Modeling Drying Time during Veneer Drying and Comparison with Experimental Study

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Abstract— **Veneer drying is an important process in manufacturing of plywood and laminated veneer lumber. In order to understand and to improve the veneer drying, a mathematical model was developed based on heat and moisture mass transfer processes within the wood in the air stream. The model was validated from commercial scale drying tests. Air temperature, humidity and exit air velocity all affect the veneering drying to a different extent. This paper describes the drying time of veneer for 0.5 mm to 2.0 mm thickness. The variables considered for two wood groups were temperature, thickness and moisture content. An empirical equation was derived from a simple physical model and used to correlate this data. The raw material used mainly are kanyin (Botanical Name: Dipterocarpus spp) and Inn. Drying is a process of reducing the water content of timber economically and with the minimal damage to the stock. The empirical equation depends on the measurement of the moisture content and indirectly the water potential, the temperature at the surface of a wood specimen and different thickness which were used for the determination of drying time.**

Key words: veneer drying, drying rates, thickness of veneer, moisture content, empirical equation

I. INTRODUCTION

Plywood is made of three or more thin layers of wood (veneer) bonded together with an adhesive. Each layer of wood or ply is usually oriented with its grain running at right angles to the adjacent layer in order to reduce the shrinkage and improve the strength of the finished piece. Most plywood is pressed into large, flat sheets used in building construction. Other plywood pieces may be formed into simple or compound curves for use in furniture, boats and aircraft.

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The plywood and laminated veneer lumber (LVL) manufacturing, control of moisture content in dried veneer is critical importance for the dryer operators. Prolonged drying will not only consume extra energy but also produce a condition known as surface-inactivation, a cause of poor glue bond strength.

In this study, the initial moisture content of veneer is 75% to 85%. The final moisture content for the veneer is normally required to be 8 % to 12% for plywood and 10% to 14 % for LVL. If the moisture content is higher than the target moisture content range, the veneer should be re-dried. From an economic point of view, an optimum re-dry proportion is normally about 9% to 14 %. The drying time is normally adjusted by checking the moisture content of the dried sheets. If the re-dry proportion is too high, in other words the average moisture content is high, either the feed speed is reduced or a higher temperature schedule is used.

One type of commonly used veneer dryers is the jet impinging dryer with its schematic drawing of such a dryer being shown in Figure 1. From previous studies (Comstock, 1971; Pang et al., 1997), the variables affecting the drying rate may be classified into three categories: (1) equipment variables, (2) process variables and (3) veneer sheet variables.

The equipment variables include those such as jet box design or orifice dimensions (size, shape), percent of the orifice area, distance of the jet to drying surface and return air system etc. In current studies, two types of jet configurations have been found in the commercial dryers. The process variables are temperature, humidity and velocity of the impinging air, while veneer variables include wood density, thickness of the veneer, types of wood and the green moisture content.

II. MODEL DEVELOPMENT AND MATERIAL

In the present work, a mathematical model for veneer drying is proposed based on both internal and external transfer processes and on wood thermodynamics. The model has been numerically solved to predict profiles of wood moisture content, temperature, vapor pressure and drying rate. After experimental validation, the proposed 1849 model

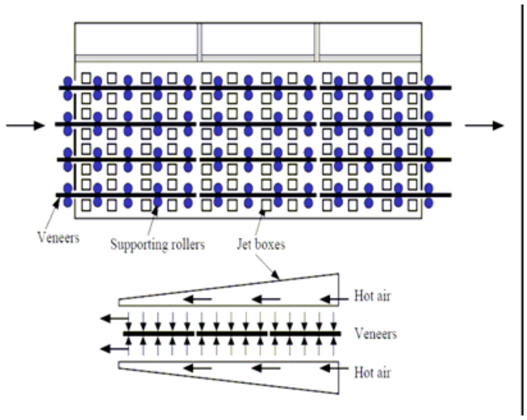

Fig.1. Schematic drawing of a veneer dryer and jet box configuration

has been used to investigate the effect of drying conditions, wood properties and veneer thickness on the drying rate. This information is very useful for the dryer operators and the schedule designers. The dryer is continuous conveyor dryer which contains the blowers, the heaters and jet boxes. The blowers run to circulate the steam into the dryer. Drying runs were conducted at the temperature of 100°C, 120°C, 130°C, 140°C and 150°C.

The advantages of conventional jet drying include (1) Continuous operation and (2) Lower capital equipment costs. The disadvantages of jet drying compared with press and rollers drying include (1) High operating costs for electric power and (2) Not as high quality veneer from press dryers.

III. MATERIAL SELECTION

The outer layers of plywood are known as the face and the back. The face is the surface that is to be used or seen, while the back remains unused or hidden. The center layer is known as the core. In plywood with five or more plies, the intermediate layers are known as the cross bands.

Plywood may be made from hardwoods, softwoods or a combination of the two. Some common hardwoods include ash, maple, mahogany, oat and teak. The most common softwood used to make plywood in the United States is Douglas fir, although several varieties of pine, cendear, spruce and redwood are also used. In Myanmar, the raw materials used mainly are Inn, Kanyin (Botanical name; Dipterocarpus spp) and Teak. The trees used to make plywood are generally smaller in diameter than those used to make lumber.

IV.NUMERICAL MODEL FOR DRYING TIME

The following simple model is proposed to describe high-temperature drying of veneer. It is assumed that heat transfer occurs at two sides of the infinite slab (veneer) and

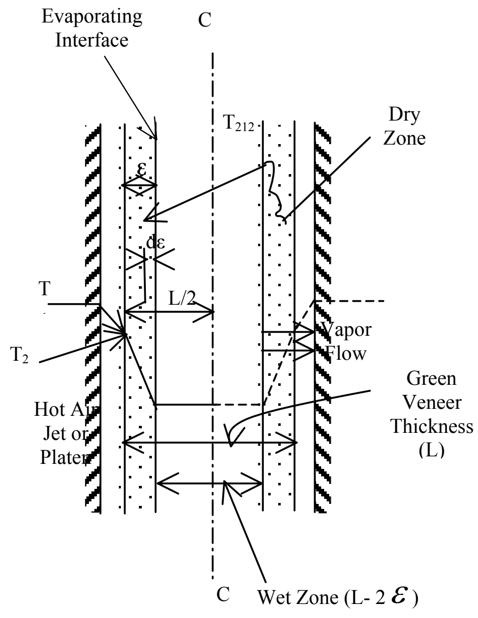

Fig.2. Model for heat transfer and vapor flow in Jet drying veneer

the corresponding vapor flow proceeds in the opposite direction perpendicular to the surface.

Drying can be considered to proceed as an expanding dry zone (ε) formed by a retreating evaporating interface (surface) resulting in a symmetrically shrinking wet zone (L/2 - ε where L = green thickness) .

$$\frac{dQ}{dt} = C_{H_2O}\lambda A \frac{d\varepsilon}{dt} \qquad \text{-------} (1)$$

Where,

Q = heat transferred, t = time, C_{H_2O} = weight of liquid water per unit volume of wood, λ = latent heat of evaporation of water, A = area of contact, ε = depth of evaporating zone from surface at any time t

But,

$$\frac{dQ}{dt} = \frac{KA}{\varepsilon}(T_2 - T_{212}) \qquad \text{-------} (2)$$

Where,

K = thermal conductivity of dry wood, T_2 = surface temperature of wood, T_{212} = normal boiling point H_2O

Combining equation (1) & equation (2), and integrating both sides and rearranging,

$$t = \frac{C_{H_2O}\lambda\varepsilon^2}{2k(T_2 - T_{212})} \text{ - - - - - - - - - (3)}$$

If

$$C_{H_2O} = \frac{W_{H_2O}}{V}$$

and

$$\rho_{wood} = \frac{W_{DW}}{V}$$

Where,
W_{H_2O} = weight of H_2O, W_{DW} = weight of dry wood
V = unit volume of wood

then,

$$C_{H_2O} = \frac{M_0\, W_{H_2O}}{100\, V} = \frac{M_0\, \rho_{wood}}{100} \text{ - - - - - (4)}$$

Since this model proposes an evaporating interface within the wood, at any time t, two zones exist:
Dry zone, MC = 0, Wet zone, MC = M_0
If ε = thickness of dry zone, and
L/2 = total distance surface to centerline
M_i = average moisture content of zone1 + zone 2

Then

$$\varepsilon = \frac{L}{2}\left(1 - \frac{M_i}{M_0}\right) \text{ - - - - - - - - (5)}$$

Substituting equations (4) and (5) into equation (3)

$$t = \frac{M_0\rho_{DW}\lambda(L/2)^2(1 - M_i/M_0)^2}{100 \times 2K(T_2 - T_{212})} \text{ - - - - - - - (6)}$$

Where, initial moisture content M_0 = 88%, final moisture content M_i =12%, Weight of dry wood ρ_{DW} = 0.606×62.4 lb/ft^{-3}, surface temperature of wood T_2 = $150^{\circ}C$, k= 0.1 Btu/lb.ft.°F, L = 0.5 mm and λ = 1000 Btu/lb H_2O evaporation

By substituting the above values and solving,

t = 5.14 min

The above value is sample calculation for drying time at temperature 302˚F and thickness at 0.5 mm. Drying rate at different values are shown in Table 1.

TABLE I. CALCULATED DRYING TIME FROM EQUATION (6)

Drying time, t,(min)	**MC at different temperature (%)**				
	230˚F	248˚F	266˚F	284˚F	302˚F
1	79.43	76.87	74.29	71.73	69.16
3	76.02	66.32	66.59	51.18	43.48
5	69.75	56.32	58.88	30.63	11.78
7	64.02	46.05	43.47	11.09	10.06
9	58.88	35.77	28.07	10.50	9.23
11	53.74	25.49	12.65	8.02	4.56

TABLE II. EXPERIMENT DATA OF MOISTURE CONTENT DURING DRYING AT DIFFERENT TEMPERATURE

Drying time, t (min)	MC at different temperature (%)				
	230˚F	248˚F	266˚F	284˚F	302˚F
1	75.43	71.87	68.29	65.73	62.16
3	70.02	65.32	65.59	50.18	41.08
5	62.75	52.32	53.88	28.63	10.88
7	60.02	46.05	38.47	10.59	9.86
9	57.88	32.77	27.07	8.05	7.29
11	50.748	27.49	11.65	4.92	4.28

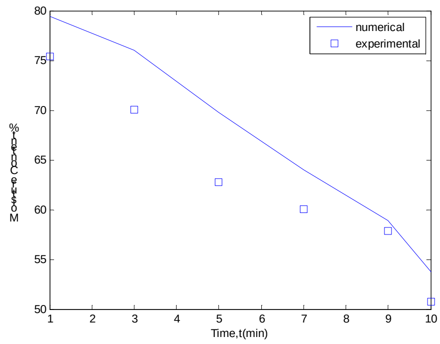

Fig.3. Moisture content at different time and temperature 230 ˚

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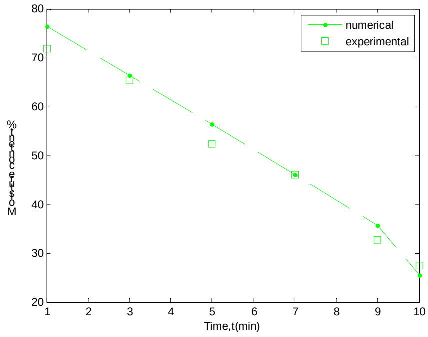

Fig.4. Moisture content at different time and temperature 248 ˚F

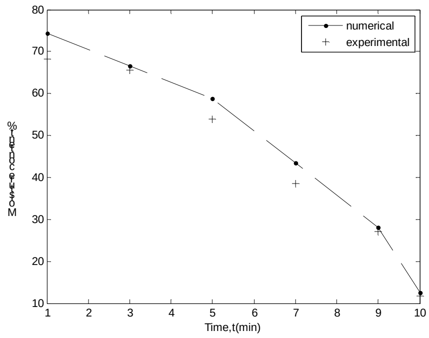

Fig.5.Moisture content at different time and temperature 266 ˚F

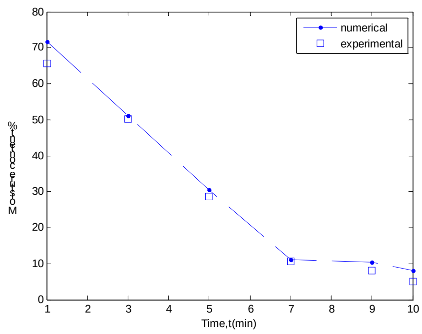

Fig.6.Moisture content at different time and temperature 284 ˚F

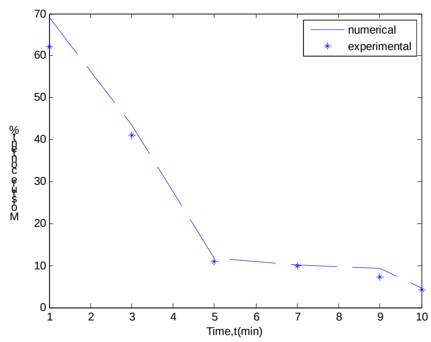

Fig.7.Moisture content at different time and temperature 302 ˚F

V. CONCLUSION

The mathematical veneer drying model proposed in previous work was validated by drying experiments which were performed in industrial dryers. The close agreement between the model predictions and the measured results gave confidence in employing the model to examine the influence of drying conditions and veneer variables. The studies presented about the experimental determination of drying time during veneer drying and compare the experiment data. Plywood veneer moisture content can be very high if the wood is cut from outer sapwood layer of a tree instead of its inner heartwood core. To maintain a good glue bond between plywood veneers and maximize veneer strength, plant operators must dry each sheet within a tightly controlled moisture range.

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