REST Journal on Emerging trends in Modelling and Manufacturing
Vol:2(4),2016
REST Publisher
ISSN: 2455-4537

Website: www.restpublisher.com/journals/jemm

Design and Development of Solar Dryer of Convergent Nozzle type Flat Plate Collector

M. A. Boda, N. M. Dhore, M. D. Jadhav, A. K. Jamadar, K. D. Kapse
Mechanical Engineering Department, V, V, P, Institute of Engineering and Technology, Solapur, India.
manoj.boda07@gmail.com Tel: +91-8657655595

Abstract
Objective of this study was to design, develop and carryout detailed experimentation on a new type solar dryer. This is new because it is having a Convergent nozzle type flat plate collector. Convergent nozzle is helps to increase the outlet velocity of nozzle, same principle here used to increase the outlet velocity of flat plate collector. By increasing velocity the drying time is reduces. The experimentation is carried out on sliced onion and grapes. Now a day the new innovations are required in solar dryer to fulfil the requirements of drying agricultural and industrial products. The design considerations and assumptions are very important to design any system. To reduce the drying time, the methodology which are using is also very important. It is observed that by using blower the drying time is reduced. The solar drying system is very good comparatively the open sun drying system.
Keywords: Solar dryer, convergent nozzle type collector, sliced onion, grapes.

Nomenclatures

Notation	Meaning	Notation	Meaning
m_w	Mass of water to be evaporate (kg)	V_a	Volume flow rate of air (m^3/s)
m_p	Mass of dried product (kg)	m_a	Mass flow rate of air (kg/s)
m_i	Initial moisture content (%)	h_i	Depth at inlet (m)
m_f	Final moisture content (%)	h_o	Depth at outlet (m)
E_p	Energy required for evaporation(J)	w_i	Width at inlet (m)
L_v	Latent heat of vaporization (kJ/kg)	w_o	Width at outlet (m)
A_c	Collector area (m^2)	T_i	Inlet air temperature (^oc)
E_a	Energy gain by air (J)	T_o	Outlet air temperature (^oc)
I_c	Solar intensity (W/m^2)	T_a	Ambient air temperature
n_c	Collector efficiency (%)	Cp_a	Specific heat of air (kJ/kgK)
t_d	Drying time (hour)	P_a	Density of air (kg/m^2)
v_a	Velocity of air at location (m/s)		

I. Introduction

Most of the agricultural products contain the higher moisture content of 25 to 80% but generally for agricultural products. This value of moisture content is very much higher than the required for long preservation. Due to this moisture content bacterial and fungal growth is occurs at very faster rate. Bacteria and enzymes may spoil the foodstuff and reduces the nutrient content in it. Therefore it is necessary to reduce the moisture content in foodstuff for its long preservation. Another case of drying is to remove the total moisture content from food. Drying is a simple process of removing water content from an agricultural or industrial product. It is oldest method of food preservation. Solar drying of agricultural products in enclosed structures is an attractive way of lowering post-harvest losses and low quality associated with traditional sun drying methods. Several successful attempts for developing natural convection crop solar dryers, both of the cabinet-type and of the tunnel-type, have been investigated over the years. Drying is one of the most cost-effective ways of preserving foods of all varieties which involves removal of water by the application of heat. The pre and post processing steps are very important to reduce the drying load as well as to make better quality products. Various pre-processing steps such as osmotic dehydration, blanching, salting, soaking are used depending on the food variety to be dried. Whereas post-processing such as coating, packaging also has a great importance after drying of food products. Solar energy is the most considerable renewable energy source in the world. Every day enough solar energy reaches the earth to supply our nation’s energy needs. The world receives 170 trillion kilowatt solar energy. Out of that reflected back to space is 30%, heat transformed to low temperature is 47%, and 23% is used for evaporation. As per a research on solar energy, sun gives 1000 times more energy than what we consume.

II. Literature Review

The scientists or researchers from different countries have presented their work in a field of solar dryer, their results and conclusions are discussed here [1]: Designed and fabricated direct natural convection solar dryer to dry tapioca in rural areas with minimum of 7.56 m^2 solar collector area to dry 100 kg of tapioca in 20 hours (two days drying period). The initial and final moisture content was 79 % and 10% respectively. The air temperature was 32ºC and 74% relative humidity with solar radiations of 13 MJ/m^2/day. A prototype of dryer was fabricated with collector area of 1.08 m^2 [2]: In this study solar energy supported, swirling flow new drying system is designed and artificial drying of seeded grapes grown around Elazığ/Turkey is investigated. With the developed swirling flow dryer with airy solar collector it is examined that drying occurs homogenously and lower moisture values are obtained in when compared with classical drying system. Also it is found that with an increase in the drying air velocity decreases drying time. Thus, drying time which is 200 hours in natural conditions decreases to 80 hours with an air velocity of 1.5 m/s with developed system [3]: Designed a mixed-mode natural convection solar crop dryer for drying cassava and other crops. Mixed-mode natural convection solar crop dryer for drying cassava 160 kg, initial moisture content of 67 % , 100 kg of water is required to be removed. Final moisture content of 17 % 30–36 hours is assumed solar radiance of 400W/m^2 and 25.1 ºC. Concluded that, minimum of 42.4 m^2 of solar collector area and expecting efficiency as 12.5% But with 340.4 W/m^2 in 35.5 hours got efficiency as 12.3% [4]: A solar assisted forced convection dryer was developed to study the effect of airflow rate (2.43, 5.25, 8.09 kg/min), air temperature (55, 65, 75^{0}C), and fraction of air recycled (up to 90%) on the total energy requirement of drying of onion slices. For drying of onion slices from initial to final moisture content 86% to 7%, the energy required per unit mass of water removed during without using recirculation of air was found between 23.548 and 62.117 MJ/kg water. The percent energy contribution by the solar air heater, electrical heater, and blower was found between 24.5% to 44.5%, 40.2% to 66.9%, and 8.6% to 16.3%, respectively. The maximum saving in total energy up to 70.7% was achieved by recycling of the exhaust air. The energy required per unit mass of water removed was found between 12.040 and 38.777 MJ/kg water. The percent energy contribution by the solar air heater, auxiliary heater, and blower was found between 22.4% to 40.9%, 33.6% to 62.6%, and 11.2% to 37.2%, respectively. [5]The work was aimed to investigate an indirect solar dryer, locally designed and constructed for drying sliced potatoes, In order to adjust appropriate conditions for safe store. They searched to improve the performance of solar dryer. An electrical resistance supplied by a variable number of photovoltaic panels was used to enhance the thermal efficiency. On the other hand, they tried to follow the impact of various controlling factors of hybrid solar drying on the quality of dried potato slices.

III. Design of Solar Dryer

The design part it plays a very important role in any engineering. The following some considerations are very important in the solar dryer system design. Minimum temperature for drying food is 30°C and the maximum temperature is 65°C, therefore 45°C and above is considered average and normal for drying samples and some other [6]. Drying times range from 0.25 sec (drying of tissue paper) to five months (for hardwood). It is suggested that for hot climate passive solar dryers, a gap of 7 cm should be created as air vent (inlet) and air passage. The metal sheet thickness of 0.8–2 mm, the outer cover is glass for the collector. The efficiency of the flat plat collector is 30%. For any system designing there are some assumptions are required, initial and final moisture content in grapes are 85% and 18 % respectively [7]. Latent heat of vaporization of water is 2257 kJ/kg. Density of air 1.225 kg/m^3. Absorptivity of absorber plate is 0.9. Heat removal factor of absorber plate is 0.1. In design the local meteorological data taken into considerations like location, weather conditions, etc.

Mass of water to be evaporates from product, $mw = m_p \times \frac{mi-mf}{100-mf}$

Energy required for evaporating water from product, $E_p = m_w \times L_v$

Nozzle Type solar collector

There are two main parameters required for calculation of solar dryer components. Those are drying time and solar collector area. Here any one parameter should be assumed, so it is easy to assume area and that is 0.8m^2. This assumed area; it is a combination of solar collector's width and length. The convergent type nozzle is used from top view it looks like trapezoidal shape.

Solar collector area (A)

$A = \frac{1}{2} \times (\text{sum of the parallel sides}) \times \text{distance between parallel sides}$

$A = \frac{1}{2} \times (0.6 + 1) \times 1 = 0.8\ m^2$

Energy gain by air from Radiation

$E_a = I_c \times A_c \times n_c$

Calculating Drying Time,

The energy required evaporating = Energy gain by air from radiation x time

$E_p = E_a \times t_d$

Therefore, $t_d = \frac{Ep}{Ea}$

Mass Flow Rate of Air (m_a),

Mass flow rate at inlet = (Inlet area of solar collector x Velocity of air) x density of air

Velocity of air at location, $v_a = 1.2$ m/s

$m_a = (A \times v_a)$

Inlet area for air entering of solar collector

$A_i = h_i \times w_i = 0.07X1 = 0.07\ m^2$

$m_a = (A_i \times v_a)$

Mass flow rate at outlet = (outlet area of solar collector x Velocity of air) x density of air

$m_a = (A_o \times v_a)$

Outlet area of solar collector

$A_o = h_o \times w_o = 0.04X0.6 = 0.024\ m^2$

$m_a = (A_o \times v_a)$

Velocity of air required

$m_a = p_a V_a$

But, $V_a = A_o \times v_a$

$V_a = \frac{Va}{Ao}$

IV. Experimental Set-Up

The actual experimental set-up consists of different components such as, solar flat plate collector, drying chamber, trays and blower. Figure 1 shows the experimental set-up. The solar dryer consists of flat plate solar collector (air heater) of area 0.8 m^2 connected with drying chamber. The solar collector has 2 mm thick galvanized sheet as absorber plate coated with black paint to absorb maximum solar radiation. The absorber plate is placed directly behind the transparent cover (glass) with a layer of air separating it from the cover. The air to be heated passes between the transparent cover (glass) and the absorber plate. To increase the temperature of the air by the greenhouse effect, a glass cover of 6 mm thickness was placed. The gap between the glass and the absorber surface at inlet and outlet of solar flat plate collector was maintained at 70 mm (h_i) [20] and 40 mm (h_o) respectively for air circulation. The drying chamber width, depth and cross sectional height of 0.6×0.6×1 m respectively. The system is faced to south direction because to absorb maximum solar radiations. The blower's mass flow rate of air is 0.0533 m^3/s with blower power is 500 watt. The outlet of the blower is kept at the inlet of solar flat plate collector. The air is get heated from convergent nozzle type solar flat plate collector and this heated air is passed into drying chamber.

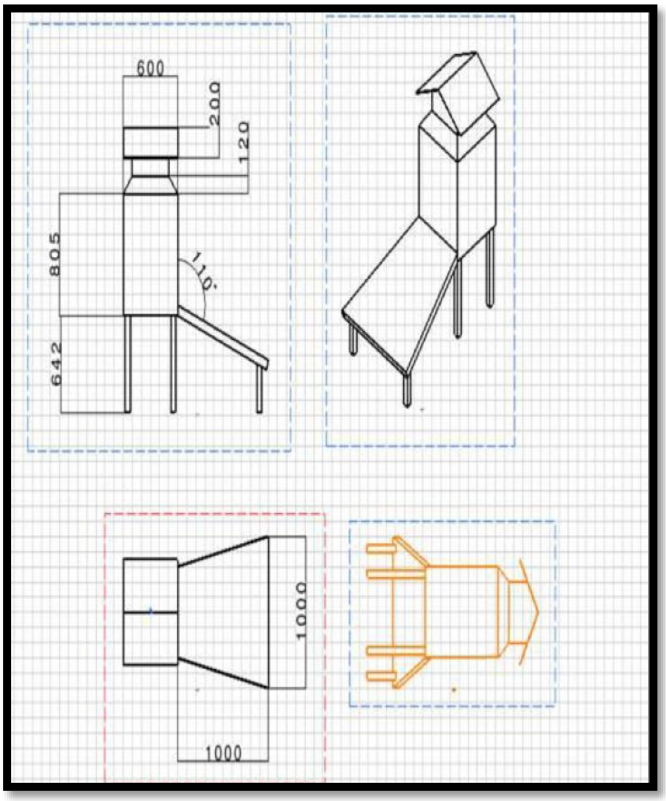

Figure 1: Actual Experimental set-up   Figure 2: Line diagram of Experimental set-up

This is very important parameter; the following experimental steps are involved in drying of onion and grapes. The food products which are fresh and undamaged are selected for drying. After selecting the food product the washing is done to remove the mud, bacteria which are on the outer surface of products. The washed products are moved for pre-treatment like peeling, slicing, quenching, etc. The pre-treatment for grapes is followed with oil emulsion application will accelerate drying process by decreasing the resistance to moisture transfer and by increasing internal moisture diffusion coefficient. The pre-treatment for onion is followed in this experiment is slicing the onions into 3-4 mm thickness. After that the product is kept for drying.

V. Result And Discussion

The performance analysis of this system carried out by testing this experimental setup, this is necessary for the purpose of evaluation of system parameters. The following tables show results of forced convection solar drying,

Table 1: Observations of Onion on 12/03/2016

Time	T_a(ºC)	Intensity(W/m^2)	T_{in} (ºC)	T_{out}(ºC)	T_b (ºC)	T_m(ºC)	T_t(ºC)
10 am	34	528	36	52	50	46	42
11am	37	530	38	53	50	49	47
12pm	39	535	39	56	54	53	46
1pm	41	538	41	59	55	52	50
2pm	40	536	40	53	52	48	45
3pm	36	532	36	51	49	44	43
4pm	41	531	41	59	55	52	50

Table 2: Observations of Grapes on 15/03/16, 16/03/16, 17/03/16, and 18/03/16

Time	T_a(ºC)	Intensity(W/m^2)	T_{in} (ºC)	T_{out}(ºC)	T_b(ºC)	T_m(ºC)	T_t(ºC)
Date 15/03/16							
10am	34	527	36	36	36	36	36
11am	37	530	37	53	51	47	43
12pm	39	534	39	53	50	49	47
1pm	40	536	40	54	53	52	49
2pm	41	533	41	56	55	52	50
3pm	40	530	40	53	52	48	45
4pm	38	528	38	48	49	44	43
5pm	35	525	36	40	47	42	43
Date 16/03/16							
10am	36	528	36	36	36	36	36
11am	37	530	37	53	51	48	45
12pm	39	532	39	55	52	49	46
1pm	40	533	40	57	53	51	48
2pm	41	536	41	55	50	48	49
3pm	40	532	40	52	49	46	47
4pm	39	530	39	48	47	47	46
5pm	38	527	38	44	45	46	46
Date 17/03/16							
10am	36	528	36	36	36	36	36
11am	38	530	37	53	51	48	45
12	39	534	38	55	51	49	46
1pm	40	533	39	57	54	53	50
2pm	40	532	40	58	56	54	52
3pm	39	531	40	57	54	53	50
4pm	37	529	39	55	52	49	46
5pm	34	526	38	54	51	48	45
Date 18/03/16							
10am	36	528	36	53	51	48	45
11am	38	532	38	55	51	49	46
12	39	535	39	56	54	53	50
1pm	40	535	40	58	56	54	52
2pm	40	532	40	55	54	53	50
3pm	39	530	39	51	50	49	47
4pm	36	528	36	48	48	49	46
5pm	34	525	34	46	46	48	46

To dry 2 kg of grapes at ambient temperature of 33^{0}C and average solar radiation is 450 W/ m^2, with grapes having 80% initial and 18 % final moisture content. From 2 kg of grapes 1.575 kg of water to be evaporate, the latent heat of vaporization of water is 2257000 J/kg from which the total energy required to evaporate water is 3687938 joule. Time required is 32 hours (four days of drying). To dry 2 kg of sliced onion minimum 6 hours drying time required at same atmospheric conditions that of grapes deying. As per the all readings it is observed that, the solar intensity is increasing from 10 am to 1 pm, it is the maximum solar intensity of that day and the atmospheric temperature also increasing, after 1 pm solar intensity gradually decreasing so the atmospheric temperature is also decreasing this is due to the sun angle changes and its direction. The drying time is depends on the atmospheric conditions, if the atmospheric temperature is more the drying time is less and vice-versa. The performance of the system is directly based on atmospheric condition, the intensity of the solar radiation, airflow rate and food sample.

VI. Conclusion

From the test carried out, the following conclusions were made. The solar dryer can raise the ambient air temperature to a considerable high value for increasing the drying rate of agricultural crops. The reduction in drying time occurs by increasing air flow rate. The food items are also well protected in the solar dryer than in the open sun, thus minimizing the case of pest and insect attack and also contamination. Although the dryer was used to dry grapes, onion but it can be used to dry other crops etc. The drying time of grapes by forced convection is 32 hours. The drying time of onion by forced convection is 6 hours.

References

[1]. Y. Cengiz and G. Çakmak, "Design of a New Solar Dryer System with Swirling Flow for Drying Seeded Grape", International Communications in Heat and Mass Transfer, 36, 2009, 984–990.

[2]. F. Forson, "Designed a Mixed-Mode Natural Convection Solar Crop Dryer for Drying Cassava and other Crops", Journal of Renewable Energy, 32, 2007, 2306-2319.

[3]. P. N. Sarsavadia, "Development of a solar-assisted dryer and evaluation of energy requirement for the drying of onion", Renewable Energy, 32, 2007, 2529–2547.

[4]. Mohamed Hafed Berrbeuh, Solar Drying of Sliced Potatoes: an Experimental Investigation, Energy Procedia, 36, 2013, 1276 – 1285.

[5]. P. Gbaha, H. A. Yobouet, J. K. Saraka, B. Kamenan Koua, and S. Toure, "Experimental Investigation of a Solar Dryer with Natural Convective Heat Flow" Renewable Energy, 32, 2006, 1817–1829.

[6]. M.A.Boda and C.V.Papade, "Design & Development of Indirect Type Solar Dryer with Energy Storing Material". An International Journal of Innovative Research in Advanced Engineering, 1(12), 2014, 109-114

[7]. Çakmak, Gülşah, and Cengiz Yıldız, The drying kinetics of seeded grape in solar dryer with PCM-based solar integrated collector, Food and bio products processing, 89(2), 2011, 103-108.