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PERFORMANCE EVALUATION OF MIXED MODE SOLAR DRYER

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ABSTRACT

Drying is a simple process of moisture removal from a product in order to reach the desired moisture content. It is an excellent way to preserve food and solar food dryers are appropriate food preservation technology for sustainable development. Various types of solar dryers are presently available in the market. In this work a mixed mode solar dryer is considered. Nowadays mixed mode solar dryer are commonly used to attain quick drying of agricultural and marine products such as fishes and prawns. In this paper evaluation parameters for various food crops are analyzed. Suitable design factors are analyzed and an approximate mathematical model is developed. Based on the loading capacity a model is fabricated. Testing is carried out with and without blower. An efficiency of 43.04% & 19.72 % was obtained with and without blower.

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INTRODUCTION

Drying is one of the most important means for the preservation of many kinds of agricultural products.Open sun drying, where the product is exposed directly to the sun allowing the solar radiation to be absorbed by the material, is one of the oldest techniques employed in agriculture. The term solar dryer is applied to a structure made for the deliberate use of solar energy to heat air and/or the products so achieve dehydration, or drying, of the products, and the process is called solar drying. The advantages of solar drying over sun drying have been well-documented (Simate, 2003; Janjai et al.,1998).However, compared to some other solar technologies, solar dryers continue to struggle to gain acceptance by commercial producers of dried products. The reasons for this are complex and varied and depend on many factors (Battock, 1990; Bena & Fuller, 2001).

A natural convection solar dryer is the most possible for use in areas where electricity is not available.Among the different types of natural convection solar dryers, the mixed-mode type has been demonstrated to be superior in the speed of drying (Simate, 2003). In this type of dryer, during day time the heat for drying are from both direct and indirect solar radiation. For direct mode, the product is allowed to directly absorb heat from solar radiation by applied a transparent cover on drying chamber.While, for indirect mode a solar collector system is commonly applied to collect heat to heat air, and the heated air flows through the drying products.

Fruits and vegetables constitute a major part of the food crops in developing countries. Drying is one of the methods used to preserve fruits. Many varieties of fruits are seasonal and most of them are consumed in their dried form to a large extent. This has been made possible by the process of drying. Grape is one of the world's largest fruit crops. The world production of grapes is presently 65,486 million tonnes out of which India accounts for 1.2 million tonnes [1]. Drying the grape produces raisins.

India receives an enormous amount of solar energy: on average, of the order of 5 kWh/m^{2}day for over 300 days/year [2]. This energy can be used for thermal or electrical applications. Thermal drying, which is most commonly used for drying agricultural products, involves vaporization of moisture within the product by heat and its subsequent evaporation from the product. Thus, thermal drying involves simultaneous heat and mass transfer [3].

In this work a mixed mode solar dryer with a "V" corrugated flat plate collector along with a pebbled storage system is constructed and testing is carried out to evaluate the performance. The testing is carried out with and without blower.

Basic Theory

The energy balance on the absorber is obtained by equating the total heat gained to the total heat loosed by the heat absorber of the solar collector. Therefore,

$IAc = Q_u + Q_{cond} + Q_{conv} + Q_R + Q\rho,$ (1)

Where, I = rate of total radiation incident on the absorber's surface (Wm^{-2});

A_c = collector area (m^2);

Q_u = rate of useful energy collected by the air (W);

Q_{cond} = rate of conduction losses from the absorber (W);

Q_{conv} = rate of convective losses from the absorber (W);

Q_R = rate of long wave re-radiation from the absorber (W);

Q_ρ = rate of reflection losses from the absorber (W).

The three heat loss terms Q_{cond}, Q_{conv} and Q_R are usually combined into one-term (Q_L), i.e.,

$Q_L = Q_{cond} + Q_{conv} + Q_R.$ (2)

If τ is the transmittance of the top glazing and IT is the total solar radiation incident on the top surface, therefore,

$IAc = \tau I_T A_c .$ (3)

The reflected energy from the absorber is given by the expression:

$Q_\rho = \rho\tau I_T A_c,$ (4)

where ρ is the reflection coefficient of the absorber. Substitution of Eqs. (2), (3) and (4) in Eq. (1) yields:

$\tau I_T Ac = Q_u + Q_L + \rho\tau I_T A_c$, or

$Q_u = \tau I_T A_c(1 - \rho) - Q_L.$

For an absorber $(1 - \rho) = \alpha$ and hence,

$Q_u = (\alpha\tau)I_T A_c - Q_L,$ (5)

where α is solar absorptance.

Q_L composed of different convection and radiation parts. It is presented in the following form (Bansal et al. 1990):

$Q_L = U_L A_c(Tc - Ta),$ (6)

where: U_L = overall heat transfer coefficient of the absorber ($Wm^{-2}K^{-1}$); T_c = temperature of the collector's absorber (K);

Ta = ambient air temperature (K).

From Eqs. (5) and (6) the useful energy gained by the collector is expressed as:

$Q_u = (\alpha\tau)I_T A_c - U_L A_c(T_c - T_a)$ (7)

Therefore, the energy per unit area (qu) of the collector is

$q_u = (\alpha\tau)I_T - U_L(T_c - T_a)$. (8)

If the heated air leaving the collector is at collector temperature, the heat gained by the air Qg is:

$Q_g = m_a C_{pa}(T_c - T_a)$ (9)

Where:

m_a = mass of air leaving the dryer per unit time (kgs^{-1});

C_{pa} = specific heat capacity of air ($kJkg^{-1}K^{-1}$).

The collector heat removal factor, F_R, is the quantity that relates the actual useful energy gained of a collector, Eq. (7), to the useful gained by the air, Eq. (9). Therefore,

$$F_R = \frac{m_a C_{pa}(T_c - T_a)}{A_c[(\alpha\tau)I_T - U_L(T_c - T_a)]} \quad (10)$$

or

$$Q_g = A_c F_R[(\alpha\tau)I_T - U_L A_c(T_c - T_a)] \quad (11)$$

The thermal efficiency of the collector is defined as (Itodo et al. 2002):

$$\eta_c = \frac{Q_g}{A_c I_T} \quad (12)$$

Energy Balance Equation for the Drying Process

The total energy required for drying a given quantity of food items can be estimated using the basic energy balance equation for the evaporation of water (Youcef-Ali, *et al.* 2001; Bolaji 2005):

$$m_w L_v = m_a C_p(T_1 - T_2), \quad (13)$$

where:

m_w = mass of water evaporated from the food item (kg);

m_a = mass of drying air (kg);

T_1 and T_2 = initial and final temperatures of the drying air respectively (K);

C_p = Specific heat at constant pressure

($kJkg^{-1}K^{-1}$).

The mass of water evaporated is calculated from Eq. 14:

$$m_w = \frac{m_i(M_i - M_e)}{100 - M_e} \qquad (14)$$

where:

m_i = initial mass of the food item (kg);

M_e = equilibrium moisture content (% dry basis);

M_i = initial moisture content (% dry basis).

During drying, water at the surface of the substance evaporates and water in the inner part migrates to the surface to get evaporated.

PROPOSED SYSTEM:

The proposed system consists of a "V" corrugated flat plate collector with a pebbled storage system, a drying chamber with four trays and a transparent cover.

Fig 1: "V" corrugated flat plate collector

Fig 2: Pebbled Storage System

Fig 1& 2 shows the schematic of a "V" corrugated flat plate collector & Pebbled storage system. The following materials were used for the construction of the domestic passive solar dryer: 1.Wood (Plywood) – as the casing (housing) of the entire system; wood was selected being a good insulator and relatively cheaper than metals. 2. Glass – as the solar collector cover and the cover for the drying chamber. It permits the solar radiation into the system but resists the flow of heat energy out of the systems. 3. Mild steel sheet of 1mm thickness and aluminum painted black – for absorption of solar radiation.4.Wooden frames with linen mesh for constructing the trays. 5. Nails and glue as fasteners and adhesives. 6. Hinges and handle for the dryer's door.7.Black colour paint on the absorber.8.Electrical Blower(220 V,50 Hz,48 WH, 1800 rpm).

EXPERIMENTAL SETUP:

The experimental setup for the mixed mode drying system is shown in the following figure 3.The designed and constructed solar dryer consists of two major compartments or chambers being integrated together, the solar collector compartment, which can also be referred to as the air heater, and the drying chamber, designed to accommodate four layers of drying trays on which the produces (or food) are placed for drying.

The dryer is a active system in the sense that it has moving parts. It is energized by the sun's rays entering through the collector glazing. The trapping of the rays is enhanced by the inside surfaces of the collector that were painted black and the trapped energy heats the air inside the collector. An electrical blower is connected to the collector. This blower helps in forcing the air through the drying chamber at a faster rate. This action causes a temperature rise in the chamber.

The green house effect achieved within the transparent glass drives the air current through the drying chamber at the top portion.

Fig 3. Experimental setup for the mixed mode drying system.

TESTING AND RESULTS:

The testing of the fabricated model was done during the month of April 2013 for four days with blower and four days without blower during May 2013. In this experiments the temperatures of the drying chamber,drying trays and collector were measured during different times of the day.Also the moisture content on wet basis was measured and percentage of weight loss was measured using a weighing balance.The sample of grapes before and after drying is shown in fig 4 & 5.

Fig 4 Sample before drying

Fig 5 Dried sample

Table 5 Parameters of the drying system:

Parameters	**Unit**	**Value**
Collector area	m^2	0.0295
Drying chamber area	m^2	0.177
Capacity of dryer	Kg	8-10
Mass flow rate	Kg/hr	2.8
Average air temperature	°C	40-60
Average exit temperature	°C	38-46

When testing was done with blower on the above four days, the blower was run by the electrical power at the specified time duration and turned off during the remaining time.

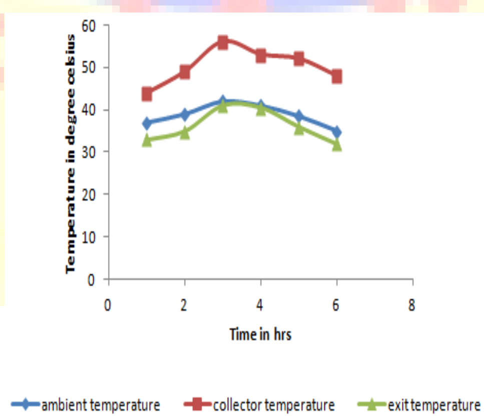

Fig 6a

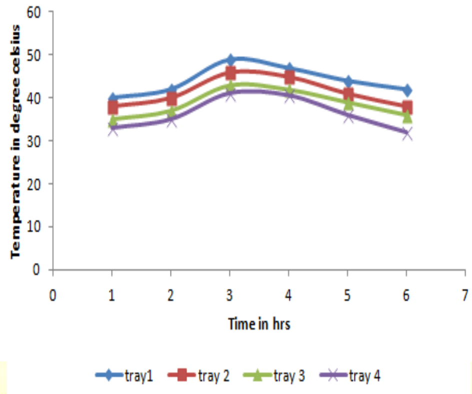

Fig 6b

Fig.6 Temperature variation without blower

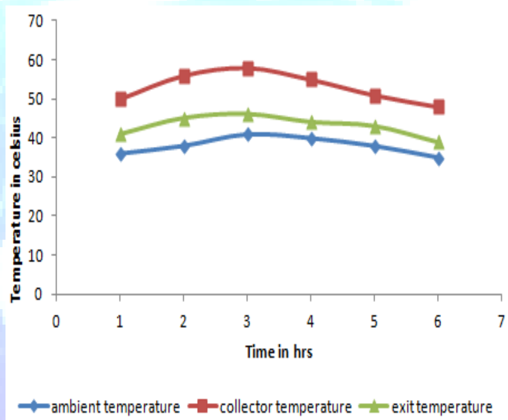

Fig 7a

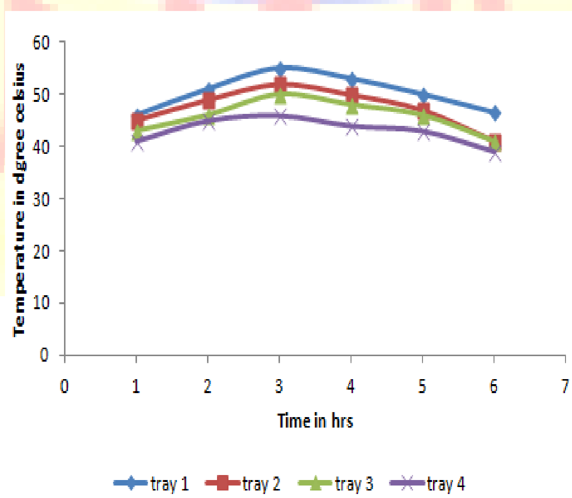

Fig 7b

Fig 7. Temperature variation with blower

Fig 6&7 shows the variation of temperatures of ambient air,exit air and air temperature of air at collectors outlet with respect to time.In fig 6a the exit temperature is slightly lower than the ambient since there is no forced mode of circulation to circulate the heated air at the collector through the drying chamber.Most of the heat is absorbed by the product to be dried in both the cases and hence the exit temperature is lower than the temperature of air at the collector's outlet.The temperatures at different regions of the drying trays decreases from the bottom tray to the top one.The variation of temperatures of the drying trays is shown in the second figure for both the cases with and without blower.

Figure 8 shows the moisture content removed using the solar dryer with and without using a blower. When dryer is operating with blower more amount of moisture is removed in the particular period of time. But while it is operating without blower the amount of moisture removed is very low. Thus the blower facilitates an increased drying rate with a higher flow of heated air within the drying chamber.

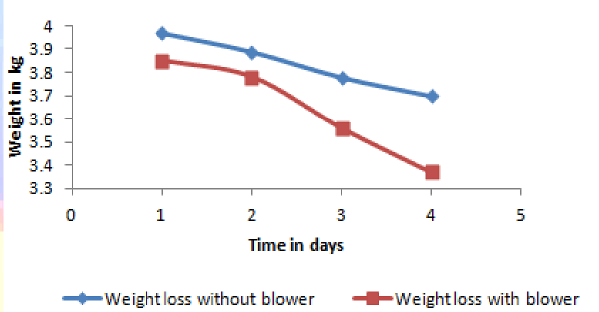

Fig 8. Moisture content variation with & without blower

The grapes were initially dark in colour before drying. The colour of the grapes turned to be dark brown colour after drying. There was also changes in smell of the product. The initial odour was not present at the final dried stage. Due to reduction in moisture shrinkage and weight loss were observed in the grapes.

Experimental Results

Parameters of measurement	Solar Dryer with blower	Solar dryer without blower

Moisture removed	0.63 kg	0.3kg
Collector efficiency %	36.56	17.74
Drying efficiency %	43.04	19.72
Power Consumed	8.628 KJ	8.362 KJ

CONCLUSIONS

From the test carried out, the following conclusions are made: The solar dryer can raise the ambient air temperature to a considerable high value for increasing the drying rate of agricultural crop. The product inside the dryer requires lesser frequent attention compare with those in the open sun drying in order to prevent attack of the product by rain or pest (both human and animals).The dryer was used to dry grapes and can be used to dry other crops too e.g. tomato,brinjal etc. There is ease in monitoring when compared to the natural sun drying technique. The capital cost involved in the construction of a solar dryer is much lower to that of a mechanical dryer.

The amounts of moisture removed from the grapes are 0.63 kg with blower and 0.3 kg without blower. The efficiency of the drying system is 43.04% with blower and 19.72% without using blower. The performance of existing solar food dryers can still be improved upon especially in the aspect of reducing the drying time and probably storage of heat energy within the system.Also,meteorological data should be readily available to users of solar products to ensure maximum efficiency and effectiveness of the system. Such information will probably guide a local farmer on when to dry his agricultural produce and when not to dry them.

REFERENCES

1. Ajay Kumar Sharma and Adulse P.G., Raisin production in India, NRC for grapes, Pune, India.. Battock M. (1990), A future for solar drying, Appropriate Technol . 17, 21–24.
2. Bena, B and Fuller, R.J. " Determination of the average coefficient of internal moisture transfer during the drying of a thin bed of potato slices ". Journal of Food Engineering. 2002,vol.48(2),pp.95-101.
3. Bena B., Fuller R. J. (2002), Natural convection solar dyer with biomass back-up heater, Solar Energy,72, 75–83.
4. El-Sebaii A.A., Enein Aboul S., Ramadan M. R. I., and El-Gohary H. G. "Experimental investigation of an indirect type natural convection solar dryer". Energy Conversion and Management, 2002, Vol.43, pp.2251-2266.
5. Excell R.H.B " A simple solar rice dryer,basic design theory",Sunworld,1980,vol.4, pp.186-191.
6. Ezekoye B. A. and Enebe O. M. "Development and performance evaluation of modified integrated passive solar grain dryer". The pacific journal of science and technology, 2006,Vol. 7, pp.185-190.
7. Fargali M. Hanaa, El-Shafy Abd, Nafeh A., Fahmy H. Faten, and Hassan A. Mohamed. "Medicinal herb drying using a photovoltaic array and a solar thermal system". Solar Energy, 2008,Vol. 82, pp.1154-1160.
8. Gallali, G; Garg, H.P; and Prakash, J. " Solar drying versus open sun drying, A framework for financial evaluation", Solar Energy, 2000, vol. 80, pp. 1568-1579.
9. Ghazanfari, A and Sokhansanj, S. " Experiments on solar drying of Pistachio nuts". Energy Conversion Management, 2002, vol. 27, pp.343-349.
10. Hodali Riyod and Bougard Jacques. "Integration of a desiccant unit in crops solar drying installation: Optimization by numerical simulation". Energy Conversion and Management, 2001, Vol.42, pp.1543-1558.
11. Holman J.P." Heat Transfer",Ninth edition,2008.
12. Hossain M. A. and Bala B.K. "Drying of hot chilli using solar tunnel drier". Solar Energy,2007, Vol.81,pp.85-92.
13. Jain Dilip. "Modelling the performance of the reversal absorber with packed bed thermal storage natural convection solar crop dryer". Journal of Food Engineering, 2006, Vol.78, pp.637-647.

14. Janjai S, Esper A, Muhlabauer W. (1994), A procedure for determining the optimum collector area for solar paddy drying system, Renewable Energy 4(4):409–16.
15. Janjai S., Srisittipokakun N. and Bala B. K."Experimental and modeling performances of a roof integrated solar drying system for drying herbs and spices". Energy, 2008, Vol.33,pp. 91-103.
16. Khalil, E.J; Al-Juamily, Khalifa, N; and Yassen, T.A. " Testing of the performance of a fruit and vegetable solar drying system in Iraq". Journal of Desalination. 2007,vol.209,pp. 163–170.
17. Leon, T.K; Mechlouch, R. F; and Brahim, A. B. "A study of the drying effect on lemon slices using a closed-type solar dryer", Solar Energy 2005, vol. 78, pp. 97-103.
18. Mohanraj M. and Chandrasekar P. "Drying of copra in a forced convection solar drier". Biosystems Engineering, 2008,Vol. 99, pp.604-607.
19. Pangavhane Dilip R., Sawhney R.L.,and Sarsavadia P.N. "Design, development and performance testing of a new natural convection solar dryer". Energy, 2002, Vol.27, pp.579–590.
20. Simate I.N.(2003), Optimization of mixed-mode and indirect-natural convection solar dryers,Renewable Energy, 28, 435–453.
21. Sodha M.S., Ram chandra, 1994, Solar drying systems and their testing procedures: a review, Energy Conversion & Management, 35(3), 219-267.