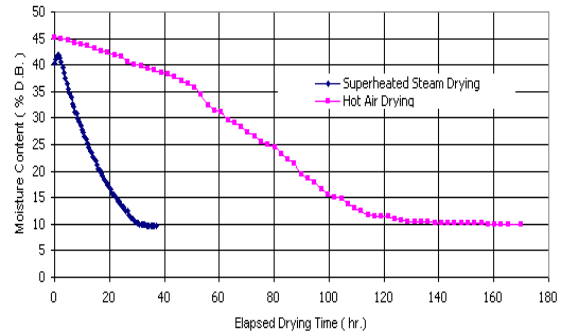

Fig. 11: Comparison between superheated steam drying and hot air drying

Quality of wood after drying: Besides the crack and crook, color and hardness of dried parawood were also considered. Generally, color of parawood might be changed by fungus and oxidation. The steam drying could reduce oxidation and keep color of dried wood similar to fresh wood. Results from Prong Test as shown in Fig. 10 revealed no bend in the prong, which means no residual stress from drying.

Comparison between superheated steam drying and hot air drying: Figure 11 shows a relationship between average moisture content and elapsed drying time of superheated steam drying at the temperature of 110 °C, flow rate of 125 m³ min⁻¹, compared with hot air drying at the air temperature of 40 °C, relative humidity of 70%. A significant difference can be clearly seen from this figure. The hot air temperature gradually increased while the wood's moisture content decreased. Therefore, longer time was needed in this drying process.

CONCLUSION

It could be concluded from results of the experiment that the most suitable steam flow rate in the drying chamber should not be less than 125 m³ min⁻¹ while the most suitable thickness of wood should not be less than 30 mm. The use of superheated steam at the temperature of 110°C in atmospheric pressure could maintain constant moisture content at about 50% throughout the drying duration; hence, no stress was caused in the dried wood. The drying of parawood with superheated steam at the temperature of 110 °C could replace traditionally hot air drying method and could reduce drying duration from 7-10 days to only 35 hrs. Moreover, the color of dried wood also remained similar to the color of the freshly transformed wood due

to shorter drying duration and no occurrence of oxidation.

ACKNOWLEDGEMENTS

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