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Economic Analysis of a Hybrid Photovoltaic/Thermal Solar Dryer for Drying Amla

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Abstract- **Drying is an important post harvesting preservation technique of fruits. As drying is an energy intensive process, accessibility to good drying methods is essential for the economical betterment of the farmers. Solar energy based drying techniques offer better return on investment to farmers. In this paper, the development and testing of a hybrid photovoltaic thermal (PV/T) solar dryer meant for drying of *amla* fruits is presented. The experimental system consists of a photovoltaic panel of rating 100 Wp and a crop dryer. Hybrid PV/T systems produce both electrical energy and thermal energy. The performance of the hybrid dryer was compared with that of open sun drying. A detailed economic analysis was done by annualized cost method. Simple payback period was found to be 5.66 years which was very low compared to the life span (20 years) of the system.**

Key words-Photovoltaic-thermal dryer, Economic analysis

1.INTRODUCTION

Amla (*phyllanthus emblica* L.) or Indian Gooseberry is grown in most part of India. *Amla* fruits are commonly used in ayurvedic medicines and a rich source of vitamin C.

The farmers face dual challenges of upgrading product quality and increasing the yield. This is possible only through the induction of sophisticated processes. The high investment required for the up-gradation of technology is beyond the reach of most of the small time farmers. So novel techniques are required to improve the quality of the products and reduce the production costs.

Drying is the process of removal of excess moisture from the food stuff in order to reduce the moisture content to the desired limit for long time preservation [1]. Post harvesting preservation of *amla* fruits in atmospheric condition is a difficult task due to the highly perishable nature of the fruits [2]. Drying by solar energy is one of the prominent and popular methods of food preservation especially in tropical areas even though various drying methods are available.

Ayensu [3] developed a cost effective easy to operate solar dryer suitable for local weather conditions. Bernal and Tiwari [4] conducted experimental studies of grape drying by using hybrid photovoltaic-thermal (PV/T) green house dryer. The group led by Othman [5] developed advanced solar assisted drying systems namely (a) the V-groove solar collector (b) the double-pass solar collector with integrated storage system (c) the solar assisted dehumidification system for medicinal herbs and (d) the photovoltaic thermal (PV/T) collector system.

Traditional open-sun drying has many disadvantages over solar energy assisted drying systems. The construction techniques and operating principles of such solar dryers have been extensively reviewed by Ekchekwn and Norton [6]. Supranto et al. [7] conducted experimental studies on a solar dryer consisting of a collector, a dryer, an auxiliary heater and a fan. Ho-Hsian chen et al. [8] studied the drying effects of sliced lemon using a closed type solar dryer. Aboul-Enein et al. [9] conducted studies on an inclined solar air heater integrated with a thermal storage for crop drying. Dilip Jain [10] performed modelling the system performance of multi-tray crop drying. Different models for simulation were proposed by researchers. Ratti and Majumdar [11] have presented mass and energy balances in the solid and in the gas phase.

In this paper a solar dryer powered by a hybrid photovoltaic-thermal (PV/T) system was developed. A hybrid PV/T system produces both electricity and heat simultaneously. A number of experimental and theoretical studies have been reported on PV/T technology. Kern and Russel [12] analysed the PV/T systems for their performance with water or air as working fluids. Florschuetz [13] developed mathematical model of PV/T system. Many studies on the improvements in the heat extraction by the PV/T systems were done by Tonui and Tripanagnostopoulos [14]. The focus of the present study is the economical feasibility analysis of the developed dryer for drying of *amla* fruits.

2.MATERIALS AND METHODS

A.Experimental setup

The photograph of the experimental hybrid system is shown in Fig.1. The hybrid PV/T system consists of a photovoltaic panel of rating 100 Wp with dimensions 1.25 m x 0.66 m. A double pass arrangement was made by placing the panel on the middle of the frame. The frame was fabricated using mild steel angles and the walls were covered with galvanized iron (GI) sheets. A glass plate was fixed 14 cm above the PV panel. The air heater was placed with an angle of 12.25^{o}. A blower was provided to improve the heat dissipation rate. A cabinet type dryer of dimensions 0.75 m x 0.45 m x 0.35 m was fabricated using GI sheet of SWG 20. Outer surface of the dryer was insulated with plywood to reduce the heat losses.

B. Experimental procedure

Two methods of drying were used here, namely (i) open sun drying by spreading the samples on a GI sheet and (ii) controlled drying by using the hybrid PV/T solar dryer. Fresh *amla* fruits procured from the local market (Calicut, Kerala, India) and sliced uniformly were used for the experiments.

Fig. 1.Experimental setup

Moisture content of the samples was found by the oven drying method. Samples of the product were weighed using an electronic balance. Then samples were placed in moisture boxes which were kept in oven at a temperature of 105 °C for 24 hours. These samples were again weighed and their moisture content was determined on the wet basis method.

C. Energy analysis

The energy analysis was conducted by assuming the drying process as a steady flow process. Mass conservation of air flow through the dryer can be expressed as,

$$\sum \dot{m}_i = \sum \dot{m}_o \quad (1)$$

where $\dot{m}_i$ and $\dot{m}_o$ are the inlet and outlet mass flow rates of air through the dryer, respectively.
General equation of mass conservation of moisture is,

$$\sum(\dot{m}_{wi} + \dot{m}_p) = \sum \dot{m}_{wo} \quad \text{or}$$
$$\sum(\dot{m}_i w_{di} + \dot{m}_p) = \sum \dot{m}_e w_{de} \quad (2)$$

where $\dot{m}_{wi}$ and $\dot{m}_{we}$ are moisture content of air at inlet and outlet; $\dot{m}_p$ is the rate of moisture removed from the product; w_{di} and w_{de} are specific humidity of incoming and outgoing air from the dryer.
Energy balance equation is,

$$\sum \dot{m}_i \left(h_i + \frac{v^2{}_i}{2} \right) + \dot{Q} = \sum \dot{m}_o \left(h_o + \frac{v^2{}_o}{2} \right) + \dot{W} \quad (3)$$

where h and v are the enthalpy and velocity of air, respectively.

$\dot{Q}$ is the net heat flow rate and $\dot{W}$ is the work (energy) utilization rate.
Useful energy gain by the heater,

$$\dot{Q}_u = \dot{m}_i C_{pa} (T_{ho} - T_{hi}) \quad (4)$$

where C_{pa}: specific heat of air, T_{ho} and T_{hi} : temperatures of air at heater inlet and outlet, respectively.
The heat used in the dryer can be determined by the following equation.

$$\dot{Q}_{du} = \dot{m}_i (h_{di} - h_{do}) \quad (5)$$

h_{di} and h_{do} are enthalpy of air at inlet and outlet of the dryer, respectively.
Since the psychrometric transformation of wet air inside the heater is exclusively a sensible heating operation, conditions of the air at the outlet of solar air heater and those at inlet of the dryer are identical.

i.e, $w_{hi} = w_{ho} = w_{di}, h_{di} = h_{ho}, \phi_{di} = \phi_{ho}$

where h_{ho} is enthalpy of heater outlet, ϕ_{di} and ϕ_{ho} are the relative humidity of air at drying chamber inlet and heater outlet, respectively. w_{hi} and w_{ho}: specific humidity of air at inlet and outlet of heater, respectively.
Specific humidity of air at the outlet of the dryer can be calculated from Eqs. (1) and (2) as,

$$w_{de} = w_{di} + \frac{\dot{m}_p}{\dot{m}_i} \quad (6)$$
$$h_{do} = C_{pa} T_{do} + w_{de} h_{sat,T} \quad (7)$$

where h_{do} and T_{do} are the enthalpy and temperature of outflow air, and $h_{sat,T}$, enthalpy of the saturated vapour.

D. Analysis of drying process of amla

Moisture content (%) in wet basis,

$$M_w = \frac{(W_o - W_d) \times 100}{W_o} \quad (8)$$

Moisture content (%) in dry basis,

$$M_d = \frac{(W_o - W_d) \times 100}{W_d} \quad (9)$$

W_o: Original weight of the sample
W_d: Bone dry weight of the sample

Moisture ratio, $MR = \frac{M - M_e}{M_o - M_e}$ (10)

where M: Moisture content (%)
M_e: Equilibrium Moisture Content
M_o: Original (initial) Moisture Content

Drying rate $K = \frac{\dot{m}_p}{t}$ (11)

where $\dot{m}_p$: Amount of moisture evaporated
t: Time

E. Economic Analysis

1) Cost- benefit analysis

The sum of all costs and benefits in a time period is analyzed. The net benefit is the total savings by the hybrid dryer over an equivalent electric dryer.

2) Benefit to cost ratio (BCR)

$$BCR = \frac{\sum(benefits)}{\sum(costs)} \quad (12)$$

3) Simple payback period (SPB)

The payback period is the duration of time needed to make an investment to recoup its initial cost.

$$SPB(\,in\ years) = \frac{\sum(investment\ \ costs)}{\sum(annual\ \ benefits - annual\ \ costs)} \quad (13)$$

4) Annualized cost

The annualized cost is calculated by,

$$C_a = C_{ac} + C_m + C_f - S_a - E_{pv} \quad (14)$$

The annualized capital cost is,

$$C_{ac} = C_{cc}\, F_c \quad (15)$$

The annualized salvage cost is,

$$S_a = S\, F_s \quad (16)$$

where
C_{cc} : Capital cost
F_c : Capital recovery factor
F_s : Salvage fund factor
C_m: annualized maintenance cost
C_f: Cost of fuel (running cost)
S: Salvage value
E_{pv}: Cost of electricity produced by the PV panel

$$F_c = \frac{d\,(1+d)^n}{(1+d)^n - 1} \quad (17)$$

$$F_s = \frac{d}{(1+d)^n - 1} \quad (18)$$

where d is the discount rate and n is life span in years.

The annualized maintenance cost (C_m) is taken as a fixed percentage of the annualized capital cost.

3. RESULTS AND DISCUSSION

A. Drying Process

The performance of the dryer for drying of *amla* was analyzed using the experimental data obtained from the experiments conducted in the solar laboratory of NIT, Calicut.

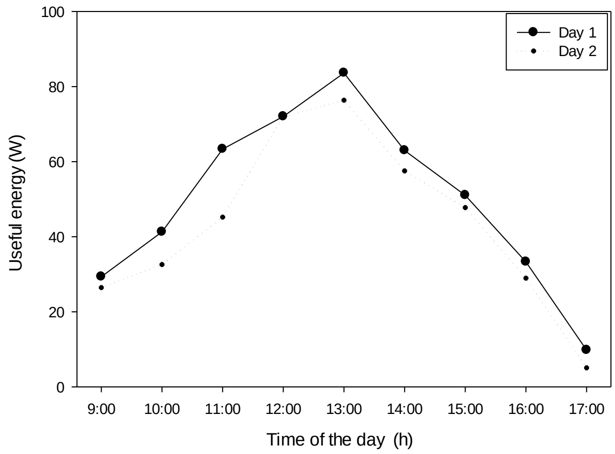

Fig. 2. Useful energy in dryer

Fig. 2 demonstrates the variation of energy used in the dryer with time during the experimental period of 2 days. The graphs show similar trends for both 1st and 2nd days. Energy utilized is found to be maximum at noon time. This pattern is predicted as the energy supplied by dryer increases with increase in solar radiation.

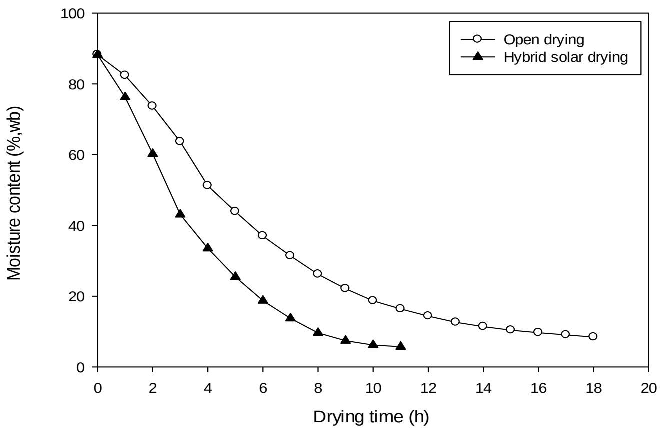

Fig. 3. Reduction in moisture content

Fig. 3 shows the moisture removal from the samples during drying. The performance of the hybrid solar dryer is better than that of open sun drying for the removal of the moisture. Fig. 3 compares the drying rate during the two different drying methods. During the initial period, moisture removal rate is high. This is due to the fact that the energy required to evaporate the surface moisture is low. After the removal of the surface moisture, drying rate decreases as the energy requirement is more.

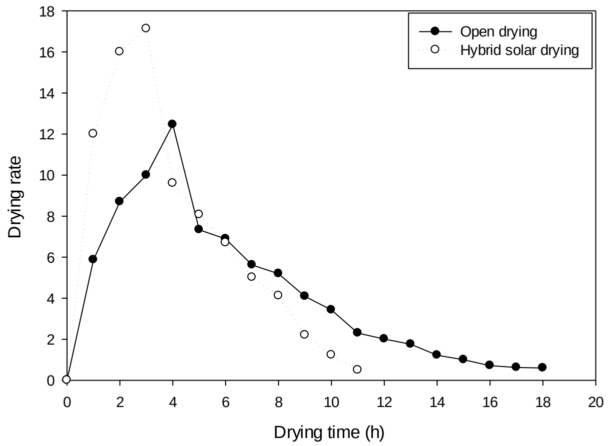

Fig. 4. Variation of drying rate with drying time

B. Economic analysis of the hybrid solar dryer

For the economic analysis, the pertinent parameters are taken based on the economic situation in India as shown in Table 1. Cost benefit analysis was done using annualized cost method. Simple payback period was also determined.

TABLE 1. COST AND ECONOMIC PARAMETERS

1.	Capital cost of the hybrid dryer	Rs. 20000
2.	Capital cost of the electric dryer	Rs. 3500
3.	Life span of dryers	20 years
4.	Discount rate	10 %
5.	Electricity cost	Rs. 4/ kWh
6.	Maintenance cost	3% of C_{ac}
7.	Salvage value	10 % of C_{cc}

For drying 1 kg of *amla*, the hybrid dryer took 11 hours. On an average 9 hours are available for drying in a clear sunny day. The number of solar days was taken as 250. A total of 187.5 kg of amla can be dried using this dryer, assuming
1 hour for loading, unloading and cleaning processes of the dryer. The blower consumed 1.26 kWh of electricity for drying 1 kg of *amla*. The annual electricity cost for blower is Rs. 1260. For drying 1 kg of *amla*, electric dryer of rating 1200 W took 9 hours. The capital cost of the electric dryer, electricity cost per kWh and efficiency of the electric dryer were assumed as Rs.3500, Rs.4/kWh and 80%, respectively.

The annual capital cost was calculated using Eq. (14). The calculated value of annual capital cost of the hybrid solar dryer is Rs.2350. The annual maintenance cost of the hybrid solar dryer is taken as 3 % of the annual capital cost. The salvage value was assumed to be 10% of the capital cost. The running cost of the blower was taken into account for the analysis. Also the economic value of the electricity produced by the photovoltaic panel was considered. The cost of drying 1 kg of *amla using the hybrid solar dryer was calculated as Rs.17.96*. The cost of drying per kg of amla using an electric heater was found to be Rs.36.79.

Net economic benefits using a hybrid solar dryer was calculated as Rs. 3530.63 per year. Benefit to cost ratio was found to be 2.8. As per the definition payback period is the time needed to make an investment to recoup its initial cost. Simple payback period was calculated using the Eq. (13) as 5.66 years. Payback period is small compared to the life of the hybrid solar drying system. So the hybrid solar drying systems are economical.

4. CONCLUSIONS

An effective hybrid photovoltaic-thermal (PV/T) solar dryer for drying of *amla* fruits has been developed and tested. The experiments were done for the controlled and open drying of the *amla* samples. The use of hybrid PV/T solar dryer considerably reduced the drying time. Economic analysis was carried out to find the net benefit and simple payback period. Payback period is small compared to the life of the solar drying system. This clearly establishes the economic viability of the hybrid solar drying systems.

5. REFERENCES

[1] V. Belessiotis, and E. Delyannis, "Solar drying", Solar Energy, 2011, pp. 1665-1691.
[2] R.C. Verma, and Ajay Gupta, "Effect of pre-treatments on quality of solar –dried amla", Journal of Food Engineering, 2004, pp. 397-402.
[3] A. Ayensu, "Dehydration of food crops using a solar dryer with convective heat flow", Solar Energy, 1997, pp. 121-126.
[4] P. Barnwal, and G. N. Tiwari, "Grape drying by using hybrid photovoltaic-thermal (PV/T) green house dryer: An experimental study", Solar Energy, 2008, pp. 1131-1144.
[5] M.Y.H. Othman, K. Sopian, B. Yatim, W.R.W. Daud, "Development of advanced solar assisted drying systems", Renewable Energy, 2006, pp. 703-709.
[6] O. Ekechukwu, and B. Norton, "Rewiew of solar energy-drying systems II and overview of solar drying technology", Energy Conversion and Management, 1999, pp. 615-655.
[7] S. K. Supranto, W. Daud, M. Othman,and B. Yatim, "Design of an experimental solar assisted dryer for palm oil fronds", Renewable Energy, 1999, pp. 643-646.
[8] Ho-Hsien Chen, C.E. Hernandez, and Tzou-Chi Huang, "A study of the drying effect on lemon slices using a closed-type solar dryer", Solar Energy, 2005, pp. 97-103.
[9] S. Aboul-Enein, A.A. El-Sebaii, M.R.I. Ramadan, and H.G. El-Gohary, "Parametric study of a solar air heater with and without thermal storage for solar drying applications", Renewable Energy, 2000, pp.505-522.
[10] Dilip Jain, "Modeling the performance of the reversed absorber with packed bed thermal storage natural convection solar crop dryer", Journal of Food Engineering, 2007, pp. 637- 647.
[11] C. Ratti, and A.S. Majumdar, "Solar drying of foods: modeling and natural simulation", Solar Energy, 1997, pp.151-157.
[12] E.C. Kern Jr., M.C. Russel, "Combined Photovoltaic and Thermal Hybrid Collector System," In Proceedings of the 13th Photovoltaic Specialists,1978, pp. 1153-1157.
[13] L.W. Florschuetz, "Extention of Hottel- Whillier Model to the Analysis of Combined Photovoltaic/Thermal Flat Plate Collectors," Solar Energy, 1979, pp.361-366 .
[14] J.K. Tonui, Y. Tripanagnostopoulos, "Improved PV/T solar collectors with heat extraction by forced or natural air circulation", Renewable Energy, 2006, pp. 623-637.