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DEVELOPMENT OF THE SOLAR KILNS USED IN DRYING THE PALM TREES WASTE IN SAUDI ARABIA

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ABSTRACT

In this work, a simple solar kiln has been investigated for drying the waste of palm trees. This kiln is manufactured from wood available in the local market. It has a vertical front facade and a roof inclined at an angle of 25 degrees on the horizontal which, made of solid transparent plastic with a thickness of 4 mm. The humid hot air at the top of the kiln can be expelled to the atmosphere by a small opening on the back wall of the kiln whereas, this humid air is compensated with new fresh air from an opening at the bottom of the kiln. The instrument of measuring the water content in the palm trees waste has been calibrated by more than one way where, the calibration equation has been created; then the effect of different parameters such as solar radiation intensity, ambient temperature and air humidity has been studied in the case of natural convection air drying process and determined their impacts on the speed of drying by climatic conditions of Taif city.

KEYWORDS: Palm Tree Waste, Solar Energy, Solar Timber Kiln, Wood Drying

INTRODUCTION

In Kingdom of Saudi Arabia, the date palm plantations is occupying 150,744 haAlhudaib et al [1], where thousands of tons of waste can be obtained from 23 million trees annually and thrown in the surrounding, which cause many environmental problems. The waste products of palm trees are fronds and empty bunches can be dried and used in modern wooden manufacturing of desks, cabinets and wooden furniture. If, palm fronds are dried directly in the open air, they will be dried out in a period of time as long as a whole month. The fronds can suffer from insect and microbial infestation, and dust accumulation. Therefore, solar drying is an effective and viable alternative to traditional drying methods. Since the sixties of the last century, lot of researches and developments has been conducted into the use of solar kilns for drying timber. Banks [2] defined the advantages of solar kilns where, the solar drying is faster than air-drying, timber can be dried to moisture content (MC) lower than 10 per cent (%), the drying quality is better than air-drying with a good control system, and the drying costs are competitive. Plumptre [3] and Haque [4], distinguish between two principal categories of kilns: solar kilns with external collectors and greenhouse type solar kilns, where the quality of drying in solar kilns is higher than the conventional kilns. A modified greenhouse solar kiln, with an arrangement to facilitate airflow through the stacks has been built and investigated by Müller [5]. Luna et all [6] suggested a classification system for timber kilns by presenting three typical arrangements by using an analytical method for product design based on TRIZ theory, and they proposed the use of eight laws to evaluate developments in solar dryers. A simulation study has been done by Luna et al [7] ona solar kiln with energy storage which can be used for continuous drying. This kiln consisted of several units where, a model was proposed for each unit, and another based on laboratory tests for drying a wooden board by passing air across. Two developed timber kilns have been designed, constructed, and tested for airflow uniformity within the stacked wood [8]. The first configuration is the arrangement found within most commercial kilns. The second configuration had contoured right-angled bends to the plenum chambers from the ceiling space, where the fans were located. A simulation system has been constructed and tested by D.E., Steinmann[9] to overcome the problem of non-repeatability of the natural weather conditions which cannot be repeated in consecutive drying runs. The simulation system consists of a miniature solar kiln placed inside a climatic chamber and was used to dry pieces of wood using a selected weather sequence which was repeated for consecutive drying runs. Metwallyet all [10]investigated a greenhouse solar kiln dryersfor drying date palm leaves midribs (DPLM) and using them as local wooden material.

In this study a solar kiln with natural convection was designed, constructed, and tested in the lab of solar energy at the College of Engineering (Taif city). Theperformance of the drying process of palm leaves in this kiln was evaluated under Taif city climatic conditions (1450 m above sea level) where, the climate is worm desert for most climatic classification and it is considered as dry climate because rainfall is less than 10inch. Also, the humidity is less than 40%for most months Hamedet all [11].

EXPERIMENTAL WORK

Figure (1) outlines the experimental system which is a semi-greenhouse solar kiln. It is composed of a vertical Perspex plastic façade measuring 150x150 cm**.** The dimension of the kiln roof which is inclined at an angle of 25^0 to the horizontal is 150 x100 cm, whereas the back and side walls are made of wood planks of 10 mm thickness. There are two rectangular openings for air inlet and outlet measuring 30 x 24 cm and 28 x28 cm respectively. The solar kiln contains rectangular shelves which are made of a metal mesh with a wooden frame where, the palm fronds will spread on them. The distance between each two shelves is 6 cm. All edges and corners of the solar kiln were well filled with silicon to prevent any leakage of heat or air infiltration.

In this study, the primary guiding factor in operating a solar kiln is MC of the palm trees waste and the principal scale of success of lumber drying is the final MC. The drying processes is controlled by a number of external factors (solar radiation intensity, ambient temperature, wind velocity and relative humidity) and internal factors (initial moisture content, type of product: fronds or trunk ….etc., and temperature and relative humidity inside the kiln).

Figure 1: Photograph of the Solar Kiln

Moisture content is expressed as a percentage of the oven dried weight of the wood. The expression of moisture content is:

$$MC\ (\%) = \left(\frac{\text{initial mass} - \text{oven dry mass}}{\text{oven dry mass}}\right) X\ 100 \quad (1)$$

The palm leave has been cut for four pieces, weighed, and then put in the oven under a temperature of 100°C for 24 hours for completely dried, reweighed, and finally the MC of this leave has been calculated by equation (1). Also, the final MC of palm leaves was measured by an electronic instrument Model RC-2 with 37E Electrode Fig. (2).This instrument has been calibrated for measuring the MC of the lumber by using the equation (2).

$$y = -0.013\, x^2 + 1.090\, x + 0.173 \quad (2)$$

Where

x Meter readings

y Moisture Content (%)

The average value of R^2 is about 0.998 can be considered as the existence of functional relation.

The internal temperature of the solar kiln was measured by using K-type thermocouples with a dual input Thermometer (FLUKE 52II) whilst, the ambient temperature and the relative humidity inside and outside the kiln were measured by a Temperature-Humidity meter- FLUKE 971.

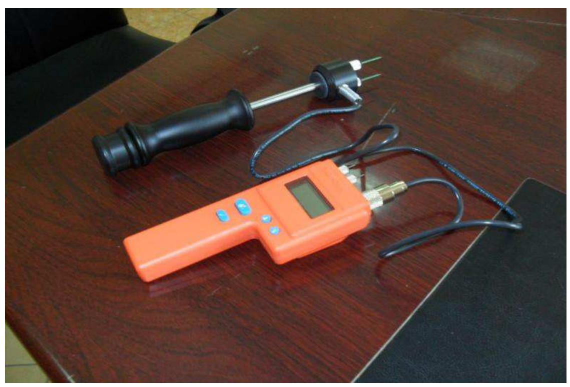

Figure 2: Photograph of Instrument Model RC-2 for Measuring MC of Palm Trees Waste

Measurements were taken at intervals of 1 hour during the period of effective sunshine from 08:00 am to 17:00 pm where, the intensity of solar radiation has been measured by using Pyranometer - LP 02 with Amplifier - AC 420 and Hand held readout unit- LI 18.

RESULTS AND DISCUSSIONS

The main objective of this study was to compare the quality of the drying process of the palm tree leaves in the solar kiln and the traditional open air drying. So, a series of experiments were conducted to understand the performance of the solar kiln and direct sun drying, where the diurnal internal and ambient conditions such as solar radiation intensity, relative humidity and temperature of drying air have been measured. The drying time was predicted to be 11 days during winter season, while this time would be much lower and the drying rate would be much faster in summer with much higher solar intensity and ambient temperature.

Solar Radiation Intensity

Figure (3) represents the comparison between the theoretical values and the experimental measurements of the incident solar radiation for the total period of the drying process between21 and 30/12/2012. This figure shows that the maximum value of the solar radiation intensityfor this period of the drying time is more than 1100 Wm^{-2}, whereas the maximum value of the ambient temperature not exceeded 23°C; it is noted that the internal temperature of the drying air in the top of the solar kiln is more than 55 °C as shown in table (1). This result demonstrates the effectiveness of the designed and constructed solar kiln for drying the leaves of palm trees even in the cold weather conditions (winter season) of Taif city.

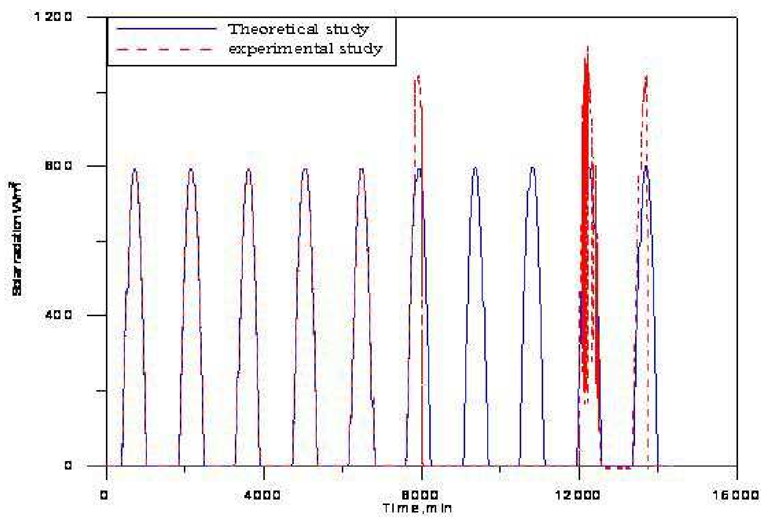

Figure 3: Comparison between Theoretical and Experimental Solar Radiation Intensity during the Drying Time between 18 and 24/12/2012

Drying Air Temperature

The temperature inside the solar kiln was measured in different locations T1, T2,……, and T11 as shown in fig.(4). Table (1) represents aclear difference between the upper and lower temperatures especially between 12:00 PM and 01:00 PM on Sunday 28/11/2012, where the maximum ambient air temperature is 24°C. This is due to the low drying air velocity where the fan was stopped. This table shows also that all the temperatures were going to decrease after 01:30 PM till they reach the ambient temperature.

Table 1: Internal Air Temperature Values in Different Locations inside the Solar Kiln on 28/11/2012 between 9 AM and 15 PM

Temperature (°C)		T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11
Maximum solar radiation intensity 885 (Wm^{-2})	09:00 AM	33.1	34.3	35.6	35.1	33.2	34.3	30.2	27.6	25.2	37.7	39.3
	10:00 AM	46.5	48.6	48.8	48.6	46.5	47.8	40.5	36.5	34.5	44.0	50.5
	11:00 AM	50.0	51.3	53.2	51.8	52.2	51.4	40.5	40.5	41.6	53.0	53.0
	12:00 PM	52.3	53.6	54.8	55.4	56.9	55.8	41.1	40.8	42.4	55.4	58.6
	13:00 PM	50.7	52.2	53.4	54.2	55.1	54.7	40.8	40.2	41.2	54.4	57.3
	14:00 PM	47.5	49.9	50.8	51.3	52.4	51.5	39.8	38.1	37.6	48.5	54.6

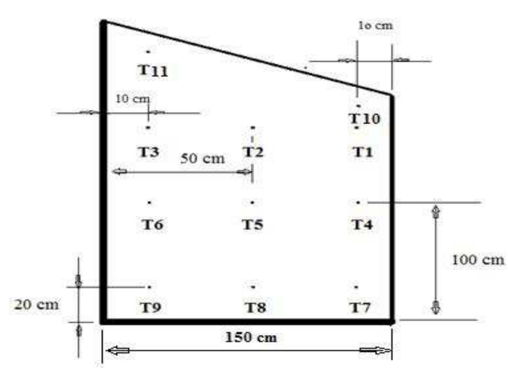

Figure 4: Locations of Temperatures Measurements inside the Solar Kiln

Relative Humidity

The variation of relative humidity of the air drying inside the solar kiln and the ambient relative humidity on typical day of December 29, 2012 has been shown in figure (5). In this figure, while the ambient and the internal air drying temperatures increase the ambient relative humidity decreases till it reaches its minimum value at 14:00 PM local time, whereas the internal relative humidity increases between 08:00 AM and 14:00 PM to reach its maximum value at the same time nearly. This is due to the solarheating, with a maximum solar radiation intensity is about 1100 Wm^{-2} as shown in figure (6), which accelerates the water evaporation process from the palm leaves, and then the internal relative humidity begins to decrease till it becomes slightly higher than the ambient relative humidity at night.

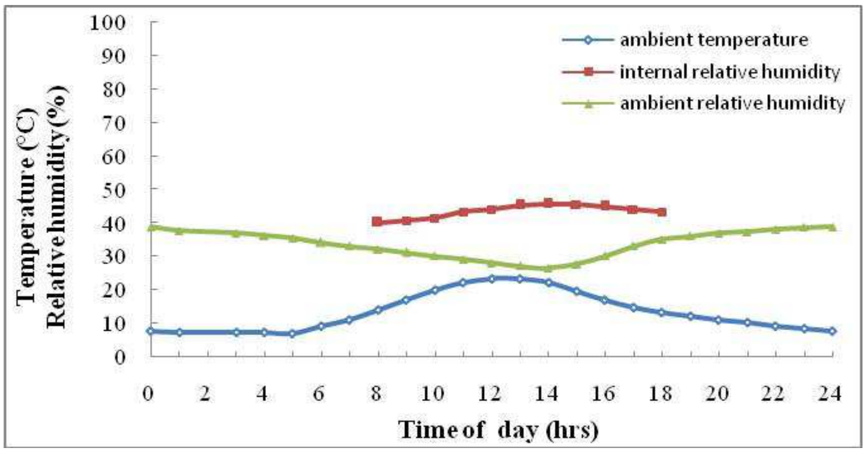

Figure 5: Variation of Internal and Ambient Relative Humidity and Ambient Temperature on 29/12/2012

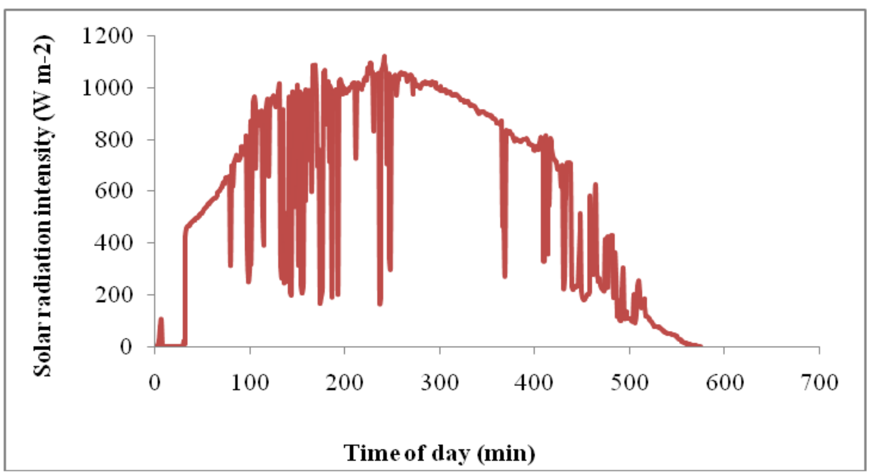

Figure 6: Hourly Variation of Solar Radiation Intensity on Saturday 29/12/2012

Moisture Content (MC)

In the first run of drying process, eight palm leaves have been tested in the solar kiln where, each three green leaves with initial moisture content (MC) more than 65 % were collected from the same palm tree have been stacked at strategic locations alongside on one shelve. These samples have been weighed on a top pan balance and then put in the middle of the kiln shelves; about 30 cm and 22 cm above the kiln floor. Each kiln sample was regularly weighed during test in the same time (11:30 AM) as shown in Table (2), where the relative humidity, the solar radiation intensity and the ambient temperature have been measured.

Table 2: Variation of the Weights of Palm Leaves for the Drying Time

Date	17/11/2012 (Sunny)	18/11/2012 (Sunny)	19/11/2012 (Sunny)	24/11/2012 (Cloudy)	25/11/2012 (Sunny)	26/11/2012 (Sunny)
Time	11:30 AM	11:30 AM	11:30 AM	11: 30 AM	11:30 AM	11:30 AM
Ambient Temp. (^{o}C)	30.6	26.4	26	23.5	28.7	23.1
Ambient RH (%)	31	34.5	36	42	28.5	38.5
Solar Radiation Intensity (Wm^{-2})	860	865	820	178	835	786
Sample	Weight (g)	Weight (g)	Weight (g)	Weight (g)	Weight (g)	Weight (g)
1	67	63	62	56	55	55
2	48	45	44	40	39	39
3	75	70	70	63	62	62
4	50	47	45	42	41	41
5	35	34	33	31	31	31
6	78	75	73	70	69	68
7	53	50	50	47	45	45
8	50	48	47	43	42	42

Figure (7) illustrates the drying curve of palm leaves in the solar kiln, where the moisture content of drying leaveswas reduced to 10% (dry basis moisture content)in about 9 days, whereasthe final average moisture content of the palm leaves with air drying is about 34%for the same drying period inside the solar kiln. This figure shows the drying rate is clearly fast (3 days for 80% reduction in moisture content), compared with open air drying (3 days for 15% reduction in moisture content). During the first 5 days of drying process in the solar kiln and in the open air drying, moisture removal rate is relatively higher than this rate in the last 5 days of this process. It is noted, also that the rate of reduction of moisture content is high during the day and decreases at night.

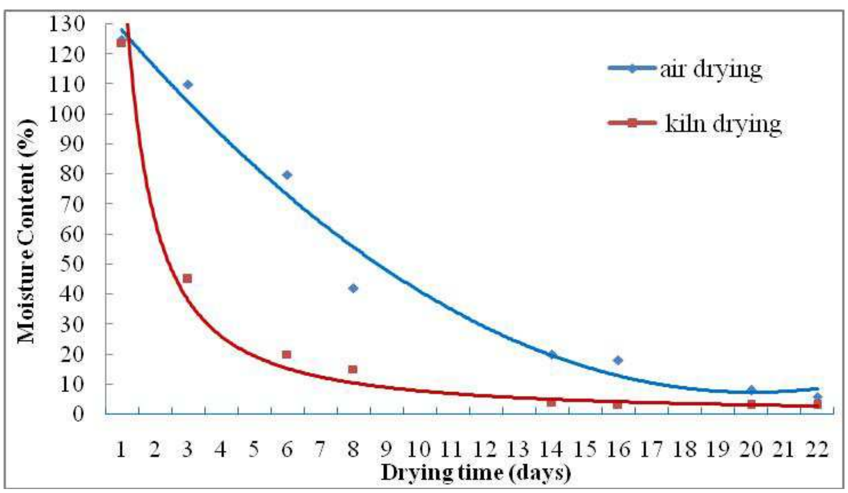

Figure 7: Variation of Moisture Content (MC) of the Palm Leaves

CONCLUSIONS

An experimental investigation has been completed comparing a solar timber kiln and open air drying of the palm waste under the climatic conditions of Taif city. The influence of the ambient temperature, and relative humidity and the solar radiation intensity on the drying process wasted. This study demonstrated the effectiveness of the solar kiln in decreasing the drying time by almost half compared with the open air drying. The performance of this timber kiln has been presented, where it can be used for drying palm fronds from moisture content of about 69% to moisture content of about 10%, for drying time of about 11 days in winter season without any auxiliary heater. Certainly, the period of drying can be reduced in the summer where the temperature will rise to higher levels with the largest solar radiation intensity.

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