Madras Agric. J., 94 (7-12) : 256-268 July-December 2007
https://doi.org/10.29321/MAJ.10.100670

Drying kinetics of arecanut using solar cum biomass drying system

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Abstract : Dried arecanut *(Areca catechu)* is widely used as a component of the betel leaf chewed in India. The arecanut processing industries are currently drying the nuts after boiling of nuts by open sun drying for 8 to 10 days. The moisture content of processed arecanut is reduced from 40 to 11 % during drying operation for safe storage and to maintain food quality. For the drying process, a solar cum biomass based dryer with a capacity of 1 tonne per batch was developed to meet the thermal energy requirement. The dryer consists of PAU (Punjab Agricultural University) packed bed model solar collector of 20m^2 area, biomass burner, heat exchanger, air blower and hot air duct. The results showed the system to have a capacity to increase air temperature by 15-20°C above. In addition the organoleptic evaluation reveals that the arecanut being dried in the solar cum biomass dryer system was completely protected from rain, insects and dust. The dried arecanut was of higher quality in terms of flavor and colour compared to open sun dried product, besides saving of time.

Key words : Arecanut, Packed bed solar collector, Biomass gas stove

Introduction

In India, Arecanut *(Areca catechu* L.) is cultivated as an inter crop in coconut fields and all the tracts of land near the paddy fields in Tamil Nadu, Kerala and Karnataka states. But, recently due to increase of price of arecanut, scientific farming is done in Assam and other places. The arecanut is generally available in trade (i) as raw ripe nut; (ii) mature green processed (whole or cut) and (iii) whole and half cut ripe nut, to cater the demands of consumer in different parts of the country. The different names are based on the shape and size of the end products.

Arecanut processing is done by various methods depending upon the end products like Kalipak, Red Supari, and Supari used as an ingredient to take with beetle leaves. Kalipak is one of the important products and is mostly used in all the functions of Tamil Nadu. The arecanut has a moisture content of 75 to 80 % (wb) at the time of harvest (Kaleemullah and Gunasekar, 2002). Traditionally freshly harvested arecanuts are boiled, filtered and sliced in to five or six pieces and dried in open sun drying for 10 to 15 days to reduce moisture to 40%. After this step, nuts are coated with areca extract, extracted while boiling to add color and to reduce the fungal growth.

The coated nuts are again dried in open sun light (Fig. 1) until the nuts make a rattling sound when rubbed with the palms at moisture content of about 11% (wb) in 7 to 8 sunny days. Such drying under hostile climate conditions leads to several losses in the quality of the dried product.

Fig.1, Open sun drying of Arecanut products at second stage of drying

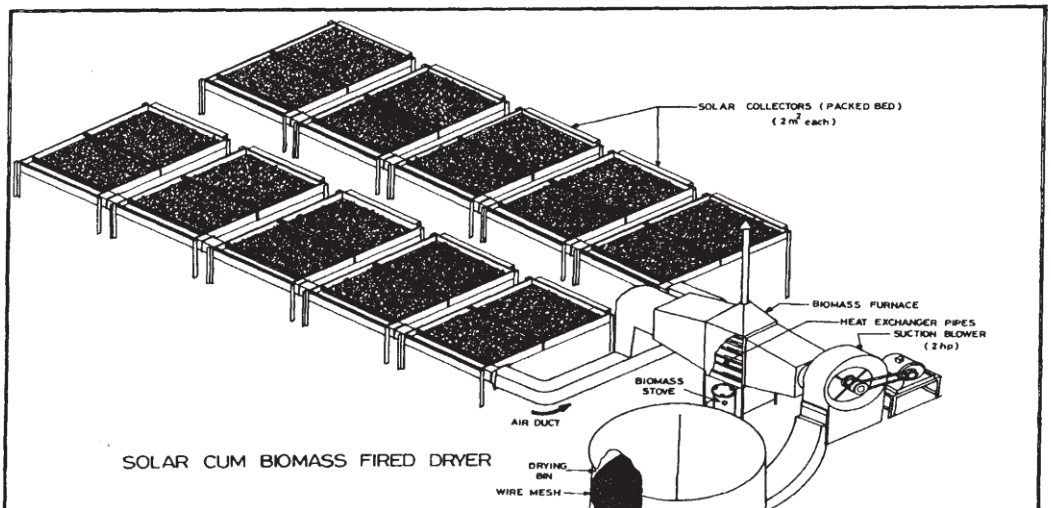

Fig.2. Schematic diagram of Solar cum biomass dryer system

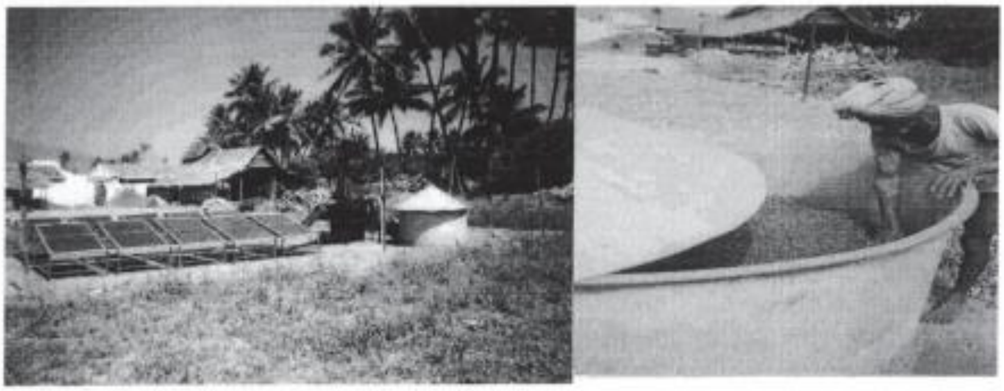

Fig. 3 & 4. In situ solar cum biomass dryer system

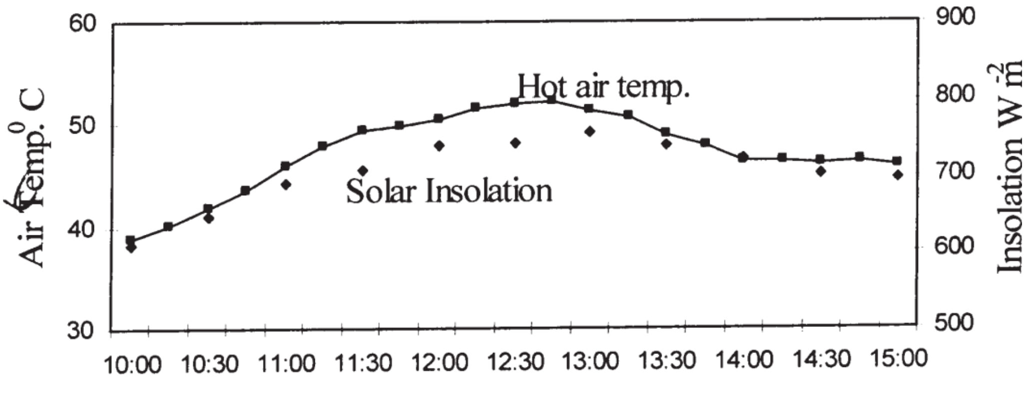

Fig.5. Temperature rise with solar air heater alone (Cloudy weather)

The drying of arecanut needs elevated temperatures. Such high temperature is attained by employing heat sources such as oil burners, furnaces using various commercial fuels. Under such circumstances, the quantum of commercial fuel consumption can be considerably reduced by intermediate pre-heating of drying air by means of solar energy. Available large numbers of solar dryers of different types like direct, indirect, natural circulation had been reviewed by Ekechukwa and Worton (1999). Drying of different types of food products by different dryers had been reported by Prakash *et al.* (2004), Forson *et al.* (2003), Panagavhane *et al.* (2002), Condori *et al.* (2001), Negi and Roy (2001) and Ahmad *et al.* (1996). Most significant disadvantage of these dryers is lack of backup heating unit. If the system is provided with a back up unit like biomass stove it can enhance the drying efficiency and also keep the product at the same moisture level during night as reported by Bona and Filler (2002) and Prasad and Vijay (2005).

Hence, present work was undertaken to evaluate the drying performance of the arecanut in solar cum biomass based drying system compared with traditionally followed open sun drying on the basis of their drying behavior of the dried products in the second stage of drying *ie.* reduction of moisture level from 40% to 11% stage.

Methods and Materials

Raw material preparation

Fresh, good quality and soft raw arecanut of 6-7 months maturity were used for making kalipak and processed by conventional practice as detailed below.

Ripened Arecanut
↓
Dehusking
↓
Cutting into segments / discs
↓
Boiling
↓
Juice extraction   Concentrate
↓
Filtered nuts
↓
Drying (First stage)
↓
Mixing / coating
↓
Drying / (second stage)
↓
Packing and marketing

Drying method

A complete set of schematic diagram of solar cum biomass dryer system is shown in fig.2 The system is having six parts: (i) Solar air heater, (ii) Heat exchanger,(iii) Biomass gas stove, (iv) Hot air duct, (v) Air blower, and (vi) Drying bin.

Solar air heater

Ten numbers of PAU model packed bed solar collectors were used with specifications as detailed below and arranged into two parallel sets, with a common air-duct connecting the hot air outlets.

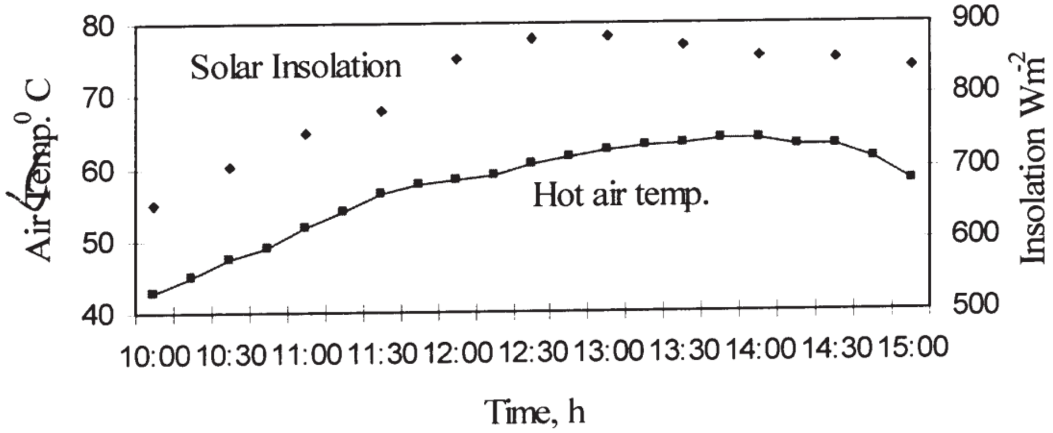

Fig. 6. Temperature rise with solar air heater alone (Bright sun shine)

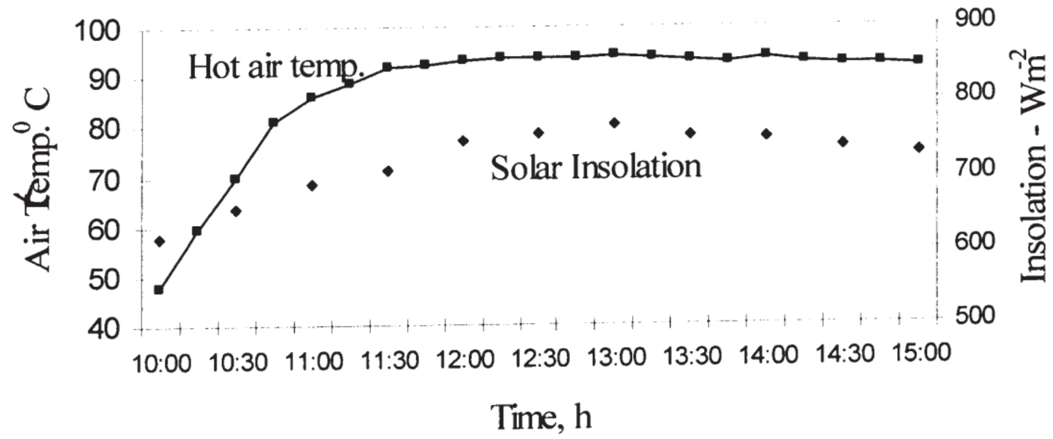

Fig.7. Temperature rise with solar cum biomass system (Cloudy atmosphere)

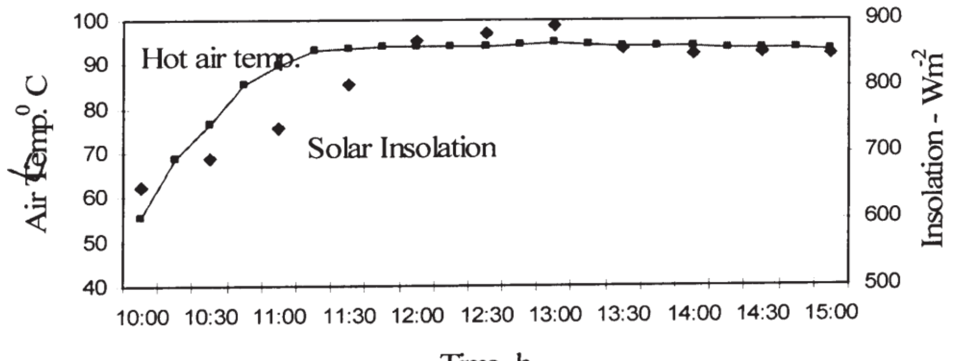

Fig.8. Temperature rise with solar cum biomass system (Bright sun -shine)

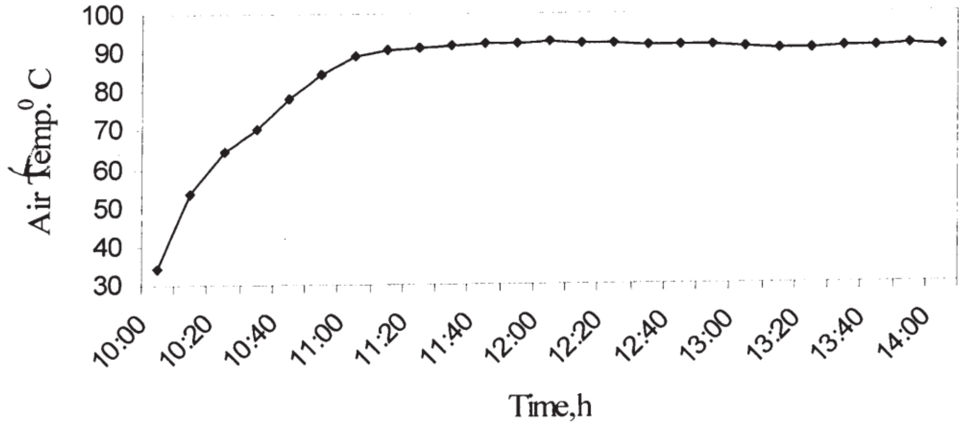

Fig.9. Temperature rise with biomass burner alone

Type	: Forced conversion solar collector with air inlet at the top with out let at the bottom.
Collector area	: 20 m^2
Absorber plate	: 1 mm thick mild steel sheet
Packing material	: Black coated Iron scrap
Collector orientation	: South facing
Tilt angle (orientation)	: 11° North
Insulation	: 50 mm thick glass wool
Air flow	: Over absorber plate and packing material

Heat exchanger

Heat exchanger is of recuperative cross flow type and made of metallic sheet and pipes. The heat exchanger pipes are of 0.6 m length and 0.25 cm diameter, 36 nos. of pipes are arranged in parallel, with one end at the solar collector side and the other end at the blower side. The metallic heat exchanger is provided with fireplace at the bottom and chimney at the top.

Biomass gas stove

Biomass gas stove (www.nifindia.org/sampathrajan.html) is a cylindrical one made of clay, sand and paddy husk mixer and it works on the principle of inverted updraft gasification. The thermal efficiency of the biomass used in stove is about 25 per cent and fuel consumption is about 4 kg of wood per hour. With one batch of 8 kg wood loaded in the burner, the system can continuously burn for about two hours. The biomass gas stove is placed directly below the heat exchanger pipes.

Hot air duct

The hot air duct provided for the system is made of metal sheet and painted in black. The diameter of the air duct is 0.35 m. To increase the residence time of hot air, vertical baffles are provided in the air duct, connecting the heat exchanger and blower.

Air blower

A suction blower operated by ½ hp motor of $10m^3$ min^{-1} capacity is directly connected to the hot air end of the heat exchanger and drying bin.

Drying bin

A circular drying bin of 1.8 m diameter is connected to the blower through a flexible, thick canvas. The overall height of the drying bin is 1 m which includes two sets of plenum chamber of 0.35 m at the bottom and it is provided with a metallic lid at the top.

No load test

The packed bed solar collector was allowed to build up temperature upto 10.00 am. The air blower was run-in the absence of biomass burner. The hot air temperature at the exit of the blower was recorded at 5 min. interval upto 3.00 pm. Corresponding ambient temperature and solar insolation were also recorded. The above test was repeated with biomass burner in operation. Under the solar cum biomass mode, the biomass consumption was also recorded besides air temperature, ambient temperature and solar insolation. The hot air temperature of the inlet and outlet of the heat exchanger were recorded simultaneously, to assess the rise in temperature with reference to time.

Full load test

The colored arecanuts of one ton (with moisture content of 40%) were spread on the two trays of the drying bin. The hot air from the blower was directly connected to the drying bin plenum chamber, from 10 am to evening 3 pm, as shown in figs. 3 and 4. The inside air temperature, relative humidity and moisture content of the product were recorded for three consecutive days.

Moisture content

The moisture content of the selected sample (ten gram) was placed in a hot air oven and the temperature was set at 40°C and the samples were dried up to borne dry condition. After completion of drying, the samples were taken out and placed in desiccators to cool down. The drop in mass of produce was determined based on its initial mass and final mass. The moisture content on the wet basis was computed using the equation:

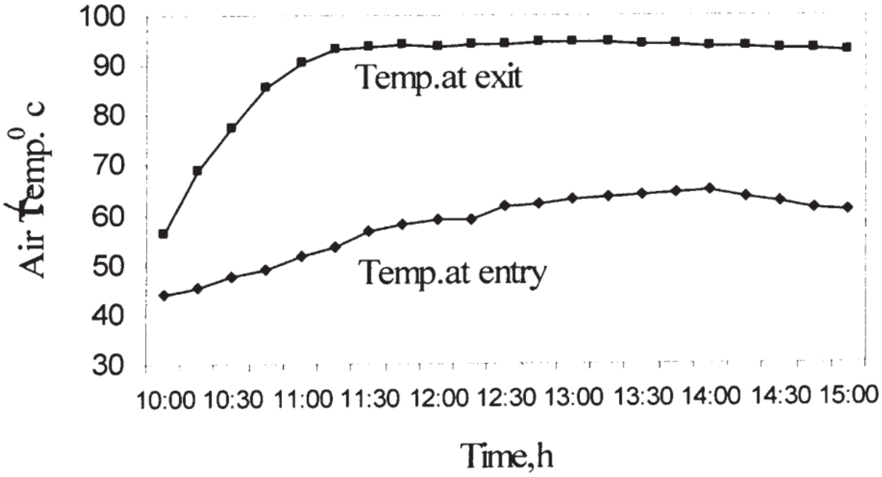

Fig. 10. Temperature difference of air at entry and exit of heat exchanger (Solar cum biomass)

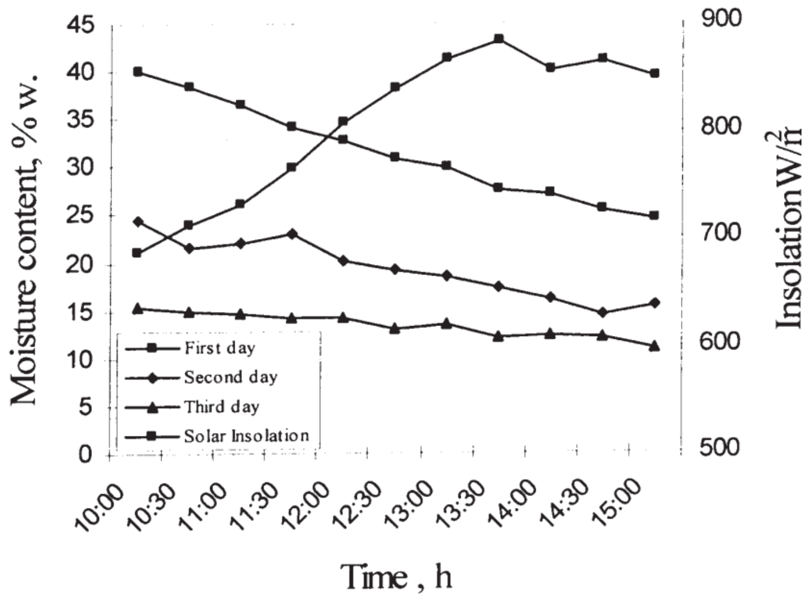

Fig. 11.Dryer performance

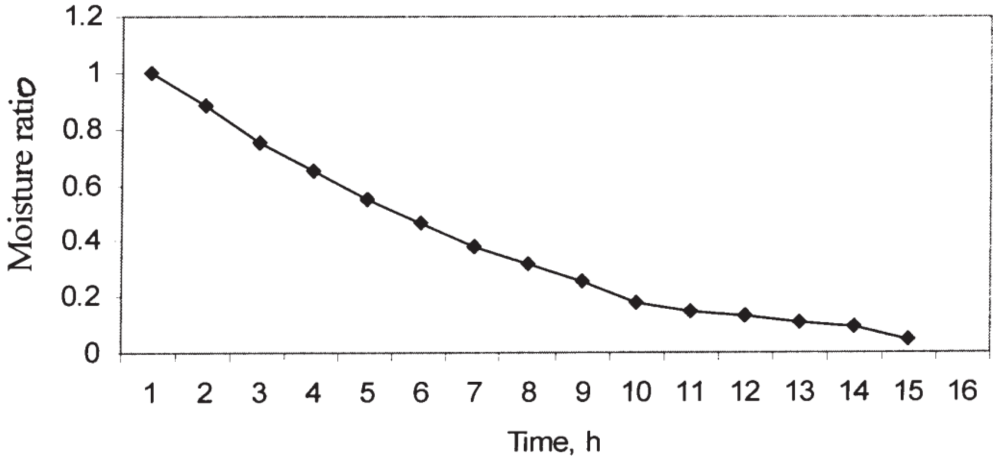

Fig.12. Moisture ratio with time

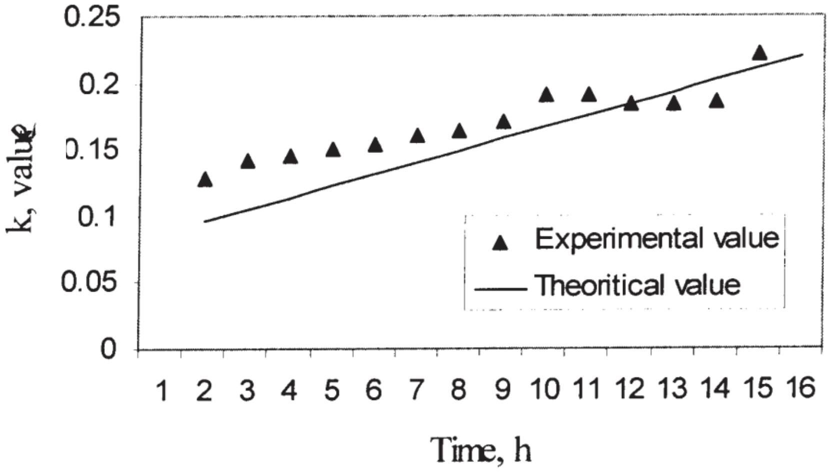

Fig. 13. Rate constant (k) values with time

$$M_{wb} = \frac{Wo - W_d}{Wo} \times 100 \quad (1)$$

The moisture content on the dry basis was computed using the equation:

$$M_{db} = \frac{Wo-W_d}{W_d} \times 100 \quad (2)$$

Where,

M_{wb} - Moisture content in wet basis, (%)
M_{db} - Moisture content in dry basis, (%)
W_o - Initial mass of the sample, kg
W_d - Bone dry mass of sample, kg

Moisture ratio and rate constant

The moisture ratio and rate constants were calculated using the equation:

$$MR = \frac{M_{(t)}-M_e}{M_o-M_e} = \exp(-kt) \quad (3)$$

Where MR is moisture ratio, $M(_t)$ is moisture content at any instant t, % (dry basis), M_o denotes initial moisture content, % (dry basis), M_e is the equilibrium moisture content %,(dry basis), t is the time hours, k is the coefficient or rate constant, hours^{-1}.

Results and Discussion

Performance of solar air heater

The solar air heater was directly connected to the blower and the performance of the system was analyzed in terms of rise in air temperature. The test was carried out in two different atmospheric conditions *viz.*, cloudy weather and bright sunshine.

The rise in air temperature of solar air heater under cloudy ambience is plotted in fig.5. The peak air temperature 52.2°C was reached at 12.45 pm. The average ambient temperature and solar insolation range was 28.6±2.5°C and 609 to 695Wm^{-2} respectively. Due to the cloudy atmosphere, the rate of temperature rise is slow during the initial period of exposure to sunlight.

The rise in air temperature of solar heater under bright sunjshine is plotted in the fig. 6. The solar heater along with the blower was run as an independent unit. The maximum air temperature reached is 64°C. The ambient temperature during the trial run was 30.9±3.5°C and the solar insolation was in the range of 650 to 838 Wm^{-2}. The rise in air temperature is more than 12°C, when compared to the performance of the unit under cloudy atmosphere.

Performance of solar air heater cum biomass gas stove

The solar heater was coupled with biomass gas stove in series and the performance of the integrated unit was tested in terms of rise in air temperature and fuel wood consumption. The above test was carried out under cloudy ambient condition, as well as bright sunshine.

The biomass gas stove was loaded with firewood and ignited. The solar air heater cum biomass gas stove assembly was set on at 10.00 am and the air temperature at the blower exit and the corresponding ambient temperature and insolation were recorded. The ambient temperature was in the range of 28.1 to 31.6°C and the insolation ranged from 618 to 730 Wm^{-2}. This assembly was able to raise the air temperature to a maximum of 94.1 °C. The firewood (Arecanut husk) consumption by the biomass gas stove was 2.5 kg per hour.

Fig.7 shows the performance of the solar air heater cum biomass gas stove assembly for air heating under cloudy atmosphere. It may be noted that the maximum air temperature fluctuates within a range of 5°C. This may be attributed to the unstable ambient temperature due to cloudy weather.

It is seen that the maximum temperature of air reached to 94.9°C at 1 pm. The ambient temperature ranged from 31.8 to 35.8°C and the solar insolation was in the range of 648 to 848 Wm^{-2}. The biomass gas stove consumed firewood at the rate of 2.5 kg per hour.

Fig.8. shows the performance of the solar air heater cum biomass gas stove assembly subjected to a bright sunshine condition. When compared to the performance of the system under cloudy atmosphere, the system was able to produce a steady flow of hot air in the range of 93±1°C without wider fluctuation.

Performance of biomass gas stove

The biomass gas stove, along with heat exchanger and blower was tested for its performance in terms of rise in air temperature and fuel wood consumption. At steady state, the biomass gas stove was able to raise the air temperature to 92.5°C. The initial temperature build-up takes about 20-30 minutes, for the heat exchanger pipes to attain maximum temperature. With biomass system alone, for hot air generation, the fuel wood consumption was noted as 4.0 kg per hour. Fig.9 shows the raise in air temperature when the biomass gas stove alone was used.

Performance of heat exchanger

The performance of the heat exchanger with solar air heater cum biomass gas stove assembly was assessed in terms of temperature difference at the entry and outlet, on a bright sunny day, with an ambient temperature range of 32 to 35.6°C and an insolation ranging from 643 to 847 Wm^{-2}.

The peak temperature of air was recorded, as 94.7°C at the exit of the heat exchanger. The maximum temperature of air, preheated by solar collector is 64.8°C as shown in fig. 10, which illustrates the temperature difference of air at entry and exit of heat exchanger. The difference in temperature of hot air at the entry and exit of heat exchanger varies during the initial period of operation (50-60 minutes). The temperature difference becomes stabilized and the system is able to produce a steady flow of hot air after this period. The burner consumed fuel wood at the rate of 2.20 kg/hr, with a saving of 45% of fuel wood.

Drying experiments with arecanut

One ton of processed arecanut (coated with areca water) were dried using the solar cum biomass fired system. The average initial moisture content of the material is 40.0%.

Fig.11 illustrates the performance characteristics of arecanut dryer. The average temperature inside the plenum chamber air was maintained in the range of 75-94°C by adjusting of the ambient air inlet provided in the hot air duct. The initial 40% moisture was reduced to 24.5 % in the first day of drying at ambient temperatures and solar insolation ranging from 31.8 °C to 32.1 °C, 673 to 874 Wm^{-2} respectively. The second day 24.5% moisture was reduced to 15.3% and 15.3 to 11 % in the third day of drying at the ambient temperature and solar isolations of 31 to 33°C (second day), 31.4 to 32.5 (third day) and 688 to 849 Wm^{-2}, 663 to

841 Wm^{-2} respectively. At the end of every day to maintain the moisture level the biomass gas stove and the blower was run for two hours during night between 10 and 12 pm. The total time taken to dry the product to 11% moisture content was 15 hours.

The moisture ratio of arecanut as a function of time is presented in fig. 12. It can be observed that, the decrease in moisture ratio in second and third day was lower than the decrease observed on the first day. This is because arecanut drying is in the falling rate period where the rate of water removal is lower. The acceptable equilibrium moisture content (emc) for the storage of arecanut which is 11% w.b was reached at the end of third day.

Based on the eqn.3 the diffusion model was fitted and the k values were calculated for experimental data for the entire drying period.

In fitting these curves an equilibrium moisture content of 11% d.b., which was the lowest moisture content achieved after three days of drying was taken. Fig. 13 shows the experimental values to be close to the theoretical values of k as a function of time. The coefficient of determination value was observed as 0.89.The total saving in time when compared to open sun drying was about 20 hours. The average fuel wood consumption by the biomass stove was 2.5 kg/hr.

Conclusion

The performance of the solar cum biomass drying system has been evaluated individually and for the drying of arecanuts in second stage of drying. Packed bed solar air heater, biomass gas stove, and heat exchanger with solar air heater were able to rise the air temperature to 64°C, 92.5°C and 94.7°C (at exit), respectively. Solar air heater coupled with biomass gas stove was able to raise the temperature to a maximum of 94.9ºC.

The savings in fuel wood consumption by the burner is 40%. The system was able to reduce the moisture content of the product from 40% to 11% in 15 hours. Solar cum biomass drier system maintains superior quality of arecanut compared to the open sun dried sample.

Acknowledgement

The authors gratefully acknowledge the Indian Council of Agriculture Research (ICAR), New Delhi for providing financial support.

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