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Solar kiln drying of tropical hardwoods using a system with a slagbed acting as roughened absorber and heating storage medium

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Abstract. This work addresses the analysis of a low temperature, forced-air, solar kiln timber dryer operated in Trinidad and Tobago (10˚N, 61˚W). The design is a 6 m^3 capacity kiln with a 36 m^2 collector external to the kiln which has a single glass cover with a slagbed roughened absorber and heat storage. Slag is the by-product in the manufacture of steel which is easily and cheaply available locally. The effectiveness of the system was proven in drying tropical hardwoods to a final equilibrium moisture content of dry basis, 16%. High quality products were obtained, in 2-5 weeks depending on climatic conditions, wet or dry season, species and thickness of the lumber. Tests carried out clearly indicated that solar kiln drying is about twice as fast as natural drying, and that the drying times are comparable with conventional kiln drying using electrical heating. These results demonstrated the great potential that such a renewable energy system using locally available materials possesses.

Key words

Solar, timber, kiln, drying, moisture content.

1.0 Introduction

Solar drying offers an alternative method of drying timber using a renewable energy source. Solar timber drying in the Caribbean is still not well developed where the commercial aspect is concerned. Most of the solar kilns operated are basically research type systems. Solar timber drying research done prior to this work, at the University of the West Indies (U.W.I.), St. Augustine has resulted in a scaled–down greenhouse timber dryer that dries hardwood in about 2-3 weeks [1].

There are several designs of solar kilns around the world, most being research kilns and not in commercial operation [1]. A few of these designs are however becoming available as production models [2].

Drying is the most energy demanding process in solid lumber production. This drying process has become increasingly costly with rising fuel prices. Developing countries with a timber resource that can be used to manufacture finished products either for local use or export often lack the capital to build high-cost drying kilns. Caribbean states with timber resources such as Guyana, Belize, Dominica, and Trinidad and Tobago are located in the tropics where ambient temperatures and insolation are high. In addition solar energy is advantageous in that it is clean, inexpensive and inexhaustible. In the Caribbean the daily insolation of the region varies between about 7 KWh/m^2 during the dry season to about 4 KWh/m^2 during the rainy season.

Solar drying provides an alternative method using renewable energy to remove the moisture from wood. Although solar drying may take longer, 5 to 14 days, than conventional kiln drying, depending on locality and climate, the small capital investment, low running cost, and ease of operation make this kind of lumber drying attractive for emerging industrial nations. Following the trend of environmentally friendly systems, renewable energy technologies such as solar drying ensures adequate health, safety and environmental standards**.**

Therefore, the primary aim of this work is to evaluate a prototype solar timber kiln [3] to effectively dry timber, which can be made available, on a commercial scale, in the tropics for medium to small saw millers and wood workers.

2.0. Description of the solar dryer

The design unit under consideration is a low temperature, solar-heated, forced-air, 6 m^3 timber dryer which consists of the kiln and an external solar collector. In a comprehensive review of solar-energy drying systems it was noted that some conventional dryers and most practically-realised design of solar-energy dryers are low temperature ones [4]. The review also concluded that properly designed forced-air convection (active) solar dryers are agreed generally to be more effective and more controllable than the natural-circulation (passive) types [4].

The solar air-heater is external to the drying chamber so that the collector area and orientation are not limited by the geometry of the dryer. Figure 1 shows an image of this solar dryer. The solar dryer has been designed, constructed, modified and tested, at the University of the West Indies Field Station (UFS), Mt. Hope, Trinidad, 10.4 °N, 61.3 °W [3]. The dryer is oriented north south (N-S) for maximum insolation. The collector is horizontal except for a 1:80 N-S drainage tilt with effective collector area 36 m^2 (actual dimensions 12.19 m long by 3.66 m wide). This tilt allows for the run-off of water on top of the collector as well as any water condensing within the collector during the night. There are two 5 cm diameter PVC drainage outlets with removable covers at the base of the southern end of the collector that allows this condensed water to be removed. The collector has a concrete base with hollow concrete blocks, one brick high (25.4 cm) forming its perimeter. There is a concrete wall, one brick high, running down the center of the collector separating it into two channels with a 2 m gap at the southern end to allow airflow. Air drawn from the kiln into the collector, travels the length of its western side, crosses over to its eastern side via the 2 m gap, and then along the eastern side and back into the dryer via a well insulated metal duct. A 46 cm diameter squirrel-type blower powered by a 1.1 kW (1.5 horse-power) motor, forces the air through the ducting connecting the collector to the kiln.

Fig. 2.1. Image of the solar kiln timber dryer.

Some solar dryer designs have tended to locate the blower inside the dryer, between the air heater and the drying chamber as is the case in this design. This keeps the collector under negative pressure, ensuring that all leaks and the additional heat generated by the blower are channeled into the system. This also allows for the easy de-coupling of each component of the system for maintenance and repair.

The wooden drying chamber has well insulated walls, roof, and doors. These components have the same make-up, that is from inside to outside, there is 9 mm thick marine plywood, then sheets of polythene, then fiberglass insulation loosely folded followed by sheets of polythene and finally lapped weatherboard. The total thickness of the wall is 15 cm. The base of the kiln is made of concrete, which is underlined with polythene sheets to prevent movement of water from the soil upwards. The internal dimensions of the kiln are 4.3 m long x 3.7 m wide x 3.1 m high. There is a 44 cm by 34 cm louvered ventilator on the western wall of the kiln to allow for release of high humidity air during drying. The ratio of lumber capacity to collector area was 0.17 m^3 m^{-2}. Internal to the kiln is a two-speed fan which aids in the circulation of air within. Airflow through the collector was 0.197 m s^{-1} and air the speed through the timber stack was 1.5 m s^{-1}.

In general, air heaters show two main drawbacks: relatively lower efficiency than other heaters and limited storage capabilities. There are two unique features of this design. The slag rocks provide these two features. They are the storage capabilities of the slag rock-bed and the enhancement of the thermal performance of the solar air heater by the roughened surfaces of the slag. Slag being inexpensive and easily available locally performs the dual role of heat absorbing medium and thermal storage unit.

3.0 Method and Drying Procedure

Perhaps the most fundamental factor governing kiln drying and even air drying is stacking and stickering. The second is proper control of drying conditions such as temperature, relative humidity and air circulation. Solar kiln drying affords limited control of temperature and relative humidity. Other factors affecting kiln drying are the required drying time and the power consumption. Good methods of lumber piling are required if good and uniformly distributed air velocity is to be achieved. Improper stacking may result in the lumber leaving the kiln with unnecessary degrade and an undesirable range of moisture content. The method of lumber piling employed was 'whole' lumber stacking in a single stack. The lengths of wood were placed so that the rows and columns were in line with each other and square-ended as shown in Fig 3.1.

Stickers separated the adjacent layers of wood and hence allow the uniform flow of air and heat through the stack and, in turn the evaporation of water out of the wood. Proper stickering prevents warping, cupping and splitting. Kiln stickers are of various thicknesses usually 12 mm to 25 mm, and are made of different materials such as wood, plywood, and aluminum. Plywood and aluminum stickers have not proven too practical for reasons of damage and short working life. Twenty-five (25) mm thick teak-wood stickers were used for the drying process in this work and placed between each layer of wood as shown Fig 3.1. They were positioned at equal intervals from one another and in line vertically over the entire width of the stack. Stickers were also placed flush at both ends of the stack to reduce warping and checking caused by faster evaporation of the ends of protruding wood.

Every pile of lumber is subject to restraint which reduces cupping or twisting: that is, the weight of wood will exert pressure on the lower layers. Unfortunately this type of restraint is zero for the top layer and progressively increases to a maximum for the bottom layer. For this reason weights in the form of concrete blocks were placed at the top of the lumber pile.

Fig. 3.1. Lumber stacked in the solar kiln timber dryer.

Good baffling is also an important pre-requisite to good kiln drying. Baffles help prevent the air from short circuiting and unnecessary turbulence. Top baffles made of plywood were employed as a vertical shield to prevent air from blowing above the lumber pile. Baffles were also used at the end of the length of the stack since some of the planks were shorter than the others.

In the drying runs for the testing of the solar kiln, 25mm thick, 10 cm - 30 cm wide, and 1.83 m – 3.66 m long timber were dried. Timber of different thicknesses, 25 mm, 50 mm, 75 mm and 100 mm were also dried for saw millers and furniture manufacturers.

The year-round analysis of the solar dryer took into consideration the climate of Trinidad and Tobago, 10 ^{0}N – 11 ^{0}N. That is, drying runs were carried out in the wet season and in the dry season. These results are presented in Section 4.0.

Each batch of lumber was firstly inspected and tests carried out to determine the initial conditions of the physical properties and dimensions of the lumber. These initial conditions consisted of the moisture content, the grade (based on the number and type of defects on each board), and the dimensions of the boards.

At least ten percent (10%) of the number of lengths in the kiln were selected as samples for moisture content and drying defect analyses. These samples were placed into 'drawers' so as to be easily removed during drying. Thicker stickers were used to provide larger spaces for the samples to be placed in. Hence removal of these samples would not upset the whole stack. This was possible because the weight of the stack does not rest on these samples.

As far as possible, samples free of defects were selected and uniquely marked and identified in the process record. The presence and extent of any existing defects were noted.

The resistance type meter used was the Delmhorst RDX-1 moisture detector with a two needle probe. This instrument has a digital readout with corrections for the species of wood and allowances for wood temperature. According to the manufacturers, this meter has a resolution of 0.1% and an accuracy of ± 1% within the range of 7% - 20%. Outside of this range the accuracy declines rapidly.

The initial average moisture content of each batch was established based on the samples selected, using the portable Delmhorst resistance type moisture meter (RDX-1). Moisture content of the batch was monitored at regular intervals. The sample boards were taken out of the stack after the solar kiln was shut down. The disadvantage here is that there is loss of heat and drying time. These measurements were taken on mornings when the kiln was at its lowest temperature. The doors of the kiln were shut while the measurements were taken so as to reduce the amount of heat loss from the system. The samples were placed back into their original locations after the measurements were taken, and the system restarted. Sampling took between twenty to thirty minutes depending on the size of the stack.

The moisture content of a sample was determined by calculating the average moisture content of three moisture content measurements taken at different positions along the length of each sample board. These positions were along the middle, lengthwise 30 cm from each end and in the middle of the board.

Under steady state conditions for the initial system, unloaded and loaded, the maximum temperatures of the kiln and fluid were measured using copper-constantan thermocouples. Six such thermocouples positioned at different locations on the collector and in the kiln monitored the temperature distribution through the system. These temperatures were recorded on a six-channel chart recorder. Five of these thermocouples were mounted along the axial centre line of the roughened base and inserted inside the duct, and located midway in the air passage and within the slagbed. The sixth thermocouple positioned at the centre of the kiln 50 cm above the stack was used to measure the kiln temperature. Temperature readings were taken at intervals of five minutes over twenty-four hour periods using the copper-constantan thermocouples.

4.0 Results and Discussion

The blower was run continuously for 24-hour-a-day period. The solar dryer was operated for an unloaded and loaded system. A typical daily cycle of drying conditions for the loaded system is shown in Fig. 4.1. The average (24 hours period) daily kiln temperatures for the unloaded and loaded systems were 38 ^{0}C and 41^{0}C, and the average daily insolation were 301 W m^{-2} and 276 W m^{-2} respectively.

At sunset (at about 18:00 hours), when there is no more direct heating from the sun, the slag-bed thermal storage unit takes over as the main heat source. This storage unit is capable of running the system until sunrise next morning, maintaining temperatures 10^{0}C - 15^{0}C above ambient during the night, as shown in Fig. 4.1. This clearly demonstrates the advantage of the unique storage feature of the slag rocks, thereby eliminating the use of auxiliary heating such as the burning of wood or electrical heating.

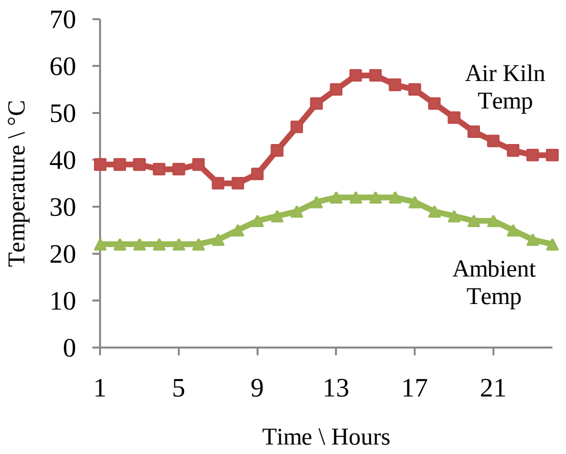

Fig. 4.1. Typical Daily Cycle of Drying Conditions in the Loaded Solar Dryer

Trinidad and Tobago (10 ^{0}N latitude) experiences a dry season from January to May and a wet season from June to December. The seasonal drying of timber using this solar timber drying facility was evaluated. The solar dryer as described in Section 2.0 has been used to dry tropical hardwoods so as to assess the year-round drying capability of this system, in order that it may be adopted by industry. Five drying runs in the dry season and three drying runs in the rainy season were carried out and the drying results are shown in Figures 4.2 and 4.3 respectively. Guyanese hardwood, 25 mm thick, Kabukalli (Goupia Glabra) and Mora (Mora Excelsa) with densities of ≈ 830 kg m^{-3} and 960 kg m^{-3} respectively, were dried for a local timber company in the dry season. The initial mositure contents were in the range 28 - 35%, and the final mositure content (MC) was 16%. The drying times were between 21 and 24 days as shown in Fig 4.2. After drying the lumber was sold as processed lumber. For both these species drying is difficult with a risk of distortion and checking. Mora and Kabukalli were also dried in the same batch since their kiln schedules are similar [4].

The drying times for the three drying runs in the wet season were longer, 23 to 34 days. The batches were dried from initial average mositure content of 32 – 37 % to final equilibrum mositure content of 16%. The difference in drying times was due to the more favourable conditions during the dry season for solar drying of timber. However, of significance, is the fact that the solar timber dryer system can be used to dry timber in the rainy season in Trinidad and Tobago.

Mahogany (*Swietenia Mahagoni*) and Cedar (*Cedrela Odorata*) were also dried for a local furniture manufacturing company that exported their products.

Lumber was also dried for the largest teak producing company in Trinidad and Tobago at that time, Tanteak Limited. An experiment comparing natural air-drying with this solar kiln facility showed that solar kiln drying was twice as fast.

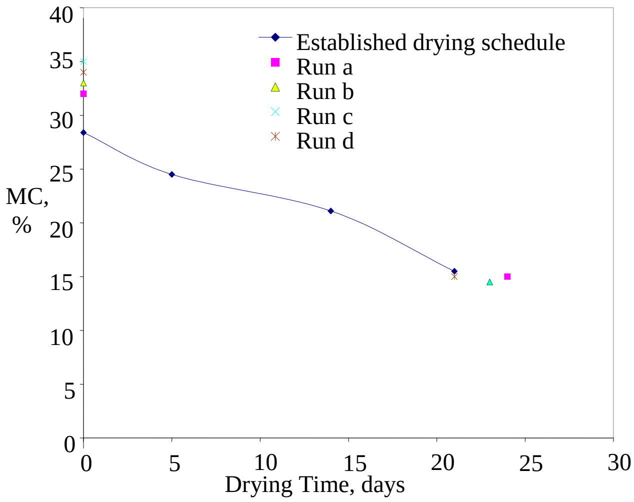

Fig. 4.2. Dry Season Drying Curve with initial and final moisture contents for commercial drying runs

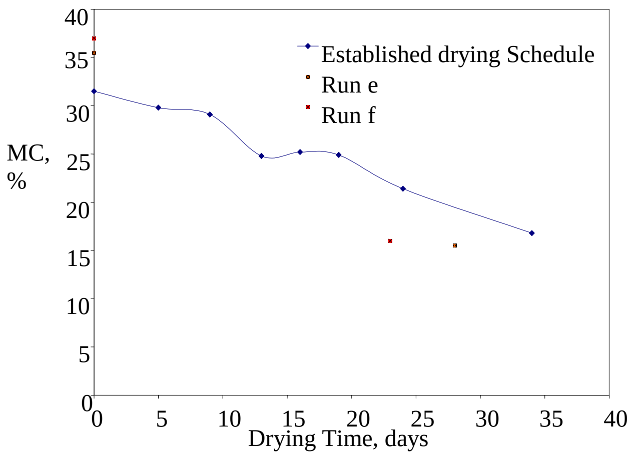

Fig. 4.3. Rainy Season Drying Curve with initial and final moisture contents for commercial drying runs.

5.0 Conclusion

This solar dryer using slag as its heat absorber as well as forming the thermal heat storage unit showed that it can operate effectively over a 24-hour-a-day period maintaining kiln temperatures 10°C - 15°C above ambient tempertures during the night. Although drying times are larger during the rainy season of Trinidad and Tobago, the year round analysis showed that hardwoods can be dried to a final equilibrium mositure content of 16 % in 2 to 5 weeks.

This solar timber dryer shows its effectiveness in drying hardwoods depending on climatic conditions, species and thickness of the lumber. Furthermore, in keeping with polices of the Kyoto Protocol, this type of solar timber dryer can make a major contribution to meeting the demands of reducing CO_2 emissions. The results of drying of timber using this solar design demonstrated the great potential such a renewable energy system possesses.

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