Design and Analysis of Solar Cabinet Dryer for Drying of Potatoes

Trinakshee Sarmah and S. K. Dhiman

Abstract A series of experiments were conducted on drying the potatoes via forced convection of heated air in an indirect-type solar cabinet dryer. Variation of the chamber temperature, the thickness of the potato slices and optimization of the water flow rate to the radiator was done. No pre-treatment of potatoes was carried out before commencing the experiments. The data, viz., the relative humidity inside the dryer, solar irradiation over the collector, temperature rise across the drying chamber and the weight lost by the specimen during the process of drying were collected. Analysis of data showed the increased drying rate with chamber temperature at a given air flow rate. For the slice thickness of 0.25 cm, the rectangular slices retained a faster drying rate compared to the square slices, while the circular slices showed the least drying rate. However, for the slice thickness of 0.5 cm, the rectangular slices still retained a faster drying rate, while square slices showed the least drying rate. The energy, exergy and cost analysis (simple payback period) of the setup was carried out.

Keywords Solar drying of potatoes · Open sun drying · Cabinet solar dryer · Cabinet dryer efficiency · Solar dryer cost analysis

Nomenclature

$\dot{m}_a$	Mass flow rate of air inside drying chamber (kg/s),
C_p	Specific heat of air (kJ/kg K)
T_{co}	Collector outlet temperature (K)
T_{ci}	Collector inlet temperature (K)
T_a	Ambient temperature (K)
Q	Heat energy used for drying process (kW)
η	System efficiency

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η_{ex} System exergy efficiency
E_{xi} Collector inlet exergy
E_{xo} Collector outlet exergy

1 Introduction

Food processing is the transformation of any raw product such as vegetables, fruits, meat, fish, etc., through a process to make it consumable and increase its commercial value. The primary aim of the food processing industry is to extend the period for which a food product remains nutritious which is done by employing various methods that balance the organic or chemical changes in the raw food product and allows enough time for distribution, sale and storage. Drying, a method of food preservation, removes the moisture from the food and helps to extend the shelf life of food. The solar dryer is used extensively in the agricultural sector for drying of perishable food in a hygienic manner and at a lower operating and maintenance cost as compared to the conventional dryers. Several authors have carried out theoretical and experimental work in the solar drying of potatoes. Jabeen et al. [1] have constructed a forced convection solar cabinet dryer for studying the effect of temperature (60, 70 °C) and thickness (2.3, 3 mm) on the drying of potatoes. Patil et al. [2] have studied the drying of tomatoes in two solar cabinet dryers, which were ran simultaneously in natural (55 °C) and forced convection mode (46 °C). Chinenye et al. [3] have dried cocoa beans in a batch dryer at 55, 70 and 81 °C with air velocities of 1.3, 2.51 and 3.7 m/s for 4–6 h continuously in a day and reduced the moisture content from 79.6 to 6% (wet basis). Naderinezhad et al. [4] have designed a tunnel dryer and studied the effects of temperature (45–70 °C) and velocity (1.6–1.81 m/s) on the circle and square shapes of potatoes. Chouicha et al. [5] carried out experimental work to study an indirect type of solar dryer for drying of potato slices for velocities of (0.31, 0.4, 0.51 m/s) in the drying chamber.

In the present work, the forced convection solar cabinet dryer has been designed. The objectives of the research are to study the drying of different thickness of potato slices by varying the temperature inside the drying chamber, to reduce the time required for drying of the potatoes as compared for open sun drying method and to bring the quality of the final product at par with the conventional electric dryers. Also, the cost of the dryer is low as the components of the model have been obtained from scrap yards and locally available materials have also been used.

2 Experimental Setup

As shown in Fig. 1, a box is constructed of 2 mm thick plywood board to house the radiator and the fan. It also serves as the duct for passing the hot air from the radiator to the drying chamber with the help of the fan. The SMPS (switched mode power supply) is fitted at the top of the box and the required connections are made. The SMPS is used because supply is of 230 V and the setup has to be run on 12 V. The experimental setup is to be connected to a solar panel. A Maruti 800 radiator of the downward flow type has been used. There are 37 copper plates and the diameter of the tubes is of 10 mm. The capacity of the radiator is 3 L. The cooling fan used in the experimental setup has a speed of 1200–2400 rpm. It runs on 220/240 V single phase AC supply. A 0.5HP pump is used to pump the water from the evacuated type solar collector to the radiator. The pump runs on single-phase AC supply of 220/240 V, 2.5 A and 50 Hz. The speed of the pump is 2800 rpm. An evacuated tube solar collector is used as a supply of hot water to the radiator. The maximum temperature attained by the water inside the collector is about (80–90) °C. The dimensions of the drying chamber are 92 cm × 61 cm × 65 cm. The body of the drying chamber is made of glass fitted on a wooden frame. The thickness of the glass pane used is 3 mm. There are two trays inside the drying chamber. These trays are perforated wire- mesh in nature to obtain a uniform drying of the food products throughout. The dimensions of the tray are 81 cm × 54 cm × 3.5 cm. These trays are lightweight, free from corrosion and cheap. These factors are favourable for medium temperature drying. There are holes drilled at the top of the drying chamber to allow the warm air to escape from the chamber after absorbing the moisture from the food products.

3 Methodology

3.1 Sample Preparation

The potatoes were bought from the local market. They were washed, peeled and sliced. An industrial vegetable cutter was used to slice the potatoes. The sliced potatoes were then placed in a die to get the required shape. As shown in Fig. 2 three shapes were used for the experiment: rectangle, square and circle. Two thicknesses of potato slices were considered: 0.25 cm and 0.5 cm. All the samples of a particular shape were identical in dimensions. Five samples of a particular shape were considered for one set of experiments. No pretreatment of the potatoes was carried out.

3.2 Experimental Procedure

As shown in Fig. 4, the samples prepared were placed on the tray evenly. The temperature of the water inside the solar collector varied from (60–70) °C. To increase the temperature of the water entering the radiator an external electric heating rod was also used. So the final temperature of the water entering the radiator was in the range of (60–80) °C. The rotameter was used to measure the flow rate of water entering the radiator. The flow rate of water entering the radiator was approximately 2.5–3 litres per minute. The air inside the enclosed and insulated

Table 1 Complete list of sample shapes, dimensions, weight loss and change in moisture content of all the experiments conducted

Sample shape and dimensions (in cm)	Temperature (celsius)	Time required for complete drying of the samples (minutes)	Initial weight of the sample (grams)	Final weight of the sample after drying is completed (grams)	Initial moisture content (% w.b.)	Final moisture content after drying is completed (% w.b.)	Initial kg of water/ kg of dry matter	Final kg of water/ kg of dry matter
Square (3 × 3 × 0.25)	45	150	9.64	1.051	89.1	32.8	8.172	0.487
	55	135	9.76	1.059	59.1	30	8.216	0.3
	65	120	9.62	1.058	89	29.1	8.093	0.411
Square (3 × 3 × 0.5)	45	250	25.51	10.156	60.2	14.3	1.512	0.719
	55	235	25.53	10.153	60.6	19.4	1.514	0.237
	65	225	25.54	10.154	60.2	9.6	1.515	0.106
Rectangle (3.5 × 4.5 × 0.25)	45	175	11.55	2.208	79.8	20.1	4.231	0.317
	55	165	11.56	1.531	86.8	28.1	6.551	0.472
	65	150	11.54	1.582	99.58	20.3	6.295	0.351
Rectangle (3.5 × 4.5 × 0.5)	45	295	36.06	10.075	72.1	17.6	2.579	0.213
	55	280	36.05	10.074	72.1	7.9	2.579	0.086
	65	270	36.03	10.073	72	10.1	2.577	0.113
Circle (3 cm dia, 0.25 cm thick)	45	190	11.44	1.15	89.9	12.8	8.948	0.748
	55	170	11.43	1.12	89	10.1	9.205	0.596
	65	160	11.42	1.15	89.2	10.4	8.93	0.4
Circle (3 cm dia, 0.5 cm thick)	45	265	22.95	7.01	69.5	13.6	2.274	0.064
	55	240	22.93	7.03	69.3	10.6	2.262	0.118
	65	230	22.91	7.03	69.3	14.4	2.259	0.24

chamber was blown forcefully with the help of a fan. This air absorbed the heat from the water flowing inside the radiator. The hot air then entered the drying chamber through an inlet hole at the bottom. The hot air absorbed the moisture from the samples kept on top of the wire-mesh trays. The warm air was then expelled from the outlet holes neat the roof of the drying chamber. The warm water from the radiator was made to return back to the hot water tank through a pipe. Thus, the temperature of water in the hot water tank was kept constant and did not fall. The velocity of air inside the drying chamber was 2 m/s. The experiments were conducted for three temperatures of air inside the chamber 45, 55 and 65 °C. The ambient temperature was 34 °C. The direct solar radiation was 750 W/m^2. The experiments were conducted between 11 a.m. to 4 p.m. The samples were weighed after every 15 min. They were removed carefully from the trays as shown in Fig. 3 and enclosed in airtight bags so as to prevent any moisture from entering or escaping them. They were then carefully weighed in the electronic balance. The loss in weight of the samples was noted. The samples were dried until the three consecutive weights after drying were similar. This meant that the moisture was completely removed from the samples and they were dry. The dry bulb temperature and the wet bulb temperature were noted with the help of the psychrometer kept inside the drying chamber. These values gave the relative humidity inside the chamber from the psychometric chart. These values were also noted at regular intervals of time. The temperature inside the drying chamber and that at the outlet was measured by the digital thermometer (Table 1).

4 Results and Discussion

Three shapes of potato samples were taken (square, rectangle, and circle) and two thicknesses of samples were considered (0.25 and 0.5 cm). As observed from Figs. 5, 7 and 8, when the temperature inside the drying chamber was 45 °C and the 0.25 cm thick samples were being dried, the square samples took the least time to get dried completely as shown in Fig. 7 and the circular samples took the highest amount of time to dry as shown in Fig. 8. This trend was repeated when the temperature was 55 °C inside the drying chamber. However, for the temperature of 65 °C inside the drying chamber the time taken for the rectangular samples to dry was higher than the other shapes, which may be observed from Figs. 5, 7 and 8. Similarly, when the 0.5 cm thickness samples were being dried, the square-shaped samples dried the fastest as observed from Fig. 6 comparing with Figs. 9 and 10.

When the temperature inside the chamber was increased from 45 to 65 °C, the time required to dry the samples also decreased as the rate of removal of water from the samples was carried out at a faster pace. The flow rate of air inside the chamber was kept constant at 2 m/s throughout the entire time of the experiment.

Fig. 1 Experimental setup

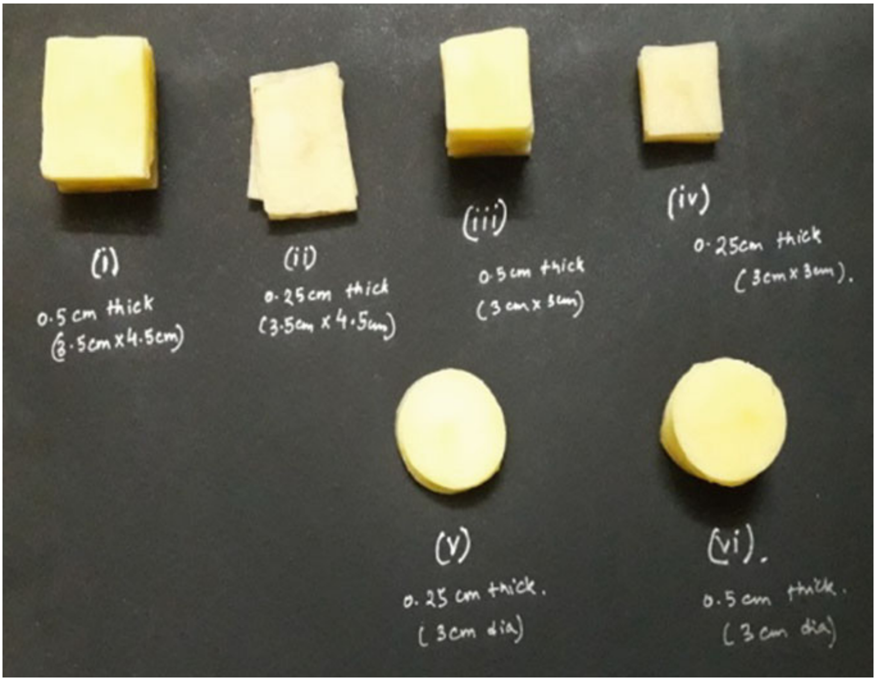

Fig. 2 Potato samples before drying

5 Energy, Exergy and Cost Analysis

5.1 Energy and Exergy Analysis

The equation for the amount of heat used for the drying process is given below [6]:-

$$Q = \dot{m}_a C_p (T_{co} - T_{ci})\ldots \tag{1}$$

The equation for the system efficiency is given below [1]:

$$\eta = \frac{WL}{IA + P_f}\cdots \tag{2}$$

The equation for exergy at the inlet to the dryer is given below [6]:

$$E_{xi} = m_a C_p \left[(T_{ci} - T_a) - \left(T_a \ln\left(\frac{T_{ci}}{T_a}\right)\right)\ldots \right. \tag{3}$$

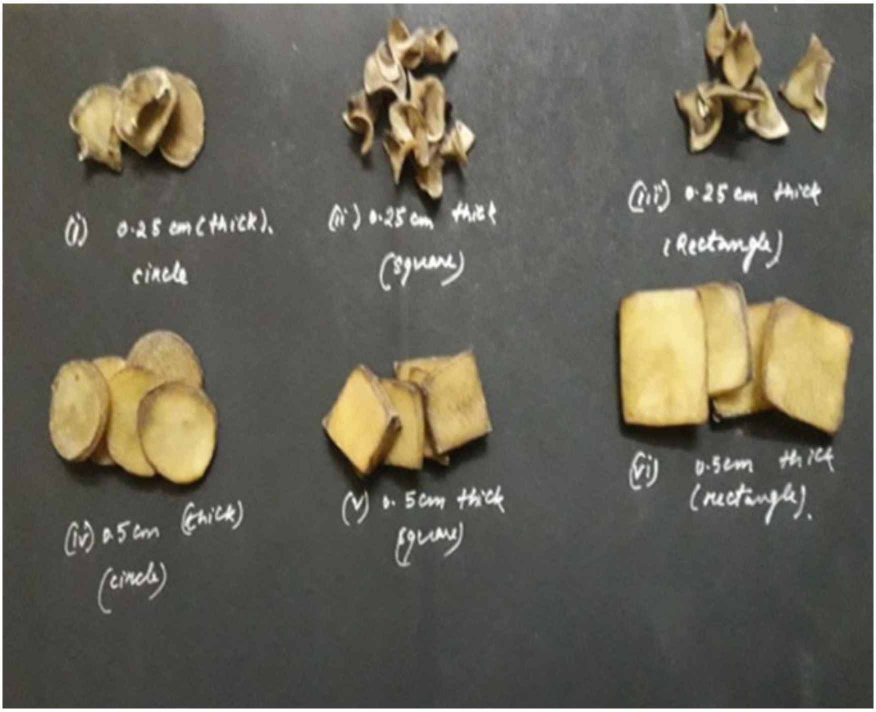

Fig. 3 Potato samples after drying

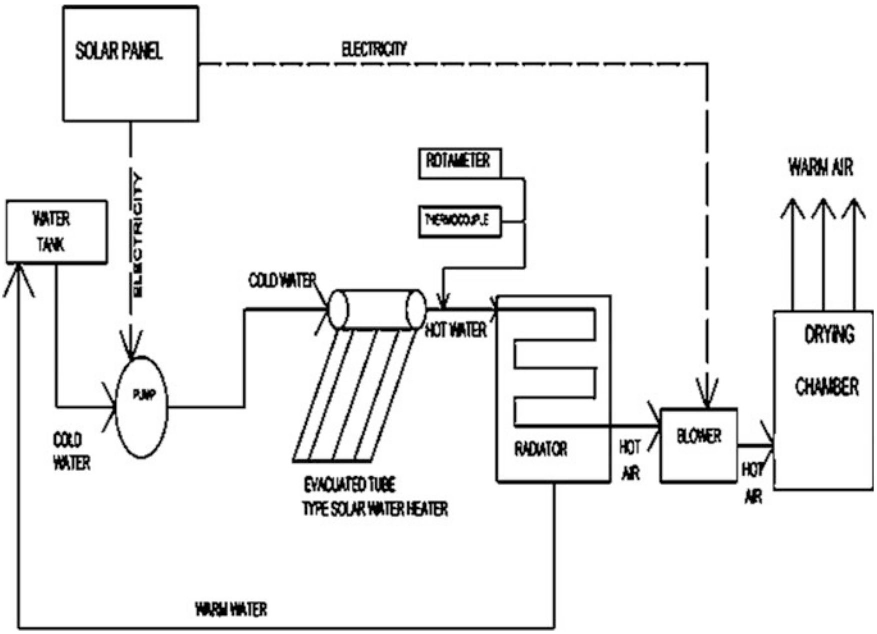

Fig. 4 Schematic diagram

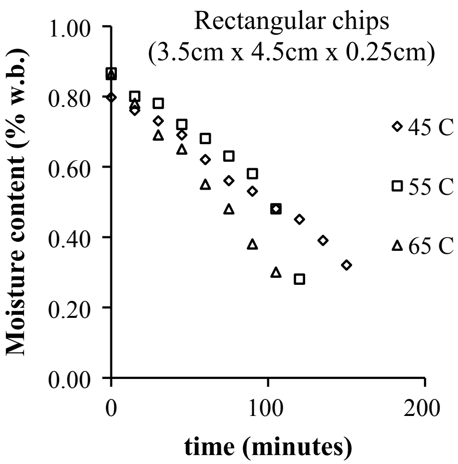

Fig. 5 Variation of the moisture content with time for rectangular chips of 0.25 cm thickness

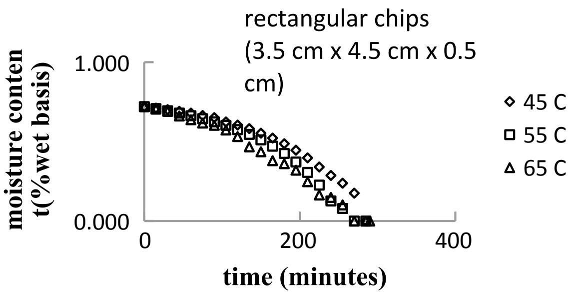

Fig. 6 Variation of the moisture content with time for rectangular chips of 0.5 cm thickness

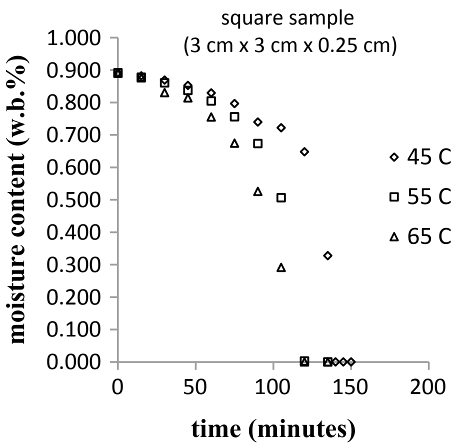

Fig. 7 Variation of the moisture content with time for square chips of 0.25 cm thickness

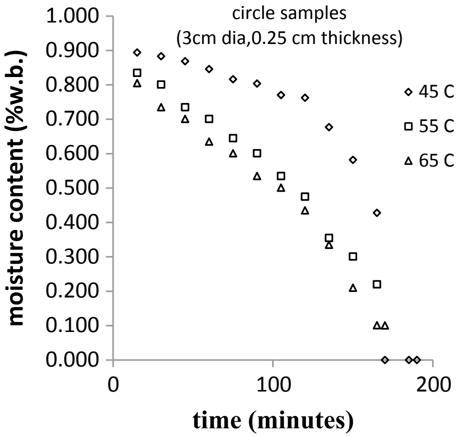

Fig. 8 Variation of the moisture content with time for circular chips of 0.25 cm thickness

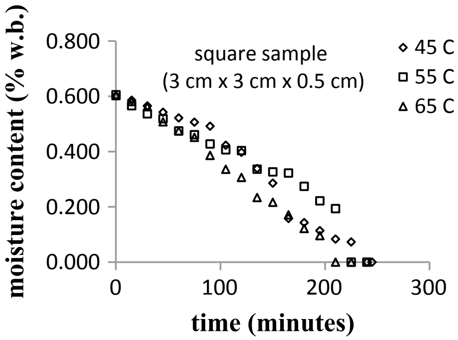

Fig. 9 Variation of the moisture content with time for square chips of 0.5 cm thickness

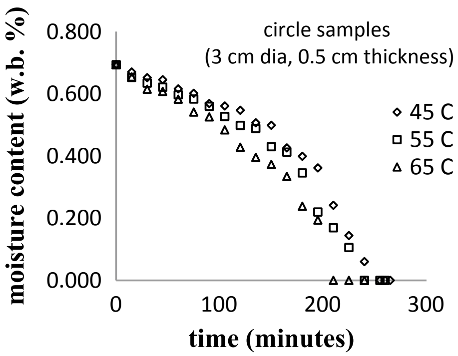

Fig. 10 Variation of the moisture content with time for circular chips of 0.5 cm thickness

The equation for exergy at the outlet to the dryer is given below [6]:

$$E_{xo} = m_a C_p [(T_{co} - T_a) - \left(T_a \ln\left(\frac{T_{co}}{T_a}\right)\right)\ldots \quad (4)$$

The equation for exergy efficiency is given below [6]:

$$\eta_{ex} = \frac{E_{xo}}{E_{xi}} \ldots \quad (5)$$

After the required calculations, it was found that the amount of heat energy used for the drying process is 5.2304 kW. The system efficiency for the forced convection solar dryer is 13.089%. The exergy efficiency of the solar dryer is 61.953%.

5.2 *Cost Analysis*

The total cost of the plywood box, heat exchanger fan, pipes etc. is Rs. 12100. The dryer capacity is 5 kg per batch and if it runs for 200 days a year, then the total cost of conventional energy used for one year is Rs. 4890.56. The expected lifetime of the dryer is 20 years. If the salvage value is taken as 10% of the total initial cost and the maintenance cost taken as 1% of the salvage value then the annual cash benefit comes out to be Rs. 4769.56. Hence, the simple payback period for the experimental setup is 1.328 years.

6 Conclusion

In the present work, the solar drying of potatoes in a forced convection solar dryer has been studied. The main results showed that when the temperature inside the chamber was 45, 55 and 65 °C, the moisture content of the potatoes reduced from 89.1% to 33% in an average time of 160 min for 0.25 cm thick slices and 260 min for 0.5 cm thick slices. For both thicknesses, the square samples took the least amount of time to dry. For 0.25 cm thick slices, the circular samples took the highest amount of time to dry and for 0.5 cm thick slices the rectangular samples took the maximum drying time. The average heat energy used for drying inside the chamber is 1.584 kW. The system energy efficiency was 13.089% and the exergy efficiency was 61.953%.

Certain improvements can be made to the existing setup. The wood used in the model may be replaced by Teflon which is a better insulator. Again an axial flow fan may be used instead of the exhaust fan. A biomass burner may be used to supplement the solar energy and increase the time of operation of the dryer.

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