Design Development and Testing of Photovoltaic Ventilated Solar Dryer for Drying Tomato and Onion Slices Used As Powder in Food

Abdulahi Umar

Fedis Agricultural Research Center, Harar, Ethiopia
Corresponding Author E-mail: umarabdulahi2010@gmail.com

Abstract: A solar dryer was designed and manufactured at Fadis Agricultural Research Center workshop of Oromia Agricultural Research Institute. The framework of all the parts of the dryer were built by joining perforated angle irons of 40 mm x 40 mm x 4 mm and 20 mm x 20 mm x 4 mm by means of bolts and nuts. The dryer covers 3.0 m x 3.0 m area of the ground of which the 1m^2 was used for drying chamber while the rest was saved for collecting solar radiation. The drying chamber surrounded by the collector from three sides, had five shelves positioned one on the top of another with 10 cm clearance in between. The roofs and walls of the dryer were covered with the flexible transparent plastic leaving the three sides of the solar collector open to allow air in. Preliminary tests with no load to the dryer showed that the solar collector raised the ambient air temperature of 20°C to 41°C to a warm air of 28°C to 64°C between the morning and midday. This lowered the relative humidity of air from average 26% in the morning to 5% at midday. The dryer, loaded at 5 kg/m^2, dried tomato slices of 8 mm thickness from initial moisture content of 93.3% (w.b) to final moisture content of 12% (w.b) in 13 hours and11hours when operated under natural convection current. Similarly, onion slices of 3 mm thickness, loaded at a rate of 4 kg/m^2, dried from 87.10% (w.b) initial moisture content to 9.1% (w.b) final moisture content in 10 hours. Using forced ventilation, the slices of tomato and onion took 11 hours and 9 hours to reach their final moisture contents of 12% and 9.1% (w.b), respectively. The open air-sun drying tests conducted side by side with solar drying needed an average of 20 hours to reach the same final moisture contents for both tomato and onion slices. The maximum drying rate of tomato slices attained under natural convection and forced circulation were 3.1 and 2.8 kg of water per kg of dry matter-hr, while those of the onion slices 2.6 and 1.5 kg of water per kg of dry matter-hr. For the open-air sun drying, the maximum drying rates for tomato and onion slices were 1.5 and 0.82 kg of water per kg of dry matter-hr. Drying tomato and onion slices to their final moisture contents took one-half, two & four days and one, two and three days in PVSD, NCSD and OASD, respectively. Drying rate coefficients ‘k’($^{-1}$hr) of Lewis model were statistically significantly different and could be used to describing solar and open-air sun drying characteristics of solar and open-sun dryings of tomato and onion slices. From economic feasibility and payback analysis of the solar dryer, the payback period was determined and was very small (1.20 months) compared to the life of the dryer, so the dryer will dry product free of cost for almost its life period of 15 years.
Keywords: solar drying, drying efficiency, temperature, humidity, onion and tomato slices, photovoltaic cell.

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Introduction

Vegetables and their products are of great nutritional importance since they make a significant contribution in supplying wealth of essential vitamins, minerals, antioxidants, fibers and carbohydrates that improve the quality of the diet. Vegetable production is seasonal in nature and during peak, harvest there is often a glut to the market and at unsafe storage moisture levels. That leads to drastic drop in the price of the produce as there are no facilities for long-term storage and that the commodity has to be sold out before it perishes. Ethiopia has different agro-climates and soil types that enable to produce various types of vegetable and fruit crops for both local consumption and export markets. However, growing and marketing fresh produce in Ethiopia is complicated by high postharvest loss, which reaches about 30% (EARO, 2000). Naturally, fresh produce needs low temperature and high relative humidity environment during storage and transportation.

However, the means of achieving these for long-term purpose is beyond the reach of the economy of the majority of the producers and local traders. Established system of cold chain consisting of packinghouses, cold storage and refrigerated transportation is needed to reduce this loss to acceptable level.

Drying is a common method for preservation of food products. The main purpose of drying is the reduction of moisture content to a safe level for extending the shelf life of products. The removal of water from fruit and vegetables provides microbiological stability and reduces deteriorative bio-chemical reactions. In addition, the process allows a substantial reduction in terms of mass, volume and packaging requirement, which reflects on handling, storage and transportation costs with more convenience (Okos *et al.*, 1992). It ensures their availability at all times of the year.

Drying kinetics is generally affected by air temperature, relative humidity of the air, air velocity and material size (Kiranoudis *et al.*, 1992). Generally, the drying phenomena can be described using thin layer drying models mainly to estimate the drying times and moisture content of the food materials at any time after they are subjected to a known temperature and relative humidity (Torgul and Pehlivan, 2004). Many research studies have been reported on mathematical modeling and experimental studies conducted on thin layer drying process of various food products such as onion and pepper (Kiranoudis *et al.*, 1992), chilli (Hussain and Bala, 2002), carrot (Doymaz, 2004) and tomato (Sacilik *et al.*, 2006).

Use of dehydrated vegetables in various convenience foods is a common phenomenon all over the world. The application of dried potatoes, tomatoes, garlic, onion, carrot, mushrooms and sweet potatoes in various food products including bread, doughnuts, soups, stews, etc. is a practice of long history.

The introduction of solar drying system seems to be one of the most promising alternatives to reduce postharvest losses. Solar dried products have much better colour and texture as compared to open sun dried products. The justification for solar dryers is that they dry products rapidly, uniformly and hygienically. Since, they are more effective than open sun drying and have lower operating costs than mechanized dryers (Diamante and Munro, 1993; Condori *et al.*, 2001); more importance is given now a day to the use of solar dryers.

The open-air sun drying process is not very hygienic. It depends on weather conditions and there is a risk of deterioration (Bala et al., 2003). Some of the problems associated with open-air sun drying can be solved with a solar dryer, which can reduce crop losses and improve the quality of dried product significantly compared to traditional drying methods (Madhlopa and Ngwalo, 2007).

Use of solar dryers is a much-preferred alternative in view of its low initial capital and running costs, and free and ample supply of solar energy in the country. However, no information is available on solar drying of fruit and vegetables under Ethiopian climatic conditions in general and particularly under the local conditions of the eastern part of the country.

Although a number of designs of solar dryers exist in various countries, there are no such dryers with proper design with adequate information on drying performance available on the market in Ethiopia. The very few attempts done in some places ended up in solar dryers that are not affordable by the farming communities, difficult to transport from place to place, and have no scientific information at all on the capacity, drying performance and utilization. Those which are imported from elsewhere are expensive, cumbersome, complicated and unavailable to the users.

One can clearly see the need for easily available and affordable appropriate drying technology as a means of tackling the unacceptably high postharvest loss of fruits and vegetables in Ethiopia. Development of solar dryer with all the necessary information on its performance and operation can be one aspect of the solution for the problems. Therefore, this research was initiated to design, develop and conduct performance evaluation of a solar dryer for drying of vegetables and fruits. Tomato and onion were considered as study crops, based on ease of supply during the test period. The solar dryer was designed and tested with photovoltaic powered fans for use to increase the drying efficiency.

The objectives of the study include:

- To design and construct photovoltaic powered solar dryer
- To test and evaluate the performance of the solar dryer for drying onion and tomato slices used as powder in food

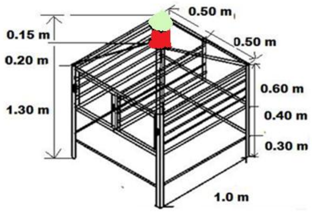
2. Materials and Methods

2.1. Description of the Study Site

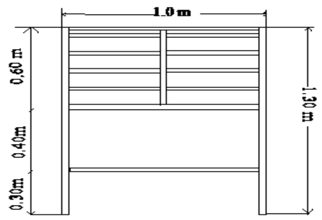
The dryer was designed and manufactured at the Fadis Agricultural Research Center Workshop, Oromia Agricultural Research Institute, Ethiopia. The drying experiment was conducted at Bate Peasant Association located at 09° 25` 03``N and 42° 02`58``E as determined by GPS. The site has an altitude 2051meters above sea level. It is located 1.50 km to the east of main campus of the Haramaya University, which is located in eastern Ethiopia.

2.2. The Design of the Solar Dryer

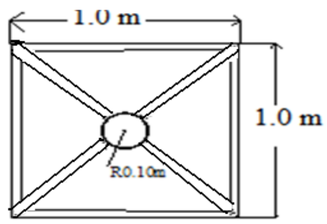
The solar dryer consists of heat collector area and drying chamber, the former surrounding the latter. Fig.1 shows the general framework of the dryer, which is built using perforated steel angle irons of 20 mm X 20 mm X 4 mm and 40 mm X 40 mm X 4.0 mm thick joined by bolts and nuts. All the sides and top surfaces, except the chimney, are covered with transparent plastic (PE), 0.2 mm thick in order to allow the solar radiation in to the unit covering an area of 3.0 m X 3.0 m. The lower side of the floor is off the ground by 0.3 m supported on eleven legs. The designs of various parts are presented in the following sections.



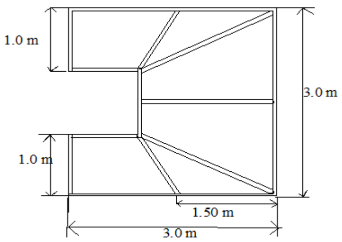
(a) drying chamber



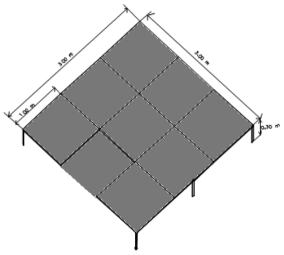
(b) drying chamber frame



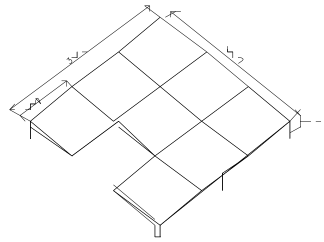
(c) drying chamber roof



(d) collector chamber



(e) floor of collector



(f) collector frame

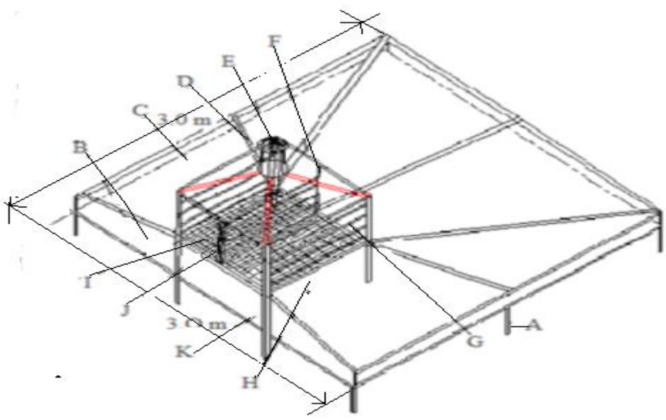


Figure 1. Framework of the solar Dryer

A) collector support; (B) collector; (C) plastic cover; (D) support for plastic cover; (E) saturated air out let (chimney); (F) drying chamber (cabinet); (G) drying cabinet layer (shelves); (H) Drying chamber air inlet; (I) Tray wire mesh; (J) Doors (product out let and inlet) I, H and E are some of the respective measuring points of temperature, relative humidity and air velocity.

Figure 2. Photo of solar dryer

2.3. Performance Evaluation of Solar Dryer

2.3.1. Measuring instruments

Thermo-hygrometer (CompuFlow 8612), temperature and humidity meter, with accuracy level of ±0.10°C and ±2.0 %RH, was used to measure temperatures and humidity at various points inside the collector and drying chamber of the solar dryer. The locations of the sensors are shown in Fig.8 at points "a"s. Both the temperature and humidity of air were measured at these points. The temperature and humidity data were recorded at one-hour interval. The air speeds (ms^{-1}) inside the dryer and, at the exit of the moist air (chimney), were measured with a vane type digital anemometer (Testo model 21-63, accuracy ±0.03 m s^{-1}).

Weight measurement was done with a digital balance DHAUS of model – CT 6000-s, accuracy (±0.0 g) it was done by removing trays from the drying cabinet for few seconds. The dryer door was opened and closed during the time required to remove each tray, weigh it, record it, and return it to the appropriate location in the shelves of the drying chamber. The design solar dryer is presented in Figure 3.

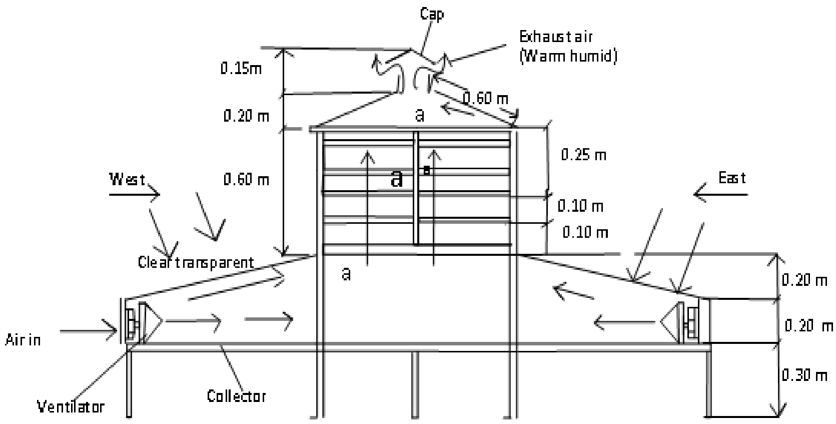


Figure 3. Schematic diagram of solar dryer

2.3.2. Preliminary test of the solar dryer

The dryer was placed on a raised platform, far from the shade of trees and buildings during the whole duration of the experiment (Fig.3). Preliminary tests were conducted to evaluate the performances of the dryer at no-load (empty) conditions. The degrees of opening of the vent (chimney) were calibrated and marked for three levels (quarter, half and fully open) positions of inside air temperature, relative humidity and velocities were measured and recorded.

2.3.3 Efficiency of solar dryer

The study of the solar dryer efficiency provides a means of assessing just how well (or poorly) a dryer operates under certain conditions. Collector efficiency of solar energy absorption and conversion to heat is defined as the ratio of energy output of the collector to energy input to the collector and is calculated as:

$$\eta_C = \frac{Q_u}{A_c G} \quad (1)$$

Where, η_C is collector efficiency (%)

$$\eta_C = \frac{\dot{m} C_P (T_{c,out} - T_{c,in})}{A_c G} \quad (2)$$

$$Q_U = mCp(T_{c,out} - T_{c,in}) \quad (3)$$

Q_u is useful heat flow rate (J/s)

$$\dot{m} = \rho q, \quad (4)$$

m is air mass flow rate (kg/s)

ρ is density of air (kg/m^3)

$$q = AV, \quad (5)$$

q is volume flow rate of air (m^3/s)
A is the collector exit area (m^2)
V is air velocity (m/s)
Cp is specific heat of air (1007 J kg^{-1} °K^{-1} for air),
$T_{c.out}$ is output collector temperatures (°C),
$T_{c,in}$ is input collector temperatures (°C),
GAc is solar energy input on the collector (J)
Ac is collector area (m^2)
G is global solar radiation (W/m^2)

2.2.3. Preparation of Onion Samples

Freshly harvested and known variety of onion *Adama* Red, which were grown in *Fadis* Agricultural Research Center and by local farmers, were procured from local market. First, the onion was thoroughly cleaned so that all dirt, soils, and mud or insecticide residues were removed. After cutting the top and root of the onion, it was peeled using sharp stainless steel knife. Cleaning was made by simply washing with a tap water. After cleaning, the onion was sliced into circular discs (thin slices) of 3 mm thickness (Ife and Bas, 2003; Wang, 2002), using an electrical operated mechanical slicer. The sliced onion was carefully loaded on the trays without overlapping the slices or in single layer, wire mesh trays at the rate of 4 kg/m^2.

Preparation of tomato Sample

Freshly harvested and known vaierity of tomato, *melkashola* , which were grown in *Fadis* Agricultural Research Center and by local farmers, were procured from local market. First, the tomato was thoroughly cleaned so that all dirt, soils, and mud were removed. Cleaning was made by simply washing with a tap water.

After cleaning, the tomato was sliced into circular discs (thin slices) of 8 mm thickness [5] using an electrical operated mechanical slicer. The sliced tomato was carefully loaded on wire mesh trays without overlapping the slices or in single layer, at the rate of 5 kg/m^2.

2.3.8. Performance evaluation of solar dryer using tomato and onion in forced ventilation

During performance evaluation of solar dryer using tomato and onion in forced ventilation, the procedures for samples preparation, moisture content determination and testing of the solar dryer were similar as those procedures used in section (3.4).

The ventilating fan of 20 cm diameter (model MSF-5503, power input 53 W, running at 800 rpm was installed for the dryer powered photovoltaic cell module, allowing the choice of the desired air mass flow. The fan was fixed below product trays at the bottom of the dryer to ensure an even distribution of air and evacuate the humidity of the product to the surrounding.

2.3.9. Kinetics of drying

Drying rate equation

During the drying tests the comparisons of moisture contents as a function of the drying time were made. A drying characteristic data were calculated (periodical data of the moisture contents and drying rate).

An appropriate thin layer drying equation can express the rate of change of moisture content of a thin layer product inside the dryer. The Newton equation in differential form is given by Lewis (1921).

$$\frac{dM}{dt} = -k(M - M_e) \quad (11)$$

The solution of (1), assuming k is independent of Mti and $M_{e\ is}$:

$$MR_{Newton} = \exp(-kt) \quad (12)$$

Where, MR is a moisture ratio given by:

$$\frac{Mti - M_e}{Mo - M_e} = \exp\ (-kt)$$

Where, Mti = moisture content, % (db),

t = time, hour,

M_o = initial moisture content (% db),

M_e = equilibrium moisture content, % or ratio (db)

k = drying constant (hr^{-1}),

The nonlinear regression, the least square was employed to evaluate the parameters of the model chosen with the process of Levenberg–Marquardt using SPSS 16.0 software package.

3.4. Statistical Analysis

All observations were recorded as means of three replications. The data pertaining moisture contents and drying rate coefficients were statistically analyzed to determine the significant difference, if any between solar drying methods of photovoltaic (PV) ventilated forced drying, natural convection solar drying and open-air sun drying, for dried tomato and onion slices. ANOVA under factorial experimental design and the mean separation by LSD ($P < 0.05$) method was carried out for the drying data.

Experimental design

The factorial experimental design where the main plot treatment is the two types of vegetables tomato and onion (T, O) and the treatment as three types of drying methods, natural convection solar drying and Photovoltaic (PV) ventilated forced solar drying with the open-air sun drying as a control were used.

3. Results and Discussion

3.1. Preliminary Test Data of the Solar Dryer

In order to characterize the solar dryer, temperature and relative humidity of the air in solar collector and the corresponding data of the ambient air need to be examined. Information on the temperature rise of air is important when evaluating a solar collector especially for drying purposes. During the preliminary tests of the dryer, measurements were taken for few days at no-load. The outlet air temperature of the flat plate collector, which is also the temperature of the drying air at the inlet of the drying chamber, is important parameter for evaluating the collector performance. The collector performance could be seen from the difference in air temperature at the exit and inlet of the solar collector. During the preliminary tests with quarter, half and fully-open positions using manually operated control valve fitted in the chimney, a maximum temperature rise of 41°C above the ambient air were recorded. Due to better temperature rise and optimum air velocity, half- open position was decided and selected to operate the dryer exit in the chimney (Table 1).

Table 1. Preliminary test data at no load of the dryer at half open position of control device

Time of the day	Ambient air	Collector outlet Tc,o	RH	Tc, out-Tc, in	Air velocity	Solar radiation
(hour)	Tc, in (°C)	(°C)	Tc, out (%)	(°C)	(m/s)	(W/m²)
7	15	28	36	13	0.01	50
8	18	36	34	18	0.02	175
9	20	42	30	22	0.02	450
10	21	49	28	28	0.04	650
11	22	53	18	31	0.05	866.53
12	23	60	8	37	0.06	965
13	23	64	5	41	0.06	1035.7
14	22	61	10	39	0.05	980
15	21	50	25	29	0.05	870
16	20	42	35	22	0.03	570

17	20	31	46	11	0.04	350
18	19	27	53	8	0.03	160

Table 2 presents the variation of the ambient air temperature and that of the air leaving the collector. The rise, in air temperature after passing through the collector varied from 18°C at 8:00 o'clock in the morning to about 37°C at midday. The period starting from 10:00 am in the morning to 4:00 pm in the afternoon was where the significant rise in temperature occurred. The one-hour interval data recorded indicated that the collector absorbed the solar radiation striking its surface, converted it to heat and transferred it to the air inside it. As the solar radiation increased from 175 W/m^2 in the morning to 965W/m^2 at midday the temperature of the air in the collector rose from 36°C to 60°C.

The data presented in Fig.10 varied with the daily radiance incident on the collector. It can be noted, in the experiment, the absorbed solar energy raised the collector outlet air temperature up to 64°C, just at 1:00 pm. The experiments during these months showed that during the peak afternoon hours, the average rise of air temperature (between the input and output of the collector) was equal to 41°C (varying between 15°C and 41°C). The average air velocity was 0.04 m s^{-1} at the drying chamber outlet.

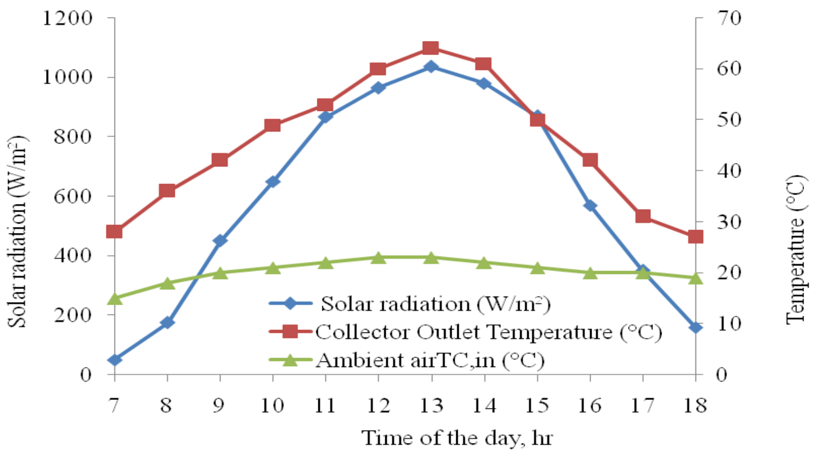


Figure 4. The solar radiation, collector outlet & ambient air temperature

4.2. Collector Efficiency

The instantaneous efficiency of the solar collector shown in Table 3, started to rise in the morning period, was relatively constant at 77% from 12:00 hours to 13:30 hours, and dropped down in late afternoon. The variation obtained is typical for a flat plate collector and indicates strong dependence of efficiency on the meteorological data. The daily efficiency, averaged over 11 hours (7:00 to 18:00) comes out to be 51%.

Table 2. Raw data of the collector efficiency analysis for solar dryer

Time of day (hr)	drying time (hr)	velocity (m/s)	Airflow rate V(kg/s)	Air Temp. (°C)			Solar radiation (W/m²)	Energy		Collector efficiency (%)
				T_{am}	T_{co}	(T_{co}-T_{am})		Total (W)	Useful (W)	
7	1	0.01	0.0065	15	28	13	50	400	84	21
8	2	0.02	0.0259	18	36	18	175	1400	468	33
9	3	0.07	0.0905	20	42	22	450	3600	2001	56

10	4	0.09	0.1164	21	49	28	650	5200	3275	63
11	5	0.11	0.1422	22	53	31	867	6932	4431	64
12	6	0.12	0.1552	23	61	38	965	7720	5926	77
13	7	0.12	0.1552	23	64	41	1036	8286	6393	77
14	8	0.11	0.1422	22	61	39	980	7840	5575	71
15	9	0.11	0.1422	21	50	29	870	6960	4145	60
16	10	0.09	0.1099	20	42	22	570	4560	2430	53
17	11	0.04	0.0517	20	31	11	350	2800	572	20
18	12	0.02	0.0259	19	27	8	160	1280	208	16

4.5. Characteristics of the Solar Dryer under Forced Ventilation

In the solar collector with forced ventilation, the increase in temperatures between the ambient and collector outlet air temperatures was observed ranging from 5°C to 25°C. This gave heated air temperature of up to 50 °C, which is more than adequate to dry fruit and vegetables. Such a rise in the incoming air temperature into the drying chamber lowers the relative humidity of air. Lowering relative humidity of air increase the capacity of air to carry more moisture.

The photovoltaic powered ventilation system increases the air velocity flowing into the drying chamber. High velocity of the drying air improves the rate of drying as it reduces the thickness of the film of the moist air around the food decreasing the resistance to release of moisture into the air.

The average air velocity recorded due to the ventilation was 0.60 $m^{-1}s$. The temperature profile of the drying chamber under forced ventilation is shown in Fig.18. The difference in temperature between the incoming dry warm air and the discharged moist air ranged from about 6°C in the early morning and /or in the late afternoon to 14°C at midday.

As the incoming warm air, passes the heat to the moist drying food, its temperature drops to wet bulb temperature. Towards the end of the drying period of the food the temperature of air remains high, close that of the incoming air.

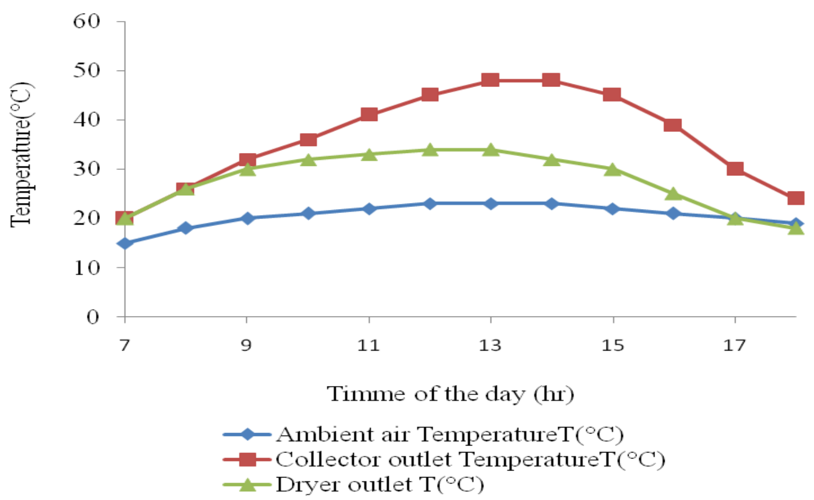


Figure 5. Temperature profile of the drying chamber

The relative humidity of the air coming from the collector was highly reduced due to the warming effect as compared to the relative humidity of the ambient air. As the air, picks up the moisture on its way up the drying chamber the relative humidity increases as can be seen in relative humidity curves of belonging to the middle chamber and that of dryer outlet air.

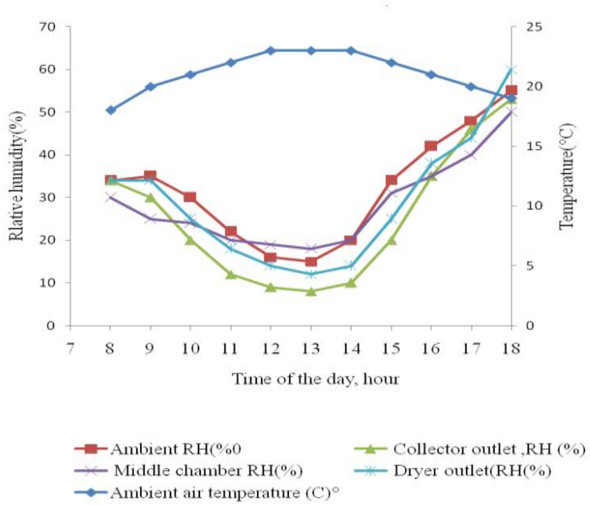


Figure 6. The profile of relative humidity in the drying chamber

4.6. Testing the Solar Dryer in Forced Air Circulation Using Tomato Slices

The drying data of tomato slices of various trays in the dryer and that of the slices dried in open-air sun are shown in table 4. Slices on tray T5 (upper most tray) and tray T1 (bottom tray) and tray T4 exhibited the lowest moisture content and shortest drying times of 11.5 hrs. The drying data of slices on trays T4, T3 and T2 had drying periods of 13.5 and 14.5 hrs, respectively. The moisture contents of slices on trays 1, 2, 3, 4 and 5 have attained the target moisture contents of 11.7-11.5 % (w.b) within the indicated periods. The drying data of the slices dried on trays in the open-air sun showed moisture content levels very much higher than those of slices dried on trays of the solar dryer.

The lowest content attained after 23.5 hours of drying was 11.2% that was the final moisture content. As it can be seen, the 12% moisture content was attained after nine hrs of drying by incorporating power-operated fans. As the drying period of tomato slices in natural circulation of the air had been determined to be 12hours as shown in Tab.3, an advantage has been noticed in drying time, attributed to use of fan for tomato drying**.**

The drying rate data (Table 4) of the tomato slices dried in the solar drier and in open-air sun drying. Slices on trays 1&5 started with the highest rate of drying followed by slices on trays 2, 4 & 3. However, after 6 hours of drying the slices on majority of the trays inside the dryer exhibited similar rate of drying. This condition persisted to the end of drying. This can be explained by the fact in the falling rate period of drying; the rate of drying is governed by the rate of internal diffusion of moisture to the surface of slices. Once the moisture on the surface of the slices is removed, which is governed by the air temperature and rate of heat transfer to the moisture on the surface, the drying rate is influenced by the rate of replacement of moisture from the interior of the food. This replacement is the same for all the slices thus making the rate of drying more or less the same. The drying rate in all cases reduced as drying time increased.

Table 3. weight of tomato, percentage, moisture content on wet basis and percentage drying rate on dry basis on Tray1, Appendix Tray2, Tray 3, Tray 4 and Tray 5 and open air sun Tray4 and Tray 5 (Ventilated tomato drying)

	Time	Drying	Moisture content on						Moisture content on						Drying rate					
	the day	time	wet basis (%)						dry basis (%)						(kg W/kg DM.hr)					
Date	(hr)	(hr)	T1	T2	T3	T4	T5	TOS	T1	T2	T3	T4	T5	TOS	T1	T2	T3	T4	T5	TOS
	12:00	0	93.3	93.3	93.3	93.3	93.3	93.3	13.9	13.9	13.9	14.0	13.9	13.9						
12/12/2010	14:00	2	68.3	71.6	72.7	72.7	68.6	90.4	10.2	10.7	11.2	10.9	10.2	13.5	3.1	2.7	2.3	2.5	3.1	0.2
	16:00	4	51.6	58.5	56.4	56.4	52.1	74.7	7.7	8.7	8.8	8.4	7.8	11.1	2.1	1.6	2.0	2.0	2.0	1.2
	17:30	5.5	39.1	46.8	43.3	43.3	39.8	71.3	5.8	7.0	6.9	6.5	5.9	10.6	1.6	1.5	1.5	1.6	1.5	0.2
	8:30	5.5	30.8	43.3	37.7	37.7	34.0	68.5	4.6	6.5	6.3	5.6	5.1	10.0						
	10:30	7.5	20.0	33.3	28.3	28.3	23.8	67.3	3.0	5.0	4.9	4.2	3.5	8.5	1.3	1.2	1.2	1.2	1.3	0.8
13/12/2010	12;30	9.5	12.0	25.5	20.9	20.9	15.5	57.0	1.8	3.8	3.8	3.1	2.3	6.7	1.0	1.0	0.9	0.9	1.0	0.9
	14:30	11.5	11.5	19.0	15.7	15.7	11.7	45.1	0.9	2.8	2.8	2.4	1.4	5.7	0.8	0.8	0.8	0.6	0.7	0.5
	16:30	13.5	11.5	14.2	11.5	11.5	11.7	38.2	0.9	2.1	2.2	2.4	1.4	4.8	0.5	0.6	0.5	0.5	0.5	0.5
	17:30	14.5	11.5	11.6	11.5	11.5	11.7	32.0	0.9	1.6	2.2	2.4	1.4	4.2	0.1	0.4	0.4	0.4	0.4	0.3
	8:30	14.5	11.5	11.5	11.5	11.5	11.7	28.4	0.9	1.6	2.2	2.4	1.4	3.3						
	10:30	16.5	11.5	11.5	11.5	11.5	11.7	21.9	0.9	1.6	2.2	2.4	1.4	2.4	0.1	0.3	0.4	0.3	0.2	0.4
14/12/2010	12:30	18.5	11.5	11.5	11.5	11.5	11.7	16.0	0.9	1.6	2.2	2.4	1.4	1.7	0.1	0.3	0.3	0.1	0.1	0.4
	14:30	20.5	11.5	11.5	11.5	11.5	11.7	11.2	0.9	1.6	2.2	2.4	1.4	0.9	0.1	0.1	0.2	0.0	0.0	0.4
	16:30	22.5	11.5	11.5	11.5	11.5	11.7	11.2	0.9	1.6	2.2	2.4	1.4	0.9	0.1	0.1	0.2	0.0	0.0	0.0
	17:30	23.5	11.5	11.5	11.5	11.5	11.7	11.2	0.9	1.6	2.2	2.4	1.4	0.9	0.1	0.1	0.1	0.0	0.0	0.0

9. Economic Feasibility and Pay Back Analysis of the Solar Dryer

The climatic conditions in the Eastern Hararghe allow using the solar dryer for almost the whole year (250 days). The capacity of the dryer 20 kg and 16 kg of fresh tomato and onion, respectively. It can uniformly dry the products within one to two days either in forced or natural convection solar dryer. The expected service life of the dryer is estimated to be 15 years. Assuming the capacity of the dryer per day for tomato and onion at the same time the costs and the main economic parameters based on the local market price situation in the area shown in Table.1. Using this data, the payback period was calculated using the formula below (Neufville, 1990).

$$\text{Payback period (PP)} = \frac{II}{ANUB} = \frac{6000.00}{61200.00} = 0.098 \text{ year}$$

Where, II is initial investment

ANUB is annual net undiscounted benefits

The payback period is determined as the time required for the investment cost to equal the return. In this case the payback period is very small (1.2 months) compared to the life of the dryer, 15 years, so the dryer will dry product free of cost for almost its life period.

Table 4. Payback period of the solar dryer used for drying tomato and onion

S.No	Item Description	Cost
1	Cost of the dryer	Birr 6000.00
2.	Capacity of the dryer	20kg
3.	Life of dryer	15 years
4.	Depreciation (10%)	Birr 600.00
5.	Cost of maintenance	Birr 300.00
6.	Labor cost 50 x 250	Birr 12500.00
7.	Cost of raw tomato 4 x 20 x 250	Birr 20,000.00
8.	Total cost	Birr 38800.00
9.	Total income 20 x 20 x 250	Birr 100000.00
10.	Net income	Birr 61200.00

5.2. Conclusions

From the data collected during the performance evaluation of the solar dryer and statistical analyses of the experimental data undertaken, the following conclusions can be drawn.

1. The solar dryer is capable of raising the drying air temperature many times higher than ambient air temperature thereby lowering its relative humidity. This increases considerably the drying potential of the air.
2. The solar dryer can give a higher drying rate than open air-sun drying, thus can considerably decrease the drying time needed for any given product.
3. Use of forced circulation in solar dryer can increase the drying rate and thus may reduce the drying time.
4. Onion can be dried from initial moisture of 87.10% (w.b) to final moisture content of 9.1% within one, two and three days using PVSD, NCSD and OASD.
5. Tomato can be dried from initial moisture of 93.3% (w.b) to final moisture content of 12% (w.b) within one & half, two and four days using PVSD, NCSD and OASD.

6. The drying process of solar and open-air sun drying can be represented by Lewis model for tomato and onion samples respectively.
7. It can also be concluded that the designed and manufactured solar dryer can be used to dry other fruits and vegetables sliced in to pieces very much faster than the open-air sun drying.

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