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Performance Evaluation of a thermal Energy Storage Assisted Solar Wood Dryer

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Abstract—*In this study, a prototype of semi-green house type solar timber drying kiln with improvised design was constructed at Forest Research Institute, Dehradun (30.32o N, 78.03o E). The kiln was provided with thermal energy storage system (TESS) based on sensible heat of water and latent heat of phase change materials (PCM). The drying system was evaluated under conditions of empty runs without TESS, empty run with TESS, wood drying run in absence of TESS and wood drying run in presence of TESS. The results reveal that during empty kiln run without TESS, the temperature fell below 40^{o}C by 22:00 hrs whereas the empty kiln temperature with TESS was able to maintain temperatures above 48^{o}C throughout the night. Wood drying run in the absence of TESS indicated that the loss of moisture from the wood was very slow, whereas, using TESS in the solar kiln resulted in a significant amount of drying of wood during nights. Thus, the latent heat and sensible heat based thermal storage may prove useful in low temperature industrial operations like wood drying.*

Keywords: *Latent heat, PCM, Solar kiln, thermal storage, wood drying.*

1. INTRODUCTION

The diurnal variation in availability of the solar energy has always been a challenge for Industrial utilization. Wood drying is an energy intensive and time consuming industrial process. Due to diurnal variability of solar energy, the solar kilns have not gained the enough popularity. Many attempts have been made to store the solar heat and re-utilize it in night time for solar timber drying. The past attempts were majorly based on the use of sensible heat storage media for thermal storage e.g. rocks, pebbles, water etc. Read et al. [1] constructed a solar kiln in Australia which had 15.5 m3 of crushed basalt as sensible heat storage material. The kiln took 20 days to dry alpine ash from 100% moisture content to 6%. Close and Dunkle [2] found adsorbent materials more suitable for energy storage for drying and concluded that reductions in store volume that can be achieved using adsorbent materials. A further benefit is that if vapour proofing is employed even without insulation, energy can be stored indefinitely. Robbins [3] constructed 3.5m3 capacity wood drying solar kiln with a concrete walled, styro-foam insulated thermal storage system. The storage was based on sensible heat of rocks. However, due to low temperature storage, kiln didn't perform well. Chen et al. [4] constructed a thermal storage with 3.6 m3 rock volume capacity which was able to heat the kiln and evaporate water from lumber for one day without sun shine. The storage unit could supply 1,30,000 KJ energy when discharge at initial temperature 60oC to 38oC. Furthermore, the solar kiln was assisted with a heat recovery system in addition to thermal storage system. Dramatic reduction in drying time was observed especially in winters. Zhang et al. [5] discussed the status and prospects of thermal energy storage technology in wood drying in China. The present chapter is focused on the use of TESS which is composed of latent heat based storage (PCM) and sensible heat based (water) media to make wood drying possible even in night time.

2. MATERIALS AND METHODS

The blow moulded High Density Poly-ethylne (HDPE) panels were used as containers for the phase change materials (PC). The size of the containers was 500x250x36 mm^3 with wall thickness 1 mm. Maximum capacity of one each container was 3.3 litres. The HDPE panels were designed in such a way that circular grooves and ridges on the sides of panels increase the surface area of the panels. Two PCMs were placed in the HDPE containers: fatty acid based OM-55^{TM} (120 kg) and paraffin wax (120 kg). The melting point and latent heat of OM-55 were 55^{o}C and 210 KJ/kg and that of paraffin wax was 61^{o}C and 210 KJ/kg.

The containerised PCMs were placed in the kiln following the line from where the southern roof was tilted to the ground. For placing the containers of PCMs, wooden stands were made on which the containers were placed in horizontal position. The containers in the stands were placed in such a way that there was as gap of 4cm between two layers of containers which facilitated the kiln air to flow through walls of the containers. Five rows of the container stands were accommodated in front of the heat exchanger (HE) fan leaving distance of 1 m from HE system, and two rows of stands were placed beside western wall of the kiln. Two insulated cylindrical water tanks with 200 litres capacity each were placed vertically in the kiln as shown in fig. 1. The water tanks were interconnected with

18 mm diameter pipes with control valves. Total quantity of water filled in both the tanks was 360kg. An Evacuated Tube Collector (ETC) array which consisted of 100 ETC tubes was placed outside the kiln. The tubes were connected in parallel as shown in fig. 1. The ETC array and water tanks were connected with pipe (18 mm diameter) and control valves was given to regulate the rate of flow. A 0.5 HP motor was connected between ETC and water tanks to circulate water between ETC and tanks.

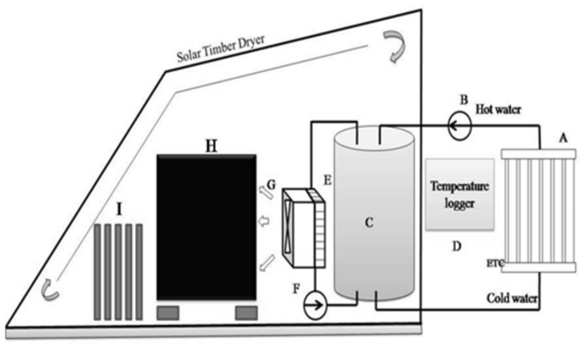

Fig. 1: Active TESS used in the study: ETC array (A), water circulation pump (B), hot water storage tank (C), temperature data logger (D), heat exchanger (E), water circulation pump (F) and the box containing HE and fan (G), Wood stack (H) and PCM filled HDPE containers (I)

The water tanks were connected with water heating ETC array and a set of heat exchanger. The pump of HE was connected with a thermostat which signalled switching on/ off as per the set and desired temperature with accuracy of ±2^{o}C. There was only one fan in the kiln and that was fitted in the HE system. The average air velocity that could be maintained in the kiln was 1.25m/s. The temperatures of various points were recorded with help of data logger at interval of one minute as described in previous chapter.

2.1 Empty kiln run test without TESS

The solar kiln was run in the month of April from 09:00 hrs to 21:00 hrs. The temperature of kiln air and ambient were recorded at interval of 20 min.

2.2 Timber drying run test without TESS

In order to compare the drying properties of *Ailanthus excelsa* (Ailanthus) wood in absence of TESS, this experiment was conducted. The green planks of Ailanthus wood were stacked in the solar kiln, where no thermal storage system was there. The moisture content (MC) of the wood was recorded using following formula:

$$MC\% = \frac{(Initial\ weight - Oven\ dried\ weight)}{Oven\ dried\ weight}\ x\ 100 \text{...........equation 1.}$$

The solar kiln was run throughout the day and night for wood drying.

2.3 Empty kiln run test with TESS

For understanding the kiln performance without load (without wood), the empty kiln run was performed in the month of October 2016. The kiln was loaded with the TESS as shown in fig.1. All the doors and vents were closed in the morning (09:00:00 hrs) and the fan of the kiln was switched on. The kiln was allowed to attain its maximum temperature in the day so that PCM placed in the kiln could melt. Simultaneously, the ETC array pump was also switched on to heat up the water placed in the insulated tanks. The kiln was allowed to run throughout the day and night. The HE motor was connected with a thermostat which was set at temperature 48^{o}C. As soon as the kiln temperature went down below 48^{o}C, the thermostat switched on the HE motor.

2.4. Timber drying run with TESS

2.5 cm thick, 10 cm wide and 1.2m long, flat sawn planks of *Ailanthus excelsa* were stacked in the solar kiln in which TESS containing PCM and water was already placed. The total volume of wood was 1 m3 and was stacked in between HE and container rows of PCM as shown in fig.1. The kiln was run throughout the day and night. The temperatures of kiln, ambient and MC of wood were recorded at various intervals using the equation 1.

3. RESULTS AND DISCUSSION

3.1. Empty kiln run test without TESS

Fig. 2 shows the temperatures of kiln and ambient in the month of April when no wood or TESS was there in kiln. It may be seen that the average ambient temperature during the experiment was 25^{o}C. The kiln temperature dropped abruptly after the sun set and achieved 40^{o}C at 22:00 hrs.

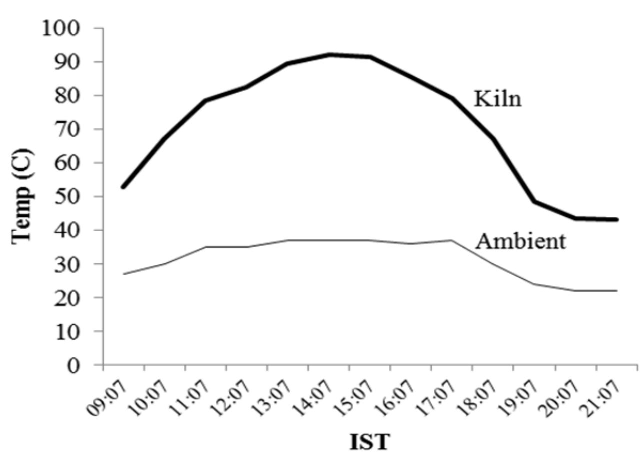

Fig. 2: Kiln and ambient temperature in the months of April

3.2. Empty kiln run test with TESS

Fig.3 presents the kiln and ambient temperatures during empty kiln run test with TESS. It can be seen that the kiln temperature started to fall gradually after the sun set. The molten PCM placed in the kiln didn't allow falling the kiln temperature rapidly even though; the average ambient temperature was 20^{o}C.

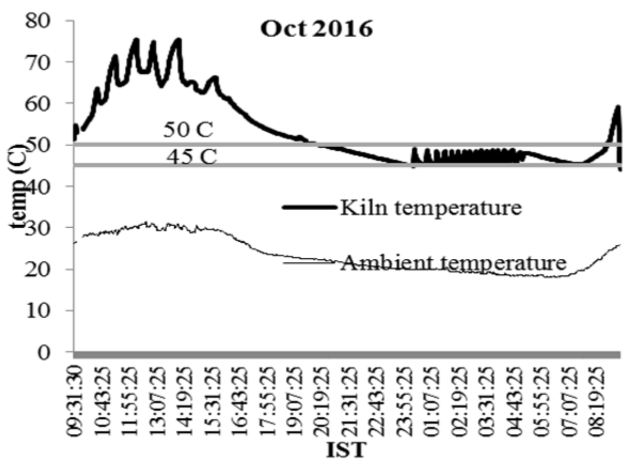

Fig. 3: Kiln and ambient temperature with empty kiln and TESS in the month of Oct

Kiln temperature reached as low as 45^{o}C at 11:20 hrs, thereafter, the HE motor was intermittently switched on/off to maintain kiln temperature at 48^{o}C till 06:00 hrs in the next morning with the help of heat stored in the water in the tanks. After attaining minimum temperature of 45^{o}C at 07:26 hrs, the kiln temperature started to rise as solar rays started to fall on the kiln surfaces.

3.3. Drying of wood in absence of TESS

Fig.4 shows the kiln and ambient temperatures during drying of Ailanthus wood in the TESS assisted solar kiln.

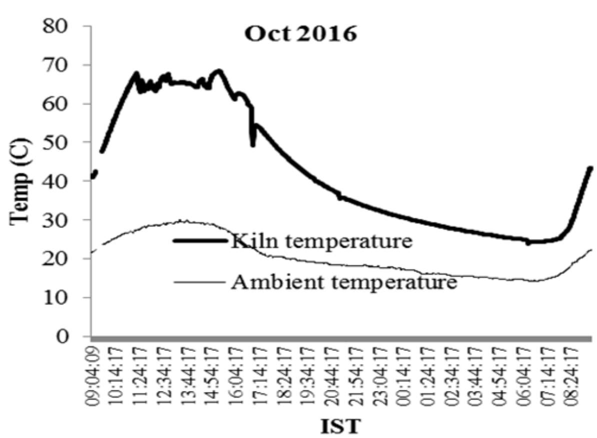

Fig. 4: Kiln, ambient and wood core temperature during drying of Ailanthus wood in the solar kiln in the absence of TESS

It can be seen that the afternoon temperature fell sharply and reached 45^{o}C by 20:00 hrs in the night.

3.4. Drying of wood in presence of TESS

Fig.5 shows the kiln and ambient temperatures during drying of Ailanthus wood in the TESS assisted solar kiln. Kiln temperature fell gradually after 17:00:00 hrs, and by 20:00:00 the kiln temperature fell below 50^{o}C. As soon as the temperature went below 48^{o}C, the thermostat controlled HE system was switch on/off automatically to maintain kiln temperature at or above 48^{o}C. The drying temperature of 48^{o}C was able to maintain till 06:00:00 hrs and then started to fall gradually.

Fig.5 show the temperature setting of the kiln to be 48^{o}C. At 22:15:00 hrs, the kiln temperature went below 50^{o}C which signaled thermostat to switch on the HS system. The temperature of 50^{o}C was maintained till 06:20:00 hrs (21 Oct 2016) and thereafter, temperature of the kiln begin to fall as water temperature in the tank too went down.

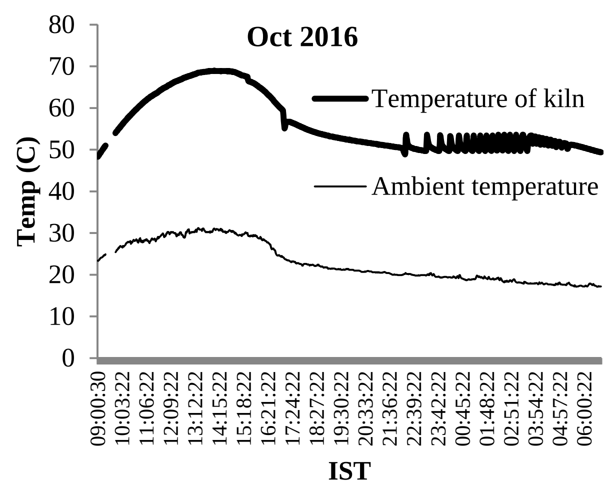

Fig. 5: Kiln, ambient and wood core temperature during drying of Ailanthus wood in the solar kiln with TESS

3.5. Moisture content drop

The solar kiln drying of Ailanthus wood without using TESS was done for only three days, while using TESS, it was dried for four days. Fig. 6 presents the MC reduction in the solar kiln drying in absence of TESS. It can be seen that reduction was very low and slow as drying didn't occur in the night time.

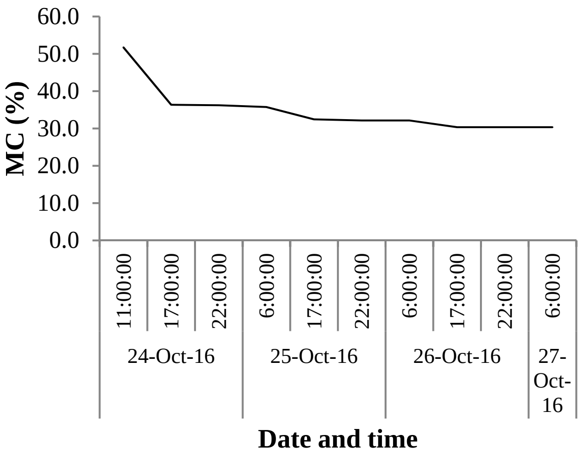

Fig. 6: MC drop in Ailanthus wood dried in the solar kiln without TESS assistance. (B)

Fig. 7 shows the MC drop during wood drying in the solar kiln which was assisted with TESS.

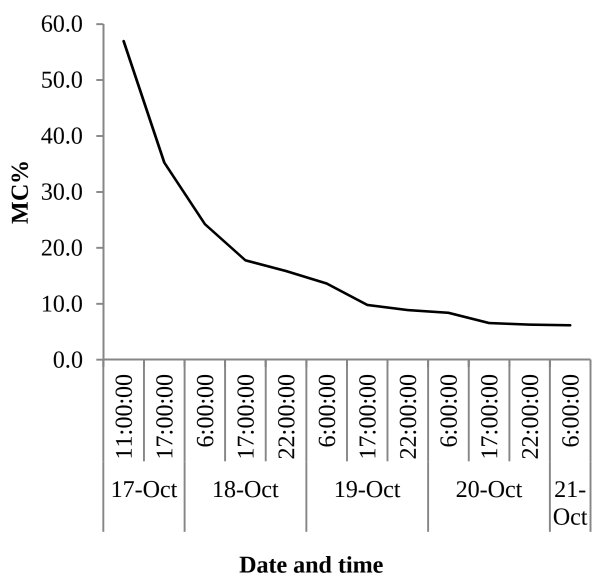

Fig.7: MC drop in Ailanthus wood dried in the solar kiln assisted with TESS

It may be seen that the MC drop in fig. 7 is very high as compared with fig. 6.

After three days of drying using TESS, the final MC of the wood samples was 8.9%, while that of dried without TESS was 30.4%. This indicates that TESS was quite effective in reducing MC in night time.

4. CONCLUSION

Using PCM based thermal storage may help to maintain higher kiln temperatures after the sun set by storing solar thermal energy in form of latent heat. The results reveal that during empty kiln run without TESS, the temperature fell below 40^{o}C by 22:00 hrs whereas the empty kiln temperature with TESS was able to maintain temperatures above 48^{o}C throughout the night. Wood drying run in the absence of TESS indicated that the loss of moisture from the wood was very slow, whereas, using TESS in the solar kiln resulted in a significant amount of drying of wood during nights. Thus, the latent heat and sensible heat based thermal storage may prove useful in low temperature industrial operations like wood drying.

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