SOLAR DRYING OF TIMBER IN LIBERIA: DETERMINATION OF THE EFFICIENCY OF AN EXPERIMENTAL SOLAR DRYER BASED ON TEMPERATURE MEASUREMENTS

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ABSTRACT

An experimental solar dryer designed and constructed at the Forest Products Research Laboratory of the University of Liberia is described. The dryer has a flat plate solar collector with transparent east and west facing walls. The collector section and the drying chamber are a single structure. Dryer temperatures and ambient temperatures are presented for the hours of 7:00 am through 7:00 pm for typical sunny and cloudy days. Results for sunny days were used to estimate the efficiency of the solar dryer. It was calculated that, on average, in this solar dryer it would take about 28 days to dry 8 m^3 of wood of 0.5 specific gravity from 55% to 15% moisture content.

INTRODUCTION

Traditionally, wood is dried by stacking lumber in an open yard. This is very inefficient in terms of drying time and quality of the dried product. Conventional dry kilns, powered by petroleum-based fuels or other fuels, are very efficient but are expensive to install and operate. Solar drying can offer an alternative to both air drying and conventional kiln drying. It is more efficient than air drying and less expensive than kiln drying.

Two basic types of solar kiln designs have been developed and used. In the first, the solar energy collector portion and the drying chamber are combined into a single unit. An alternative design has the collector and the drying chamber as separate units. Both designs have advantages and disadvantages. The combined system has a major advantage of being simple and relatively inexpensive. The major advantage of the separate system is that the collector area and orientation is usually free from the constraints imposed by the geometry of the drying chamber. Thus, the collector could be made large enough to optimise heat output and the drying chamber could be heavily insulated to reduce losses.

The purpose of this study was to design and construct an experimental solar wood dryer to assess solar drying possibilities in Liberia.

Energy analysis of solar drying process

In a typical solar dryer, solar radiation is collected to provide energy in the drying chamber that may be converted into useful work for drying. A simplified energy equation may be stated as:

$$U = E + L \tag{1}$$

where U is the total energy input into the system; E is the amount of energy available for the drying process; L is the total energy loss from the system.

In the case of a solar dryer, the total energy, U, is made up of the solar energy derived from the total radiation reaching the solar collector, the indirect radiation received from surrounding ground and objects, and radiation due to back reflections between the collector plate and the solar screen.

The amount of energy available for the drying process, E, is given by:

$$E = H_1 + H_2 + H_3 \quad (2)$$

H_1 is the energy required to heat the wood substance and is given by:

$$H_1 = W_t C_w (T_d - T_a) \quad (3)$$

where: W_t is the total weight of the wet wood (kg); C_w is the specific heat of wet wood (cals/g/°C); T_d is the dryer temperature °C; and T_a is the ambient temperature.

H_2 is the energy required to overcome hygroscopic forces, and it is dependent on heat of sorption of wood.

H_3 is the energy required for heating and vapourising the moisture removed from the wood, and it is given by:

$$H_3 = H_v W_r \quad (4)$$

where: H_v is the heat of vapourisation of water (cals/g); and W_r is the weight of water removed from the wood (kg).

The heat losses, L, are made up of

$$L = s + r + v + q \quad (5)$$

where: s is the unavailable energy due to absorption by the solar screen; r is the energy reflected by the solar screen; v is the energy loss through ventilation; and q is the energy loss through the wall, roof and floor of the kiln by both conduction, and conductive-convective mechanisms.

Thus for a given quantity of lumber being dried in a solar dryer, the energy that will be used for the drying process, E, will depend mainly on the difference between the operating temperature of the dryer and the corresponding outdoor temperature at any given time. The efficiency of a solar dryer is determined by what fraction of the total input energy is made available for the drying process. However, the value of E in equation 1 is almost constant for a given dryer design and kiln load. It is possible, however, to design a solar dryer which is capable of absorbing a greater amount of input energy, U, and reducing the heat losses, L, in which case the energy that will be made available for drying will be increased.

THE EXPERIMENTAL SOLAR DRYER

The solar dryer built at the Fendell Campus of the University of Liberia, is a wooden frame with a 3/8 inch plywood interior wall. The exterior wall is made of 26 gauge galvanised iron sheets. The dryer has the following dimensions:

Length (east to west)	5.1m
Width (north to south)	3.6m
Height (north wall)	2.7m
Height (south wall)	2.3m

The top half of both the east and west facing walls and the roof are made of 6mm thick glass sheets. The 75 x 150 cm roof panel is interconnected with moisture proof silka flex mastic and fitted into tongue and groove wooden strips. The 4.5 x 6.0m foundation of the dryer is concrete and one metre above the ground.

The heat absorber is made of black painted corrugated, 26 gauge galvanised sheets fastened to a wooden frame and suspended at about 30 cm below the main roof. A 15cm air passage gap is left between the heat absorber and the south wall. The distance between the heat absorber and the north wall is about 40 cm, which is large enough to facilitate the installation of fans to provide air circulation within the dryer.

All surfaces inside the dryer are painted black to improve the total heat absorbing capacity of the entire system. The total cost of materials for the construction of the dryer (excluding labour, supervision, etc.) was about $3000.00.

MEASUREMENTS OF DRYER TEMPERATURES

The temperature inside and outside the dryer was measured every hour from 7:00 am through 7:00 pm over a 10 week period. This provided enough data for clear (sunny) and cloudy (over-cast) days.

PRELIMINARY RESULTS

Figures 1 and 2 show the average dryer temperatures with respect to the hour of the day, for a typical clear and over-cast day, respectively. The average rise in temperature above ambient temperatures, ranged from about 5°C to 22°C for clear (sunny) days. The average rise for cloudy days ranged from about 2°C to 16°C.

On sunny days the average dryer temperature during the day (7:00 am through 7:00 pm) was about 49°C and the average rise in temperature is about 20°C.

These results were used to determine the theoretical efficiency of the solar dryer and to estimate the expected rate and schedule of drying for typical hard wood species of Liberia.

THERMAL ENERGY OUTPUT

The magniture of energy available for drying from a solar dryer can be determined on the basis of temperature rise in the dryer, that is, the differences between the dryer temperatures and the corresponding outdoor temperatures. If the dryer is considered as a typical heat exchanger, the thermal energy output from the system is given by:

$$Q = C_p \times M \times T \qquad (6)$$

where: C_p is the specific heat of the medium, which in this case is air; M is the mass flow of air from the entire volume of the dryer; T is the operating temperature of the system.

The rise in temperatures takes into consideration heat losses from the system. Hence in calculating the thermal energy output from the dryer it is appropriate to use the value of the difference between the dryer temperature and the ambient temperature. Hence:

$$Q = C_p \times M \times (T_d - T_a) \tag{7}$$

where: T_d and T_a are dryer and ambient temperatures, respectively.

The volume of the solar dryer is approximately $46m^3$. The specific heat of air is 0.24 cals/g - °C. Density of air, , at a dryer operating temperature of about 50°C, is 1.12×10^{-3} g/cm³. The thermal energy output from the dryer for a typical sunny day between 7:00 am and 7:00 pm was thus calculated to be about 35,000 k cals.

ENERGY REQUIRED TO DRY KILN LOAD OF LUMBER

The total energy required to dry a quantity of lumber that will constitute one load in the solar dryer can be determined by considering the various elements for heat consumption indicated in equation 2. The following data or assumptions must be considered.

a. The capacity of the solar dryer for one inch lumber is 3500 bd ft $8m^3$.

b. It will be assumed that the average initial moisture content of the lumber is 55%, and that the wood could be dried to an average final moisture content of 15%.

c. It will again be assumed that the average specific gravity of a typical Liberian hardwood species is about 0.50, based on green volume.

d. It follows, therefore that the dry weight W_o, of 8 m³ of lumber is 4000 Kg and its wet weight, W_t, is about 6200 Kg.

The energy required to heat the wood substance (H_2) is given by Equation 3. The energy required to overcome hygroscopic force in drying the wood from fibre saturation point to 15% moisture content is about 10 BTU/lb or 5.55 cals/gm. Thus

$$H_2 = 22{,}200 \text{ k cals}$$

The energy required for heating and vapourising the water removed from the wood is given by:

$$H_3 = H_v \; W_r$$

where: H_v, the latent heat of vapourisation, is about 572 cals/g at the operating temperature of 50°C; and $H_3 = 0.4 \times 4000 \times 572 = 915{,}200$ k cals.

The total energy required for drying the quantity of wood in the solar dryer is the sum of all the above.

$$E = H_1 + H_2 + H_3$$

$$E = 1{,}004{,}000 \text{ k cals.}$$

CONCLUSIONS

Energy output from the solar dryer is about 35,000 k cals per day, on a clear sunny day. It would take approximately about 28 days to dry 8 m^3 of 25mm thick lumber, of an average initial moisture content of 55% to an average moisture content of 15% in the solar dryer.

This estimate is based on temperature measurements for clear (sunny) days only. For cloudy days the thermal energy output from the dryer would be much less. Preliminary drying experiments conducted with one inch boards of Niangon (Tarrietia utilis, Sprague) indicated that such boards could be dried in the solar dryer from an average moisture content of about 60% to 15% in 35 days. It takes about 90 days to dry similar boards of the same species in the open air under a shed. And in an electric heated dry kiln of 1 m^3 capacity about 14 days.

From these preliminary results it appears that solar drying is much more efficient than air drying. Even though solar drying did not appear to be as efficient as the electrically heated dry kiln, the cost of solar drying is much less than kiln drying.

However, these experiments need to be repeated to obtain more reliable data of both the efficiency and economic viability of the solar drying process.

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FIGURE 1: Average Temperatures Versus Time of Day for Clear (Sunny) Days

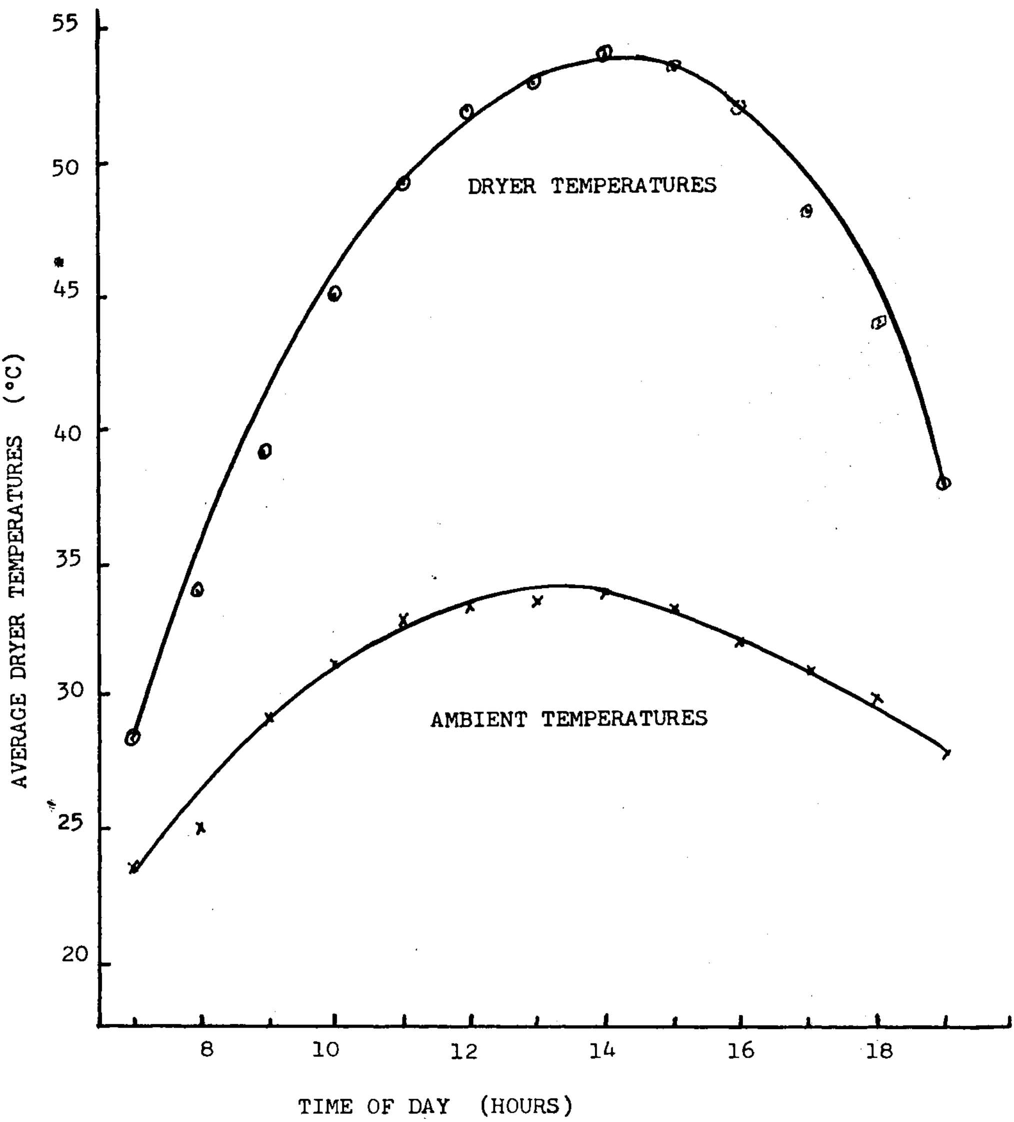

FIGURE 2: Average Temperatures Versus Time of Day for Cloudy Days