INTEGRATED SOLAR DEVICES FOR RURAL AREAS: EXPERIMENTS ON DRYING MUSHROOM

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1. Introduction

Solar devices and PV systems are useful for different domestic agricultural and cottage industrial purposes. However, it is important to integrate solar devices for making it useful round the year for one or other purpose and thus making it more economically viable (Pande, 2011). Attempts have been made earlier to develop dual purpose solar devices such as solar cooker cum dryer (Pande and Thanvi, 1988) and solar water heater cum dryer (Pande and Thanvi, 1991) and with emphasis on optimized geometry and design to get better performance in stationary mode. The experience gained on these devices was used to design and develop three-in-one integrated solar device (solar water heater-cum-cooker cum-dryer) [Pande, 2007]. The utility of the device in making water melon candies was reported earlier (Pande, 2009 a). On the other hand photovoltaic based systems such as PV pump based drip system for growing orchards (Pande et al. 2003) and PV duster for plant protection (Pande 1998) were also developed and reviewed (Pande et al. 2009). In this connection, a PV winnower cum dryer was also designed and developed to contemplate winnowing of threshed material to separate grain and dehydrating agricultural produce, the two important post-harvest applications (Pande and Dave, 2007). More attention was given on the dehydration of fruit and vegetables considering the obvious advantage of getting more benefits to farmers from selling of the stored dried material in off season. Solar dryers of different types are well described by many workers (Sodha et al. 1987, Fargali et al. 2008, Sharma et al. 2009) The drying of some materials by using this system have been reported earlier [Pande 2009 b, Pande et al. 2010].

The three in one device, when used as dryer, has the facility to provide heat during the night also, thereby providing a better quality of dried product. However, in these integrated devices it was observed that water surface does not touch some portion of the top inclined sheet of GI tank leading to formation of an air gap that causes poor heat transfer from absorber to water. The design was modified suitably to ensure that water surface remains in touch with top surface of the tank. This feature contributed to enhance the performance of the system. On the other hand there were problems of thermal gradient in the drying chamber of PV dryer across the height leading to non uniform drying. This was addressed and improved system was developed with incorporation of a pre air heating tunnel (Pande et al., 2010). While utilizing these devices, it was felt that there are difficulties in transporting fresh mushroom from remote hinterland to consumers. Drying of mushroom is one of the options for longer storage, but especial care is required while drying with solar energy due to its high moisture content. In the present work the utility of these improved integrated solar devices was studied especially to dehydrate mushrooms. The improved systems are discussed and results on drying are enumerated.

2. Design details of the devices

2.1 The Integrated three- in- one solar device

The three in one integrated device (Fig. 1) comprises especially designed oblique shaped GI tank (capacity 50 L) having better heat transfer, optimized geometry to use the device in stationary mode, irradiance on horizontal and vertical surfaces (Mani and Rangarajan, 1982), double glazed windows with reflectors at the top and in the front side, facility to operate the system as cooker even from inside of a kitchen if installed on the south facing window, especially designed cooking cum insulting tray and vents with caps for facilitating the air circulation while using it as a dryer. There were efforts to improve the design and in this series three models were developed. During the performance evaluation, it was observed that in these integrated three in one solar devices water surface does not touch some portion of the top inclined sheet of GI tank leading to formation of an air gap causing poor heat transfer from absorber to water. The pipe fittings at the outlet were modified suitably to ensure that water surface remains in touch with metallic surface of the tank. This feature contributed to enhance the maximum water temperature further to 2-3 ^{0}C and hence improving the performance of the system. In addition, the design of GI tank has been improved and fabricated with a provision of better heat transfer. The water tank is kept in a double walled GI box with fibre glass insulation filled in between the two boxes. The topside is provided with a double glazed window (89.5 cm x 35.5 cm) and another window (86.5 cm x 34.5 cm) is fixed in the front side. A mirror is hinged at the top on a GI sheet cover with mechanical spring to change the angle of the mirror. Another reflector cum cover is provided for the front window. These covers can be put gently on the top and front windows respectively to reduce the thermal losses in the night.

Fig. 1: Three in one integrated solar device

A door (89 cm x 35.5 cm) is provided at the top of the rear side from where a cooking tray can be inserted to make it easy to use the device as a cooker. This feature enables one to operate the system even from inside of a kitchen if installed on the south facing window. The cooking tray also acts as an insulating cover when slid on rail provided over the water tank during evening and helps reduce the heat losses during the night. Four plastic pipe nipples with caps are provided at the bottom and top of the sides of the box to facilitate the air circulation when used as a dryer. The device has been kept on an iron angle stand having slots for holding drying and cooking trays beneath the main unit.

As a water heater, maximum water temperature could be 50-60 ^{o}C in winter afternoon while as a cooker food for a family could be boiled with in 2-3 hours in summer (loading time 10 A.M). As a dryer, fruit and vegetables like *ber*, grated carrot, spinach, watermelon flakes, tomato slices etc. could be dehydrated efficiently with regulation of temperature during day time and continuation of the drying process even in the night through the heated water. With the use of the device can save about 230 kWh during winter as a water heater and 70 kWh as a solar cooker when used in the forenoon of 210 days in a year. In addition 50 kg fruit and vegetables can be dehydrated from the same device saving additional 30 kWh and providing the dried material for its subsequent use.

2.2 PV winnower cum dyer with pre air heater

The system comprises an especially designed drying chamber, PV module (reflector optional), an air heating tunnel and interconnecting fixtures (Fig.2). The drying cabinet is made of iron angle with a top cover of two glass windows fixed on wooden frame and inclined at an angle of 23 degree from horizontal. Two vertical glass windows (each 98 cm x 68 cm) are provided in the front side and another glass window (55.5 cm x 65.5 cm) is fixed on east side of the cabinet. Doors are provided at the rear side for loading and unloading of the material. Four ventilation holes (each of 5 cm diameter) are provided at the base with wire mesh and detachable caps. The openings on the east side above the window and on the rear side above the doors are provided with GI wire mesh to prevent the entry of insects and to facilitate the air circulation. The inclined top and front vertical windows enable to take the advantage of the sun's position in different months for getting the required energy gain. The drying material can be conveniently loaded on twelve trays stacked one above another in two parallel compartments.

Fig. 2: PV winnower cum dryer with pre air heater

The pre heater comprises an appropriately designed blackened aluminium sheet tunnel of about 2 m in length, 34.5 cm width and a height of 31 cm and it is encased by PVC sheet on an especially designed frame and provided with suitable fins for better heat transfer. There is a provision of interconnecting the tunnel to the bin on the west side and PV fan on the other end of the tunnel. The fan is fixed at one of the vertical openings on the frame, which is essentially a trapezoidal chamber having hopper and guide for feeding the material and guide flaps for enhancing the air speed and thus the fan becomes an integral part of the system used for cleaning the grains. The incorporation of reflector with extended length was done after carrying an extensive study on PV-reflector systems where it was found that the energy gains between 9 to 11 a.m. was 22.6 and 35.4% more respectively for PV module-reflector system having 1.5 and 2 times more length of the reflector compared to that of obtained from PV module without reflector and the overall gain was about 20% with additional cost of some 2-3 % of the PV panel (Pande and Dave, 2007). Experiments were conducted with two PV panels (35 Wp each), one PV panel with and without reflector and a PV panel with storage battery back up. Some of the results were reported earlier (Pande and Dave 2007, Pande 2009 b, Pande et al. 2010).

3. Drying mushroom in integrated device

Fresh mushrooms were given a pre treatment and then kept on the drying tray after measuring the initial moisture content. The caps of the vents and both windows were opened and reflectors were fixed. The weight of mushroom was measured at different stages of drying to evaluate the moisture content. The irradiance on horizontal and vertical planes, temperature inside the dryer and ambient temperatures was recorded.

In first exploratory experiment 220 g mushrooms loaded at 10.30 a.m, in January when ambient temperature varied from 16-21 ^{o}C, were dehydrated from 96 % to 7% moisture content within 26 hours. In a separate experiment, 250g mushrooms were loaded in integrated device at 1 p. m. and dehydrated to provide about 19 g dried material after 28 hours. It was observed that 146 g water from the product evaporated during the day while 85g water evaporated in night through the use of thermal energy of hot water stored in the tank beneath the drying tray. The irradiance on the top horizontal surface and vertical windows were 20.16 MJ $m^{-2}day^{-1}$ and 19.44 MJ $m^{-2}day^{-1}$ respectively and maximum ambient temperature during day was 17.5 ^{o}C. The temperature inside the device remained less than 60 ^{o}C and varied in between 28- 58 ^{o}C during 11a.m. to 5 p.m. The average temperature of water inside the tank beneath the drying trays was about 40 ^{o}C at 4 p.m. that helped drying during the night.

Fig.3: Drying of mushroom in integrated solar device

In a separate experiment to optimize the loading, 500g mushrooms were loaded at 1 p. m. and dehydrated to provide about 38g dried material after 28 hours. It was observed that 292 g water from the product evaporated during the day while 170g water evaporated in night through the use of thermal energy of hot water stored in the tank beneath the drying tray. The better drying in the night was due to higher temperature of water, which was about 47 ^{o}C. Further, when loaded with 1 kg, there were problems in drying and some fungus growth was observed. The improved three in one solar device has been installed in a village, Newra Road, Osian, District Jodhpur, Rajasthan, India for field evaluation.

4. Drying of mushroom in PV dryer in mixed mode

Mathematical model was developed to predict its performance for air heating tunnel under different conditions with varying mass flow rate of air (Pande et al. 2008). Following simplified equation was used for predicting the performance of the air- heating tunnel

$$Tx=b/a(1-e^{-ax})+Tae^{-ax} \quad \text{(eq.1)}$$

Where
a = (Ub w b/ (b+1) + U (A c /Ab) w)/mCa
b = [(τα.Hw+UbTaw) {b/ (b+1)} +UAc/Ab wTa]/mCa
m=air mass flow rate, kgs^{-1},
Ca=specific heat of air, $Jkg^{-1}{}^{o}C^{-1}$,
Tx = temperature of air along the length of tunnel ºC,
Ta = temperature of ambient air ºC,
w = width of tunnel m,
U = over all heat loss coefficient, $Wm^{-2}{}^{o}C^{-1}$
Ac/Ab = ratio of cover to base area
τ = transmittance of cover
α = absorptance of surface/fins
Ub = base heat loss coefficient, $Wm^{-2}\,{}^{o}C^{-1}$,
b = ratio of sensible heat to latent heat, which is taken as high as 20 for dry surface
H = Solar radiation (W/m^2)

The drying of different produce such as herbs has been discussed in detail by Kavak and Bicer, 2008, Fargali et al. 2008, Koya and Aydin, 2009. Mathematical model developed for the performance prediction of the temperature at different trays of the dryer (Pande et al. 2010) with the incorporation of an extended air heater to pre heat air for reducing the thermal gradient in the drying bin was validated for drying mushroom in winter.

Fig 4: Drying of mushroom in PV dryer with pre air heater

In an exclusive experiment, 900 g mushroom were dehydrated from 92 % moisture content to 5 % with in 48 hours first in forced convection mode during day and letting the natural convection to prevail subsequently (Fig.4). The material was loaded equally in different trays at about 1 p.m on a chilly day when ambient temperature varied from 16.5 to 18.5 ^{o}C. The temperature inside the drying chamber varied from 24-35 ^{o}C in different hours of the day and the predicted temperature of the drying trays was close to those observed ones. The thermal gradient reduced 2-3 ^{o}C with the pre air heater and this resulted in quite uniform drying of material in different trays, indicating the utility of the pre air heater. The quality of the dried material was better with less browning.

The dried material was soaked in lukewarm water and was rehydrated to prepare mushroom curry. Organoleptic tests revealed very good taste of the curry prepared from the dried mushroom. Although, curry prepared from fresh mushroom had an edge over that, especially in the softness of the cooked mushroom compared to prepared from dried one, the ease of storing and preparing the dish in off season compensates it. The device was extensively tested as a winnower in the farm of the institute and also for drying different produce. Based on year round performance, and with a calendar of using the system as dryer for 250-275 days, it was estimated that PV winnower cum dryer costing $350 has a pay back period of 1.2 years only.

5. Conclusions

Mushroom can be dehydrated successfully in three-in- one integrated solar device as well as in PV winnower cum dryer. The quality of the dried product was comparable due to advantage of night drying in integrated device through thermal energy stored in hot water where as in the PV dryer the forced circulation during day makes it slightly less brown compared to the one with natural circulation due to drying at low temperatures. The PV dryer with pre air heating tunnel reduced the thermal gradient in the drying chamber. Since integrated solar device and PV winnower cum dryers can be used round the year, the solar devices have potential for adoption in rural areas.

6. References

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