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ESTABLISHING SOLAR GREENHOUSE KILN DRYING SCHEDULES FOR TWO THICKNESSES OF *EUCALYPTUS CAMALDULENSIS* DEHN. LUMBER IN THE GOVERNORATE OF DOHUK, IRAQ

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ABSTRACT

Though its greenhouse solar kiln drying qualities are unknown in Iraq's Kurdistan region, Eucalyptus (*Eucalyptus camaldulensis* Dehn.) trees are used in the world's wood industry. A lack of knowledge about the drying characteristics of these species may result in value losses during drying. After being sawed into flat-sawn and quarter-sawn boards and dried using various drying schedules, the dried board was evaluated by the European Drying Group (EDG) Standards. The results show that drying 50 mm thick samples from 55% moisture content (MC) to 14% at an initial relative humidity of 95% and temperature of 35°C took around 94 days. The second drying cycle was finished at the following temperature and a drying gradient value of 1.6: The 25 mm thick board required a total of (94) days to dry out from 60% to 8% at the same beginning relative humidity rate and temperature. After that, the study's boards were separated into groups based on their drying quality, with quarter-sawn boards obtaining the best quality and the fewest defects, including mild collapse, low end-split, low bow, cup, and twist, as well as moderate case-hardening.

***KEYWORDS*:** Eucalyptus, greenhouse solar drying, schedules, board thickness, drying defects.

1. INTRODUCTION

Eucalyptus camaldulensis Dehn. is the most widely distributed of all eucalypts in the world and has success in Iraq and the Kurdistan region of Iraq Taha, (2013). Olufemi, and Malami (2011) and Raven *et al.*, (1997) cleared that the wood of *Eucalyptus camaldulensis* Dehn. is a promising species for utilization in timber industries.

In order to add value to solid wood products, drying is now acknowledged as a crucial step. As a result, efforts are being made to increase drying quality and lower drying costs. Eucalypts, especially back-sawn boards, are famously difficult to season without degrading due to their characteristically high shrinkage and low mass diffusivity values Vermass, (2010). Improved timber quality, lower costs, and environmental friendliness are all advantages of the solar kiln drying method. The most popular drying methods, include the use of solar greenhouse kilns, drying schedules to achieve ideal drying conditions, and enhancing drying quality Herritsch *et al.*, (2010). According to studies by Gough (1981), Kennedy (1984), Sattar, (1993), Luna *et al.*, (2009) and Stangerlin *et al.*, (2012), drying time for wood of the same thickness in solar greenhouses is two to five times faster than it is for drying outdoors.

In general, air-drying has been preferred over the solar kiln as a pre-drying technique for hardwoods. To raise the temperature within the kiln during the winter, external heat was introduced; but, during the summer, this additional heat was just not needed for this low-temperature drying process. Haque, (2006). There has been a flurry of activity in response to interest in solar energy as a heat source for drying wood Chen *et al.*, (1982), Steinmann *et al.*, (1981), and Steinmann *et al.*, (1980). Eucalyptus trees are being dried in Western Australia using a solar-assisted greenhouse-style timber drying system McDonald, (1991), and Glossop, (1992).

The collapse and internal checks of *Eucalyptus pellita* dried in air drying circumstances were reportedly lower than in kiln drying conditions Chadwick and Langrish (1996). *Eucalyptus regnans* boards dried intermittently have fewer internal checks than boards dried in a kiln. It is necessary to research different schedules with various heat and relative humidity intensities to determine whether they can increase the quality of wood dried in solar kilns Chafe, (1995).

The main characteristics of solar greenhouses, according to Plumptre, (1979) and Santini, (1981), are excellent quality dry wood, obtaining MC below the region's equilibrium humidity, and a shorter drying period when compared to conventional drying. Santini, (1981) adds that, in addition to drying factors, the location and climatic conditions influence how long it takes to dry a load of wood in a solar greenhouse. A drying schedule is a process of employing wet-bulb, dry-bulb temperature, relative humidity (RH), and air velocity to dry timber as fast as possible while avoiding undesirable drying defects Bekele, (1994).

This study aims to assess the drying of Red gum (*Eucalyptus camaldulensis* Dehn.) boards in a solar greenhouse kiln with various schedules in the Sumail district, Dohuk governorate, Kurdistan Region of Iraq.

2. MATERIALS AND METHODS

Red gum eucalyptus (*Eucalyptus camaldulensis* Dehn.) wood was used, and boards (25 and 50 mm thicknesses) were uniformly stacked in a solar greenhouse kiln lumber should then be stacked in the kiln with two different thicknesses 25mm and 50mmm clearance on either side of the stack to permit adequate air circulation, and separated by stickers perpendicularly to the lumber's length at the College of the Agricultural Engineering Sciences University of Dohuk in the Sumail district. Four control samples were used in the assessment of the moisture content of the board as measured throughout the drying process. Each sample had two distinct dimensions of 25 and 50 mm with varying width dimensions and 200 mm in length (thickness × breadth × length). The cut boards were sprayed with oily paint to obtain control samples from the top, bottom, right, and left locations of various board stacks (to decrease the water loss by the ends) Bergman, (2021).

Control samples were placed in a variety of locations that made removal and replacement easy to enable an accurate and representative assessment of the moisture content of the same by Placing the fan for circulation of air through the board stack, and also, for controlling ventilation (such as air exchange between the interior and exterior of the solar greenhouse). The means for controlling ventilation may include a simple adjustable opening, a door, a vent fan, an adjustable roof vent, a shutter, a window, and any equivalent thereof Wang, (2010).

After drying, the moisture content of the boards was measured, and the fork test was used to determine the moisture gradient and internal stresses recommended by Luna *et al.,* (2009). Weighing the control samples was used to check the moisture content every week. the digital thermometer and digital hydrometer instrument were used to continuously record the outside air temperature and relative humidity. It also measured the inside air temperature and relative humidity.

The relationship between temperature and relative humidity will be used to determine the equilibrium moisture content (EMC) of the air (RH). The EMC of the air will determine the moisture content of wood in this environment, regardless of the species or earlier moisture records, which only have a minor effect. Mills, and Rozsa, (1997).

The following formula was used to get the equilibrium moisture content (EMC).

$$\text{EMC\%} = \frac{1800}{\text{w}}\left(\frac{\text{kh}}{1-\text{kh}} + \frac{(\text{k}_1\text{kh})+(2\text{k}_1\text{k}_2\ \text{k}^2\text{h}^2)}{1+(\text{k}_1\ \text{kh})+(\text{k}_1\text{k}_2\text{k}^2\text{h}^2)}\right) \quad \text{Eq. (1)}$$

Where,

W, is dry weight; k, are coefficients defending in the material's parameters where be determined by temperature (˚F); and h is relative humidity expressed in decimal from (100%); and the constant parameters (Eq. No. 1) can be directly used to determine the EMC:

EMC: $\text{k} = 0.791 + 0.000463\text{T} - 0.0000000844\text{T}^2$

$\mathbf{k_1} = 6.34 + 0.000775\text{T} - 0.0000935\text{T}^2$

$\text{k}_2 = 1.09 + 0.0284\text{T} + 0.0000904\text{T}^2$

$\text{W} = 330 + 0.452\text{T} + 0.00415\text{T}^2$

EMC= is the equilibrium moisture content (%).

The drying schedules for *Eucalyptus camaldulensis* Dehn. boards in thicknesses of 25 mm and 50 mm are shown in Tables No. 1 and No. 2 respectively.

Table (1):- The Drying Schedules for *Eucalyptus camaldulensis* Dehn. boards of 25mm thickness.

MC%	Time (Days)	Temperature(F˚)	Relative humidity(%)	MC%	EMC(%)
60-50	16	97	89%	58%	17
50-40	11	100	88%	44%	19
40-30	7	99	86%	30%	16
30-20	12	95	84%	22%	15
20-15	35	102	81%	16%	20
15-10	11	82	43%	10%	14
Equalization 10-8	2	86	40%	9%	13
	94 Days				

Table(2):- Shows the Drying Schedules for *Eucalyptus camaldulensis* Dehn boards of 50mm thickness.

MC%	Time (Days)	Temperature(F˚)	Relative humidity(%)	MC%	EMC(%)
60-50	14	97	86%	60%	23
50-40	16	90	82%	48%	21
40-30	18	86	75%	37%	18
30-20	19	91	68%	25%	15
20-15	12	75	61%	17%	16
15-10	13	72	44%	10%	12
Equalization 10-8	2	75	41%	9%	14
	94 Days				

The European Drying Group standard EDG, (1994) criteria for classifying boards into different merchantable grades were applied for the final quality evaluations of drying defects. The criteria and their allowances for the various quality classes that were used to evaluate the drying quality are described in Tables No. 3 and 4.

Table(3):-. Shows the criteria for the Drying Quality of flat-sawn boards and the tolerances according to EDG, (1994).

Properties	Standard 7-13	Quality dried 8-12	Exclusive 9-11
(Mean MC%)	Max. deviation between mean MC of the load and final(target) MC		
d ≤ 25 mm	+2.0% / -3.0%	+2.0% /-2.0%	+1.5% / -1.5%
d ≤ 50 mm	+3.0% /-3.0%	+2.5% /-2.5%	+2.0% / -2.0%
(MG)	Max. deviation between individual MC measurements and final(target) MC		
d ≤ 25 mm	+4.0% / -open	+3.0% / -3.0%	+2.0% / -2.0%
d ≤ 50 mm	+6.0% / -open	+4.0% / -4.0%	+3.0% / -3.0%
Collapse	S Max. 6mm	Q Max. 3mm	E Max. 2mm
d ≤ 25 mm	Severe		
d ≤ 50 mm	Severe		
End split	Severe Max. L.200mm	Moderate Max.L.200-50mm	Low Max. L.50mm
d ≤ 25 mm		Moderate	
d ≤ 50 mm		Moderate	
Bow	1Grade. (10 mm)	2 Grade. (20mm)	3 Grade. (40 mm)
d ≤ 25 mm	Low		
d ≤ 50 mm	Low		
Cup	1Grade. (20 mm)	2 Grade. (40 mm)	3 Grade. (60 mm)
d ≤ 25 mm	Low		
d ≤ 50 mm	Low		
Twist	1Grade. (10 mm)	2 Grade. (20mm)	3 Grade. (40 mm)

d ≤ 25 mm d ≤ 50 mm	**Low**	**Moderate**	
Case hardening	**Standard (3mm)**	**Quality (2mm)**	**Exclusive (1mm)**
d ≤ 25 mm d ≤ 50 mm		**Moderate** **Moderate**	
Deformations	**Deformation produced by shrinkage and anisotropy of shrinkage, as well as those caused by natural wood properties are allowable**		

Table (4):- Shows the criteria for the Drying Quality of quarter-sawn boards and the tolerances according to EDG, (1994).

Properties	Standard 7-13	Quality dried 8-12	Exclusive 9-11
MC (%)	**Max. deviation between mean MC of the load and final(target) MC**		
d ≤ 25 mm d ≤ 50 mm	**+3.0% / -4.0%** **+4.0% /-4.0%**	**+3.0% /-3.0%** **+3.5% /-3.5%**	**+2.5% / -2.5%** **+3.0% / -3.0%**
(MG)	**Max. deviation between individual MC measurements and final(target) MC**		
d ≤ 25 mm d ≤ 50 mm	**+5.0% / -open** **+7.0% / -open**	**+4.0% / -4.0%** **+5.0% / -5.0%**	**+3.0% / -3.0%** **+4.0% / -4.0%**
Collapse	**S** **Max. 6mm**	**Q** **Max. 3mm**	**E** **Max. 2mm**
d ≤ 25 mm d ≤ 50 mm	**Severe**	**Moderate**	
End-split	**Severe** **Max. L.200mm**	**Moderate** **Max.L.200-50mm**	**Low** **Max. L.50mm**
d ≤ 25 mm d ≤ 50 mm			**Low** **Low**
Bow	**1Grade.** **(10 mm)**	**2 Grade.** **(20mm)**	**3 Grade.** **(40 mm)**
d ≤ 25 mm d ≤ 50 mm	**Low**	**Moderate**	
Cup	**1Grade.** **(20 mm)**	**2 Grade.** **(40 mm)**	**3 Grade.** **(60 mm)**
d ≤ 25 mm d ≤ 50 mm	**Low** **Low**		
Twist	**1Grade.** **(10 mm)**	**2 Grade.** **(20mm)**	**3 Grade.** **(40 mm)**
d ≤ 25 mm d ≤ 50 mm	**Low** **Low**		
Case hardening	**Standard** **(3mm)**	**Quality** **(2mm)**	**Exclusive** **(1mm)**
d ≤ 25 mm d ≤ 50 mm		**Moderate** **Moderate**	
Deformations	**Deformation produced by shrinkage and anisotropy of shrinkage, as well as those caused by natural wood properties are allowable**		

3. RESULTS AND DISCUSSION

It took a total of (94) days for the 25 mm thick drying Eucalyptus board to dry out (target final MC = 8%; initial MC = 60%). The greatest and lowest MC were determined to be 17.3% and 15.2%, respectively. The 50 mm thick lumbers dried for a total of (94) days (target final MC: 10%; initial MC: 60%). The greatest and minimum MCs at the final MC measurements were 20.7% and 10.9%respectively.

At the conclusion of the drying processes, the drying quality was evaluated using the comparative results of eucalypt tree flat-sawn boards and quarter-sawn boards based on the final MC, the gradient of the MC, drying tensions, split formation, and occurrence of the collapse. All test boards fell within the allowed range of 10 mm for bow, cup, and twist, however flat sawn board collapse surpassed the permitted range of 5 mm in both thicknesses, but quarter-sawn board collapse in both thicknesses is mild and less than 3 mm. The species of eucalyptus are prone to collapse Goker and Bozkurt (1996).

End-split boards of flat sawn and range in thickness from 50 to 200mm whereas, quarter-sawn boards range in thickness from low to high and are rated as "1 grade." Additionally, the casehardened boards of all samples had a grade "quality" of less than 2mm EDG, (1994).

The increase in thickness and flat-sawn Eucalyptus boards in the results demonstrated how drying becomes difficult. Drying should be applied gradually and the equalizing time should be increased to 50 mm thickness as a result.

High-quality results were achieved by considering the best drying conditions that should be used in greenhouse kiln drying for both flat-sawn and quarter-sawn boards of 25 and 50 cm thicknesses.

The greenhouse kiln's internal temperature variation is essential for minimizing timber drying degradations and deformations. It is proposed that during periods of higher temperature, controlling EMC in the kiln by maintaining a high level of RH, steaming before drying, and drying flat-sawn boards and quarter-sawn boards of 25 and 50 cm thickness below the Fiber Saturation Point (30%) could reduce the rapid change of MC in wood that causes moderate end-split.

Besides, pre-drying should be used on boards with a high MC. This application should be developed slowly and in a protected environment

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