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Design and development of mixed mode natural convection solar dryer

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Abstract
This paper deals with the critical design specifications and field performance of movable type mixed mode natural convection solar dryer for drying agricultural products. A mixed mode natural convection solar dryer was designed and fabricated with the locally available materials and commissioned at Sangareddy (17.6294 °N, 78.0917 °E), Telangana, India for drying agricultural product. The performance of solar dryer was evaluated through no-load and full-load conditions tests in the summer months. The cost economics of the construction of solar dryer was also analysed. Under load conditions, the dryer has been used in experimental drying tests varying from 0.5 kg to maximum capacity of 1.5 kg of agricultural products (grapes, tomatoes). This prototype dryer was designed and constructed to have a maximum collector area of 0.558 m^2.

Keywords: mixed mode type, natural convection dryer, solar collector, cost economics

1. Introduction
Agricultural products especially fruits and vegetables are highly perishable in nature and are seasonal. About 50% of produced fruits and vegetables are lost after been harvested (FAO, 1989) [1] and they cannot be stored for longer period. Drying is one of the oldest methods of food preservation practiced by humans and it extends the shelf life of the food product. It also makes the seasonal food available throughout the year to meet the thirst of food lovers (Reddy *et al*., 2018) [13]. It also reduces transportation cost by lowering the weight and volume, packing size, storage space (Demir and Sacilik, 2010; Arepally *et al*., 2017a) [4, 12]. Solar energy being the renewable energy is used by human by directly drying the food produce in the hot sun. It requires large area, results in uneven control of drying, involves high labour cost and also product quality is degraded because of dust, insects, birds and other foreign matter (Basunia and Abe, 2001; Arepally *et al*., 2017b) [3, 11]. To overcome these difficulties, improvement of sun drying has led to evolution of solar drying protecting the food from contamination and weather conditions while retaining the nutritional qualities as such (Ukegbu and Okereke, 2013) [17]. Therefore, the introduction of solar dryer systems become popular to reduce losses of agricultural food material and to improve the quality of the dried product significantly when compared to the traditional drying methods (Yaldiz *et al*. 2001; Togrul and Pehlivan, 2003; Ravula *et al*., 2017a) [18, 16] and also they are cheaper and more practical when compared to mechanical dryers, for example, the conventional drying process of fruits, using hot air, is generally expensive due to the water phase change and also requires high energy requirement (Ravula *et al*., 2017b) [11]. However, solar dryers must be properly designed in order to meet the particular drying requirements of crops of interest and to give satisfactory performance with respect to the energy requirement (Akpinar *et al*., 2004) [2].
The direct solar dryers involve the thin layer of product spread over large space to expose to solar radiation. This type of drying method is useful for grains. In indirect solar dryers or convective solar dryers, the atmospheric air is heated in flat plate collector or concentrated type solar collector in which the hot air or the heated air flow in the cabin where products are dried. Moisture from the produce is lost by convection and diffusion. This method of drying is used to avoid direct exposure to the solar radiation. In this kind of drying process, the chamber temperature and thickness of drying samples are the main factors taken into consideration (Diamante and Munro, 1993) [6]. In mixed mode type, the product is dried with both direct exposure to solar radiation and hot air supplier on it. In this process the product is dried according to convective moisture loss. Kornsakoo and Exell introduced a cheap and simple mixed mode dryer for farmers. This type of dryer is often used for drying crops in the wet season (Mustayen *et al*., 2014) [10]. However, solar dryers must be properly designed in order

to meet the particular drying requirements of crops of interest and to give satisfactory performance with respect to the energy requirement (Akpinar *et al*., 2004) [2]. Tomato (*Lycopersicon esculentum*) is considered as one of the most important vegetables occupying second position amongst the vegetable crops in terms of production (Abano *et al*., 2011) [1]. It is a perishable vegetable that contains higher moisture content so that it is necessary to dehydrate it without changing nutritional and sensory characteristics to use in off season. Dried tomatoes can be made into powder and is used as an ingredient in the manufacturing of different food products. At the market, rejection rates for tomatoes are 23% for good grades (Singh and Singla, 2011) [15]. As per 2015-16, some of the vegetable production in India is shown in Table1.

Table 1: Vegetable cultivation and production in India as per 2015-16

Data	Area, '000' ha	Production, '000' tonnes	Yield, kg/ha
Potato	2134	43770	20510.78
tomato	760	18399	24209.21
Onion	1225	20991	17135.51
Brinjal	664	12552	18903.61
Total	4783	95710	20010.45

(***Source***: Department of Agriculture and Cooperation, Govt. of India (Horticulture Division))

This study was undertaken to fabricate a low cost mixed mode natural convection solar dryer with the locally available material for drying of tomato, grape and to estimate the cost economics of fabricated dryer.

2. Design of solar dryer

To carry out design calculation and size of the solar dryer, the following assumptions and conditions were made as follows (Seveda, 2012) [14]:

2.1. Quantity of Water to Be Removed: Mass of initial water content was calculated using following equation:

$$M = \frac{(m_1 \times x)}{100} \quad (1)$$

Where

Mass of bone dry product was calculated as follows:

$$M_d = x - M \quad (2)$$

Initial moisture content (db) was calculated as follows:

$$M_1 = \frac{m_1}{(100 - m_1)} \times 100 \quad (3)$$

Final moisture content (db) was calculated as follows:

$$M_2 = \frac{m_2}{(100 - m_2)} \times 100 \quad (4)$$

The mass of water to be removed during drying was calculated using following equation:

$$M_w = \frac{(m_1 - m_2)}{100} \times x \quad (5)$$

2.2. Total energy required for drying: Total energy required for drying was calculated using following equation:

$$Q = (M_d \times C_d \times (T_2 - T_1)) + (M \times C_p \times (T_2 - T_1)) + (M_w \times \lambda) \quad (6)$$

Energy required per hour for drying was calculated using following equation:

$$Q = \frac{Q}{t} \quad (7)$$

2.3. Drying Rate: Drying rate was calculated as follows:

$$k = \frac{Mw}{t} \quad (8)$$

2.4. Collector area of solar dryer required for drying

It has been found that about 68 per cent area of solar dryer faced towards south is able to receive sunlight whereas remaining 32 per cent area toward north is from the sun. It is assumed that the overall efficiency of solar dryer is ranged from 17.33 to 35%. Collector area of solar dryer required for drying was calculated using the following equation:

$$A_t = \frac{Q_r}{I \times \eta \times 0.68} \quad (9)$$

3. Construction details of solar dryer

A mixed mode natural convection solar dryer (Fig. 1) was fabricated at College of Agricultural Engineering, Sangareddy, Medak district, Telangana state of India. It is situated on the latitude of 17.6294 °N, longitude of 78.0917 °E and at an elevation of 621 m above mean sea level. Tomato (Lycopersicon esculentum) used for the drying experiment were procured from a local market. The solar dryer has been modelled and simulated using pro/engineering software (auto CAD). Different components of developed solar dryer are mainframe with wheels, drying chamber with door, drying trays and solar collector.

3.1 Main Frame

Main frame was fabricated with 25 mm × 25 mm angle iron pieces of 4 mm thick 25 mm gauge to make the main supporting structural members of height 1300 mm for the drying chamber. The iron material is selected as it is easily available in rural areas and even scrap material can be used whereas as wood is expensive and is not durable like iron. The pieces are welded together as shown in Fig. 1. The pieces are welded so that the structure is stable and sturdy to make drying chamber. The dimensions of the main frame are 1300 mm×525 mm. Two brake wheels and two castor wheels are fixed to the legs of the main frame for the easy moment of the dryer.

Fig 1: Main Frame

3.2 Drying chamber

The drying chamber is created in the top portion of the main frame separated by tie rods of angle iron pieces on all the sides in two layers to hold two trays with a vertical spacing of 130 mm. The chamber dimensions are 590 mm × 525 mm horizontal to vertical. The drying chamber, as shown in Fig. 2 has been designed to facilitate drying of different vegetables and spices. The air from the solar collector enters from the bottom of the drying chamber and flows upwards carrying the moisture through it. Drying chamber in which the trays are placed is fixed with a door for the movement of the trays and for loading and unloading of the product. Thermocol sheets are fixed on all the sides and in the bottom of the box to insulate the drying chamber from heat loss and saving the costs. A ventilator with a circular whole of 5 mm radius is provided with a pipe to one side of the chamber to let out the hot humid air from the chamber.

Top of the chamber is covered with a glass of 5 mm thickness. This also the traps the solar radiation along with the solar collects and aids in achieving higher temperatures in the chamber. Sufficient opening to fix the solar collector was made at the bottom of the drying chamber beneath the bottom tray for the hot air from the solar collector to enter. All the gaps between different parts are insulated with thermocol to prevent heat transfer losses.

Fig 2: Drying chamber

3.3 Drying trays

The two drying trays are made from aluminum sheets of dimensions 495 mm×495 mm to load the product. Perforations of 5 mm diameter have been made in the aluminum sheets for the air to flow through the product easily. The drying trays are as shown in Fig. 3. To avoid bending of the perforated trays, when loading and unloading, 25 mm gauge angle iron pieces are welded across the frame beneath the perforated trays. An opening of 508 mm×30 mm is provided for the easy movement of trays.

Fig 3: Drying trays

3.4 Door

Door is a frame with the dimensions of 512 mm×312 mm fitted with a fibre sheet and with the help of hinges for the moment of the trays. The fibre sheet is fitted with screws along all edges. Locking arrangement is provided to secure the product in the chamber.

Fig 4: Door

3.5 Solar collector

Flat plate collector is fabricated with the help of 25 mm×25 mm angle iron pieces of 25 gauge and thickness of 4 mm.

They are welded together with supporting angle iron tie pieces to make it stable, sturdy and box like structure with the dimensions of 1095 mm×510 mm×215 mm as shown in the Fig. 5. It consists of an absorber plate covered with a glass top to trap solar radiation. At the bottom is provided with thermocol to prevent heat loss in that direction. Absorber plate is a copper plate of thickness 1 mm and the dimensions are 1095 mm×510 mm coated with black paint which acts as a black body. It is directly nailed at a depth of 132 mm from the glass. The dimensions of the glass are 1080×500×5 mm and it is fitted at the top of the collector. Two ends are open and the sides are covered with thermocol to give it a box like shape. Absorber plate is fixed in between so that air moves on either side of the absorber plate. One open end is pushed into the drying chamber and other opening is left open to let the air from the surroundings.

The solar collector absorbs the solar radiation and traps in the absorber plate. The air coming into contact with the hot absorber plate gets heated up and moves up because of the difference in the densities of cold incoming air and the hot air. The hot air enters is circulated naturally upward through free convection and enters the drying chamber and moves upwards through perforations in the aluminum trays. Product gets dried with the direct radiation coming from the top of the drying chamber and the hot air coming from the solar collectors. The hot air picks up the moisture from the product and the humid air leaves the chamber through ventilator. In order to prevent the breakage of the glass, care must be taken. The completed dryer was checked for overall stability, ease of handling and unloading of the trays (which should fit in any position) and the opening and closing of doors (which must operate freely). Care must be taken to prevent glass from breakage.

Fig 5: Solar collector

3.6 Description of the solar dryer

The dryer that was fabricated, is a type of mixed mode natural convection solar dryer. This type of solar dryer has a collector for heating the air and a drying chamber to accommodate trays over which fruits and vegetables are spread over. The solar collector uses a glass and a black painted absorber sheet. The drying chamber is covered by a transparent foil cover which protects the product from air and dust and traps the solar energy to dry the product. The solar collector collects the heat energy and heats the air entering through the inlet. Heated air enters the drying chamber from beneath the tray and flows upwards through the product carrying moisture with it. This moist air goes out of the ventilation provided at the top. Air circulation is provided by natural convection inside the collector and drying chamber.

The mixed mode natural circulation solar dryer is shown in the Fig. 6. A glass cover fixed over the copper plate with an air gap for the air to enter. An insulation layer is provided at the bottom of the collector to minimize heat losses from the back of the collector. Hot air is circulated because of the buoyant force created in the air stream due to the temperature difference. The drying trays are loaded and unloaded through the door from one side of the drying chamber. The solar collector should face due south for best stationary performance. The collector is placed at an inclination of 32.4 degrees to face the sun most of the time and to trap the solar radiation effectively. The tomatoes and grapes were dried and is shown in Fig. 7 and 8.

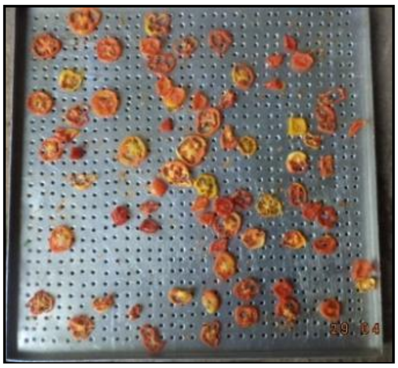

Fig 6: Solar dryer **Fig 7:** Solar dried tomatoes

Fig 8: Solar dried grapes

4. Cost economics
The cost estimation of solar dryer and its performance was divided into fixed cost and variable cost. It includes the calculation of fixed cost, variable cost, selling price, profit and benefit cost ratio.

4.1 Fixed cost and variable cost
Fixed cost includes the cost of wheels, aluminium sheet, copper sheet, aluminium tray, iron box, angle iron, thermocol, transparent glass, fibre sheet, toughened glass, nuts and bolts, fevicol, and paint. The dimensions, quantity used and amount are discussed in the Table 2. Variable cost includes the cost of raw tomato, no. of packets required and the maintenance cost.

Table 2: Fixed cost of solar dryer

S. No	Particle of raw materials	Quantity	Price (Rs)
1	Wheels (2inch)	4	640/-
2	Aluminium sheet (1mm)	1	655/-
3	Copper sheet (0.5mm)	4.5 kg	2330/-
4	Aluminium tray (2mm)	2	1900/-
5	Aluminium sheet (0.5mm)	1	550/-
6	Iron bars (40mm)	10 kg	1200/-
7	Angle iron (25mm)	6 kg	450/-
8	Thermocol (10mm)	15	100/-
9	Thermocol (15mm)	15	200/-
10	Transparent Glass (6mm)	1	350/-
11	Fibre sheet	1	350/-
12	Toughened glass (5mm)	1	680/-
13	Nuts and Bolts	45	135/-
14	Lappam (1kg)	1	50/-
15	Fevicol (1litre)	1	70/-
16	Paints (0.5litre)	2	300/-
		Total	9960/-

4.1.1 Variable cost
Raw tomato for 90 day drying = 1.5 kg/day × 90 days =135 kg Dried tomato obtained = 0.38 kg/day × 90 days = 34.2 kg

Packing weight of Tomato per packet = 0.1 kg
Number of packets required = 34.2 ÷ 0.1 = 342 packets

Table 3: Variable cost of drier for tomato dehydration

S. No	Description	Quantity	Unit Price (Rs.)	Amount (Rs.)
1	Maintenance cost @ 5% of cost of dryer (9960×0.05)	-	-	498/-
2	Cost of raw Tomato	135 kg	10	1350/-
3	Packing material cost @ Rs 10/ packet	342 Nos.	10	3420/-
			Total	5268/-

Table 4: Total investment

S. No.	Cost Particulars	Amount (Rs.)
1	Fixed Cost	9,960/-
2	Variable Cost	5,268/-
Total Cost		Rs.15,228/-

Revenue
Sale of dried tomato (@ Rs.60/- per packet) = 60×342 =Rs. 20,520 /-

4.2 Profit
Profit is calculated by subtracting investment from the revenue.
Profit = Revenue – Investment

Revenue – Investment = Rs.20,520/- – Rs.15,228/- = Rs. 5,292 /-

4.2.1 Benefit cost ratio
The ratio of revenue to the investment gives the Benefit cost ratio.
Benefit cost ratio = Revenue ÷ Investment
Benefit cost ratio = Revenue ÷ Investment = 20520 ÷ 15228 = 1.34

5. Conclusion
High quality and aesthetically appealing dried agricultural produce can be produced from solar drying. Solar dryers also demand a greater labour input than traditional methods, e.g. loading and unloading of trays of produce, but above all, the structure can be cheaply constructed using simple and affordable technologies and capable of being made and repaired in the areas where they are to be adopted, and are constructed using simple tools and limited locally-available resources. No special skills are required. A natural convection mixed mode solar dryer was designed and constructed with low cost locally available material. The designed dryer was expected to dry 1.5 kg/m^2 of agricultural produce in two to three days under ambient conditions during summer months. The performance of solar dryer for drying of agricultural produce was also evaluated through no-load and full-load conditions tests in the summer months. The air temperature inside the dryer was higher than outside by 37–50.5 ºC.

Nomenclature

wb	:	Wet basis
db	:	Dry basis
x	:	Mass of selected product taken for drying, kg
m_1	:	Initial moisture content of selected product in % (wb)
m_2	:	Final moisture content of selected product in % (wb)
T_1	:	Ambient air temperature (◦C)
T_2	:	Temperature inside the solar tunnel dryer (◦C)
C_p	:	Specific heat of water (kJ kg^{-1} ºC^{-1})
t	:	Total drying time (h)
C_d	:	Specific heat of product (kJ kg^{-1} ºC^{-1})
λ	:	Latent heat of vaporization of water (kJ kg^{-1})
M	:	Mass of initial water content (kg)
M_1	:	Initial moisture content in % (db)
M_2	:	Final moisture content in % (db)
M_d	:	Mass of bone dry product (kg)
M_w	:	Mass of water to be removed (kg)
Q	:	Total energy required for drying of selected product (kJ)
Q_t	:	Energy required per hour for drying of selected product (kJ h^{-1})
A_c	:	Collector area of solar tunnel dryer required (m^2)
η	:	Overall thermal efficiency of solar tunnel dryer, %
k	:	Drying rate (kg h^{-1})

6. References

1. Abano E, Ma H, Qu W. Influence of air temperature on the drying kinetics and quality of tomato slices. Journal of Food Process Technology. 2011; 2(5):1-9.
2. Akpinar EK, Sarsilmaz C, Yildiz C. Mathematical modelling of a thin layer drying of apricots in a solar energized rotary dryer. International Journal of Energy Resources. 2004; 28(8):739-752.
3. Basunia MA, Abe T. Thin-layer solar drying characteristics of rough rice under natural convection. Journal of Food Engineering. 2001; 47(4):295-301.
4. Demir K, Sacilik K. Solar drying of Ayaş tomato using a natural convection solar tunnel dryer. Journal of Food Agriculture and Environment. 2010; 8(1):7-12.
5. Department of Agriculture and Cooperation, Govt. of India. (Horticulture Division) http://agricoop.gov.in/ statistics/publication-reports.
6. Diamante LM, Munro PA. Mathematical modelling of the thin layer solar drying of sweet potato slices. Solar Energy. 1993; 51(4):271-276.
7. Divyasree A, Sudharshan Reddy R, Gulshan Kumar M, Venkat Reddy K. Mathematical Modelling, Energy and Exergy Analysis of Tomato Slices in a Mixed Mode Natural Convection Solar Dryer. Chemical Science International Journal. 2017b; 20(4):1-11.
8. Divyasree A, Sudharshan Reddy R, Venkat Reddy K. Mathematical modelling of mixed mode natural convection solar drying of tomato slices. International Journal of Chemical Studies. 2017a; 5(4):1274-1279.
9. FAO. Prevention of Post-harvest Food Losses: fruits, vegetables and root crops, A Training Manual. Food and Agriculture Organization of the United Nations, Rome, 1989.
10. Mustayen AGMB, Mekhilef S, Saidur R. Performance study of different solar dryers: A review. Renewable and Sustainable Energy Reviews. 2014; 34(3):463-470.
11. Ravula SR, Arepally D, Sandeep G, Munagala SR, Ravula PR. Effect of process variables on osmotic dehydration of carrot slices. International Journal of Chemical Studies. 2017b; 5(4):1280-1284.
12. Ravula SR, Munagala SR, Arepally D, Reddy P. Mathematical modelling and estimation of effective moisture diffusivity, activation energy, energy and exergy analysis of thin layer drying of pineapple. Journal of experimental biology and agricultural sciences. 2017a; 5(3):392-401.
13. Reddy RS, Malik GK, Madhava M, Golla S. Sensory evaluation of flavoured milk: Effect of incorporation of dried pineapple powder and drying temperature. The Pharma Innovation Journal. 2018; 7(3):246-248.
14. Seveda MS. Design and development of walk-in type hemi-cylindrical solar tunnel dryer for industrial use. International Scholarly Research Network Renewable Energy, 2012, 1-9.
15. Singh S, Singla N. Fresh Food Retail Chains in India: Organisation and Impacts. Centre for Management in Agriculture (CMA) (Publication No – 238). Allied Publishers, 2011, 1.
16. Togrul I, Pehlivan D. Modelling of thin layer drying kinetics of some fruits under open- air sun drying process. Journal of Food Engineering. 2003; 65:413-425.
17. Ukegbu PO, Okereke CJ. Effect of solar and sun drying methods on the nutrient composition and microbial load

in selected vegetables, African spinach (Amaranthus hybridus), fluted pumpkin (Telferia occidentalis), and okra (Hibiscus esculentus). Sky Journal of Food Science. 2013; 2(5):35-40.

18. Yaldiz O, Ertekin Can, Ibrahim Uzun H. Mathematical modelling of thin layer solar drying of sultana grapes. Energy. 2001; 26(5):457-465.