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An Experimental Investigation and Performance Analysis of a Solar Drying of Bitter Gourd using an Evacuated-Tube Air Collector

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Abstract: Drying is one of the important post-harvest methods to increase the self-life of the produce, which can be used during non-available periods. Solar Drying is done in solar dryers, which use the solar energy to dry crops, vegetables and Fruits. The objective of this study is to develop a forced convection solar dryer using evacuated tube air collector and study its performance on drying of bitter gourd. The designed solar dryer consists of a drying chamber, evacuated tube air collector, a blower, and a chimney. Drying parameters of moisture ratio (MR) and moisture content are calculated and their performance is compared with natural sun drying. The results of the present study show that the Evacuated tube assisted solar dryer Collector temperature developed between 47.4^{o}C to 91^{o}C and efficiency varied from 26.68% to 54.72%.The moisture content of bitter gourd is reduced from 90.93% to 7.61% in 6 hours as compared to 10 hours in natural sun drying. In this Evacuated tube assisted solar dryer, the products are uniformly dried, and the moisture content of the bitter gourd is controlled. Both sun dried and solar dried bitter gourd tested for its phosphorous and iron content, it is found that almost same amount of minerals, while solar dried bitter gourd using evacuated tube assisted solar dryer retained chlorophyll of 53.41 mg/kg and sun dried of 139.58mg/kg.
Keywords: Evacuated tube solar Collector, solar drying, Bitter Gourd drying, open sun drying, Phosphorous, Iron, Chlorophyll.

1. Introduction

Drying of agricultural products is an important post-harvest operation since it requires high energy consumption. Considerable energy savings can be achieved by using solar energy as energy source for drying of agriculture products. Traditional sun drying has many disadvantages like insect infestation, enzymatic reactions, microorganism growth, and micro toxin development and thus drying by solar dryer is an option. Besides conventional sun drying takes longer duration to reach the desired moisture content (1). Artificial mechanical drying process is highly energy intensive and expensive, which ultimately increases product cost. In natural sun drying products are not uniformly dried, and the moisture content of the sample cannot be controlled. Thus solar drying is the best alternative as a solution of all the drawbacks of natural drying and artificial mechanical drying (2).

Solar dryers have been used in all parts of globe and extensive research has been carried out, aiming at the improvement of these systems. From the literature, it is found that most of these solar drying systems use flat plate air collectors of various designs and only a few of them considered a different type of collectors, One of them being natural and forced convection solar tunnel driers. Solar collectors with evacuated tubes (EVT) are a special type, offering significant advantages compared to flat-plate collectors, such as higher efficiencies (3). EVT collectors, flat-plate ones alike, are classified into two broad categories, water and air-collectors, based on their heat transfer fluid (4).

Bitter Gourd is a seasonal vegetable and very bitter in taste and it is a rich source of phosphorous besides Vitamin C, Vitamin A and Iron (5). The needs of phosphorous in human body can be fulfilled by its regular use. Bitter gourd purifies blood, activates spleen and liver and is highly beneficial in diabetes. The fruits of bitter gourd are very much consumed as fresh and as dried vegetable for curries, bakery products, pickle or stuffed products. It is also used for the preparation of several dishes. It can be fried, deep-fried, boiled, pickled, juiced, and dried to drink as tea. The bitter Gourd was blanched in hot water resulted into complete inactivation of catalase and peroxidase enzyme (6). The solar cabinet drying of Bitter Gourd was found to be fastest drying method as compared to sun drying resulted in best quality. Solar drying enables vegetables export worthy processed foods with long shelf life meeting the sanitary standards of the importing countries. So solar drying is very viable and valuable one (7). In this experimental study, a novel forced convection solar active dryer with four trays is designed and developed with an evacuated tube air collector, and its performance is studied on bitter gourd and compared with natural sun drying.

2. Experimental Setup

Figure – 1 Experimental Setup

The solar drying system mainly consists of a drying chamber, evacuated tube collector (ETC), a blower, and a chimney. The experimental setup is as shown in Figure -1. The size of the drying chamber used for the study is 460 mm x 460 mm x 535 mm which is made of stainless steel sheets of thickness 5mm and insulated on all sides with fiberglass insulation of thickness 50mm to prevent the loss of heat. The chamber consists of four aluminium perforated trays to place the product for drying. A 125 mm diameter and 2250 mm length pipe is concentrically placed in the 300 mm diameter and 2250 length tube with 30 number of 12.7 mm GI pipes connected and is inserted in Evacuated Tubes to a length of 1300 mm. The collector header is divided into two parts, in first fifteen numbers of tubes the air flows in downward direction in the GI pipes and upward direction in the remaining fifteen numbers of tubes. The 300 mm diameter tube is insulated with 50 mm fiberglass insulation. The twin glass evacuated tube collector is made of borosilicate of 1.6mm thickness, and the gap between the glass tubes is evacuated. The inner tube of the collector is coated with a three-layer magnetron sputter coating. Heat loss due to convection, conduction, and radiation is thus minimized, and it can with stand high temperature. The length, inner diameter, and outer diameter of each tube are found to be 1500 mm, 38 mm, and 48mm, respectively. The Collector has a dimension of 2250 mm X 1500 mm. The collector is placed at optimum tilt in accordance with the latitude and longitude of Chennai (13.084^{o}N, 80.27^{o}E) Tamilnadu, India along North-South direction, facing south so as to track maximum solar radiation throughout the day. This collector which is used as a heat source is connected to the drying chamber with the help of GI pipes and the pipes are insulated. A blower motor of 0.375 KW, with three speed regulator to control the rate of flow of air is attached at the inlet of the solar collector to blow air into the collector. A chimney of height 50 cm made of Standard wire gauge Galvanized sheet is used at the top of the chamber which increases the air flow rate inside the chamber due to convection.

Temperature at different locations inlet and outlet temperatures of the collector, temperature of inlet, outlet of Drying chamber and four trays is measured with the help of k – type thermocouple (8 nos.) connected to 12 point Data logger and display unit, besides a hygrometer is attached to measure relative humidity. The ambient temperature, relative humidity, and wind velocity are measured using a digital anemometer (Lutron AM 4201). Solar insolation is measured using a solar power meter (TENMARS-TM207). A digital electronic balance is used for weighing the samples.

Solar drying and natural sun drying experiments are carried out for bitter gourd. Fresh bitter gourd is cut into thin slices of 5 mm and the initial moisture content is measured by oven-drying method, maintained at a temperature of 105°C for 24 hours by taking 200 g sample (1). Total of 1875 grams of bitter gourd is spread uniformly on four trays for solar drying equally in all four trays (Figure - 2) and 200 grams of bitter gourd was spread on a stainless steel plate for sun drying (Figure - 3). The blower motor is then switched on. The air that is passed through the evacuated tube collector gets heated up and is made to flow into the drying chamber, where bitter gourd is loaded in four trays. During the experiment, ambient temperature, relative humidity and wind velocity, solar insolation, inlet and outlet temperatures of the collector, and temperature of all the trays inside the chamber, temperature of the chimney are recorded (Table -1) on hourly basis from 10.00 am to 5.00 pm. During the experiment, all the drying trays are weighed on hourly basis until the product acquires constant weight, that is, equilibrium moisture content. The solar dried bitter gourd (Figure - 4) and sun dried bitter gourd (Figure - 5) are obtained after drying. The solar dried and sun dried samples of bitter gourd was tested (Table - 2) for its chlorophyll retention, Phosphorous and iron content at Chennai Testing Laboratory Pvt. Ltd, Chennai, a National Accreditation Board for Testing and Calibration Laboratories (NABL) approved Laboratory.

Table –1 Hourly Variation of Solar Insolation, Wind Velocity, and Temperature for Bitter Gourd

Sl.No	Time	Solar Insolation W/m^2	Wind Velocity m/sec	RH in %	Ambient Temp °C	ETC Inlet °C	ETC outlet °C	Drier Inlet °C	Drier Outlet °C
1	10.00	912	0.55	60	31	34.5	66.0	70.4	40.9
2	11.00	1097	0.63	47.5	42	46.0	78.4	72.3	60.5
3	12.00	1071	0.46	44.5	43	48.0	80.7	74.6	56.2
4	1.00	1032	0.61	41	32	43.0	81.4	76.3	65.2
5	2.00	846	0.76	56	27	38.0	73.4	70.6	60.3
6	3.00	471	0.97	57	30	34.0	58.9	58.8	50.6
7	4.00	421	1.5	56.5	31	34.0	59.2	56.6	48.4
8	5.00	302	2.64	58.5	29	32.0	47.4	46.9	39.0
9	10.00	899	0.52	64	30	35.5	68.0	62.7	52.0
10	11.00	1037	0.84	42.5	33	41.0	91.0	84.9	72.8
11	12.00	1078	1.2	42	32	39.5	80.1	74.5	68.8

Table –2 Laboratory Analysis of Dried Bitter Gourd

Name of the mineral/ Nutrient	Chlorophyll mg/kg	Phosphorous mg/100 g	Iron mg/100 g
Solar Drying	53.41	446.55	5.91
Sun drying	139.58	457.16	6.68

Figure – 2 Drying of Bitter Gourd in the Cabinet Dryer

Figure – 3 Sun Drying of Bitter Gourd

Figure – 4 Solar Dried Bitter Gourd

Figure – 5 Sun Dried Bitter Gourd

3. Data Analysis

3.1 Determination of Moisture Content

The initial mass (m_i) and the final mass (m_f) of the sample are recorded at an interval of every one hour till the end of drying using the balance. The moisture content on wet basis (M_{wb}) is given as

$$\text{Moisture content } M_{wb} = \frac{m_i - m_f}{m_i}$$

3.2 Determination of Moisture Ratio (MR)

The instantaneous moisture (M) at one hour interval is calculated from the drying data, the initial moisture content (M_o), and equilibrium moisture content (M_e) are calculated from the drying data. Then the moisture ratio at any time interval is given by

$$\text{Moisture ratio MR } = \frac{M - M_e}{M_o - M_e}$$

3.3 Determination of Efficiency of the Evacuated Tube Collector

The inlet temperature (T_{in}) and outlet temperature (T_{out}) of the Evacuated tube collector are recorded at one hour time interval. The mass flow rate (m_c) of the air is recorded. The solar insolation (I) is recorded at one hour time interval. With aperture area (A_p), Specific heat of air (C_{pc}) and number of Evacuated Tubes (N) are known; the efficiency of the evacuated tube is given by

$$\text{Evacuated tube collector Efficiency} = \frac{m_c C_{pc} (T_{out} - T_{in})}{N A_p I}$$

4. Results and Discussion

4.1 Experimental Evaluation of Collector Performance

For the evaluation of Evacuated tube collector performance, the measurements were taken for three different flow rates of 142 m^3/h, 163 m^3/h, and 182 m^3/h during the dry run and 182 m^3/h is selected for actual drying experiment according to the need of the bitter gourd drying requirement since at low flow rates the exit encounters higher temperature. The ambient temperature of the air varied from a minimum of 27^{o}C and the maximum of 43^{o}C. The relative humidity of air varied from a minimum of 41% to a maximum of 61%. The inlet temperature of air to the collector varied from 32^{o}C to 48^{o}C (Figure 6). The exit temperature of the collector varied from 47.4°C to 91°C. This shows that the atmospheric temperature is doubled in the cabinet drier (5).The data used to determine the Evacuated Tube Collector efficiency corresponding to solar radiation varied from 302 W/m^2 to 1097 W/m^2 (Figure 7). The Figure 8 shows the variation of collector efficiency during the drying period. The drying process is carried for the second day and hence the fluctuation in solar radiation intensity. The collector efficiency varied from a minimum of 26.68% and a maximum of 54.72%. The collector efficiency increases with increase in solar radiation and it attains a maximum of 54.72% at end of the day one drying and the same pattern followed in the subsequent days. The efficiency of evacuated tube assisted collector efficiency is better than flat plate collector efficiency (3).

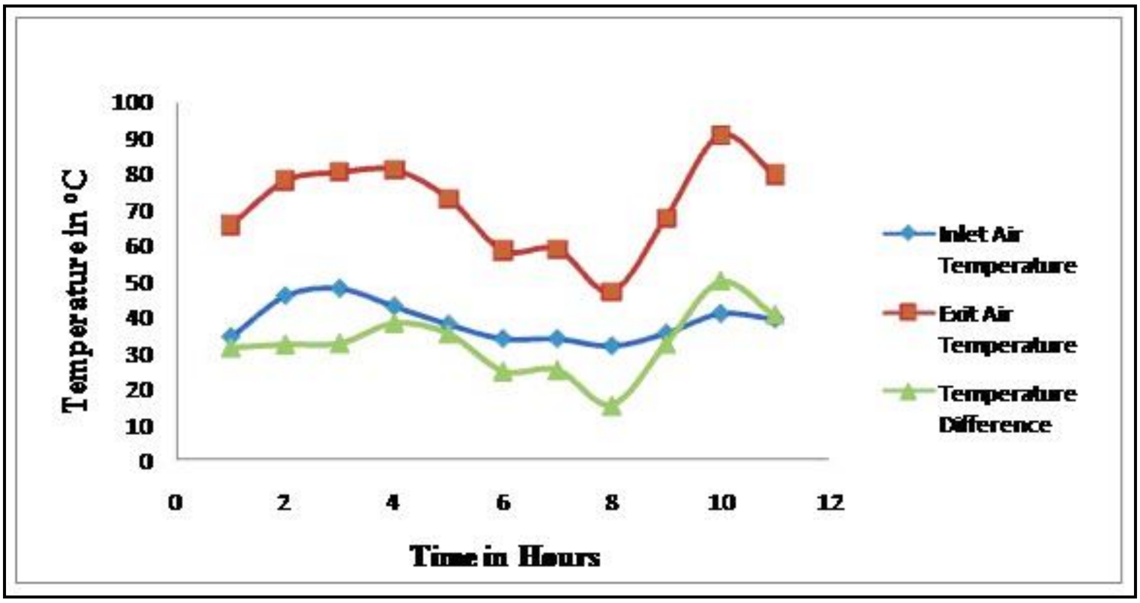

Figure – 6 Variation of Air Inlet, Exit Temperatures and Temperature Difference

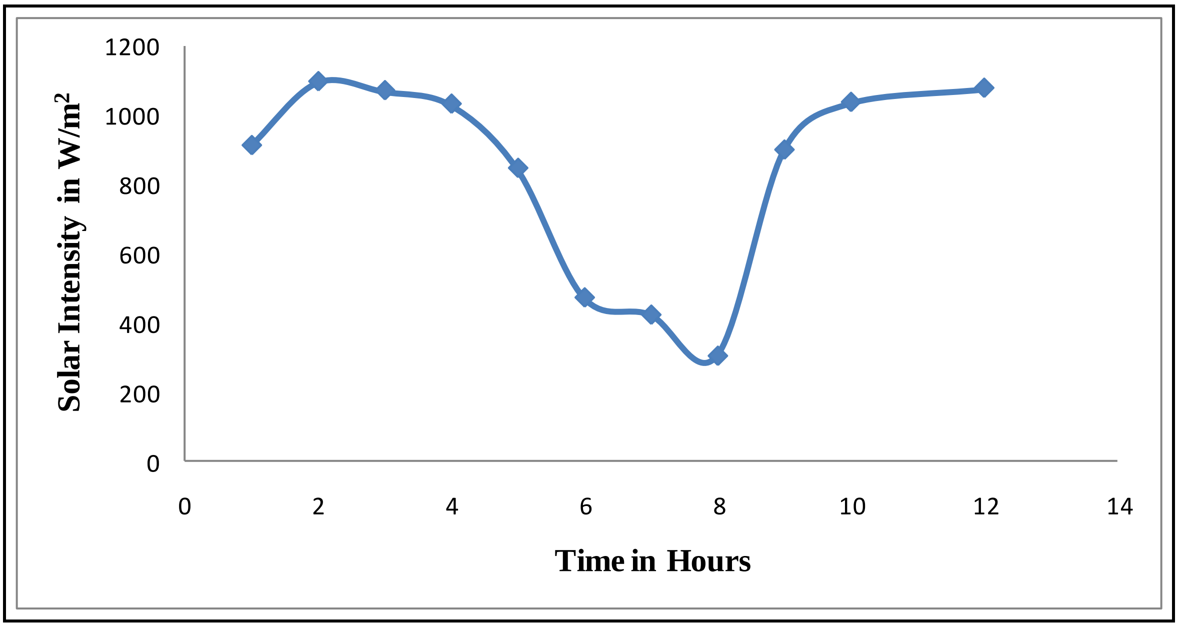

Figure – 7 Variation of Solar Intensity

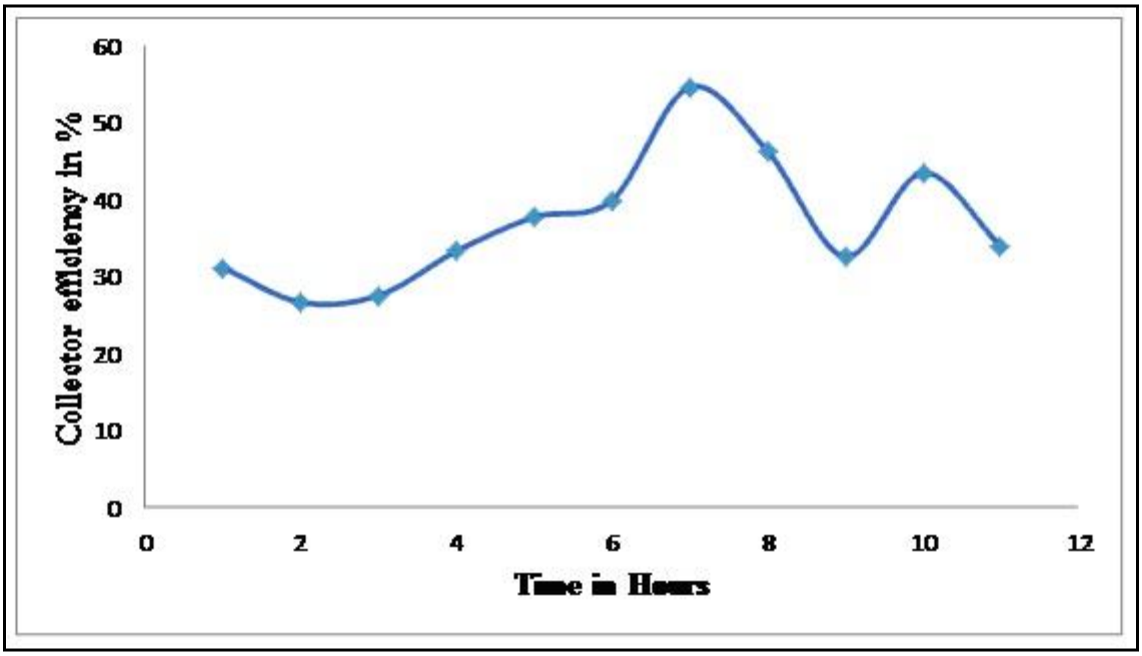

Figure – 8 Variation of Evacuated Tube Collector Efficiency

4.2 Thin Layer drying of Agriculture Products

The temperature rises that can be obtained with this Evacuated Tube Collector are appropriate for agriculture product drying. The Evacuated Tube Solar Collector under study connected to a Cabinet drying chamber. The drying chamber consists of four trays which are loaded with bitter gourd for drying. Some 200 grams of bitter gourd was spread on a steel plate for sun drying. The dried products of solar drying and sun drying are obtained after 6 hours and 10 respectively.

4.3 Bitter Gourd Drying

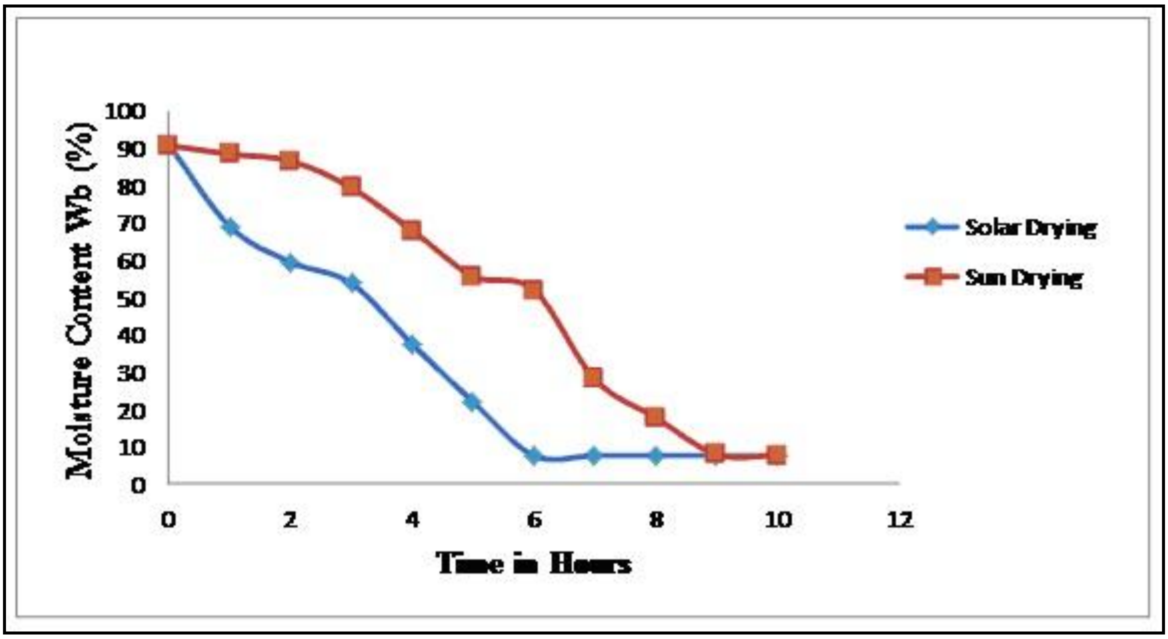

Figure – 9 Variation of Moisture Content

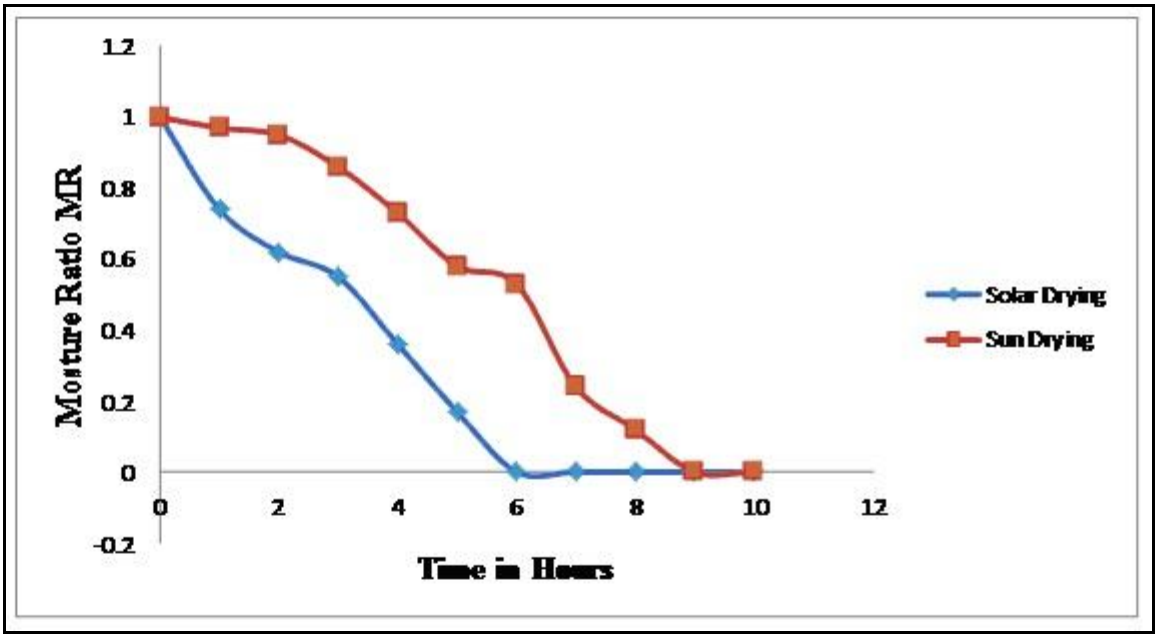

Figure –10 Variation of Moisture Ratio in Drying

The product loaded was bitter gourd having an initial moisture content of 90.93% (wb). The final moisture content of 7.61% is obtained in 6 hours of solar drying, whereas sun drying took 10 hours. The experimental conditions of bitter gourd are shown in Table -1, while the variation of moisture content (MC) (Figure 9) and moisture ratio (MR) (Figure 10) are illustrated. It is observed that the moisture removal is high initially and then gets reduced exponentially (1), this may be because of the moisture removal first from the surface and followed by the movement of moisture from internal part of product to its surface. This can be correctly observed (Figure -9) in sun drying the slope of the curve during 5^{th} hour to 6^{th} hour of drying is less, whereas from 6^{th} hour to 7^{th} hour slope of the curve is higher. This because of at the end of the 6^{th} hour the drying stopped and the bitter gourd was preserved in bottles, during night time the diffusion of moisture to upper layers resulted in higher slope during 6^{th} hour and 7^{th} hour. It is observed that after 6 hours solar drying and 10 hours of sun drying the slope is flat, this shows the bitter gourd obtained equilibrium moisture. The dehydrated bitter gourd was excellent in colour, flavour and good in texture (6). Evacuated tube solar dried product retained the minerals of phosphorous 446.55 mg/100g, iron of 5.91mg/100g and the chlorophyll retention was 53.41 mg/kg. The sun dried product the minerals of phosphorous 457.16 mg/100g, iron of 6.68mg/100g and the chlorophyll retention was 139.58 mg/kg. Lower chlorophyll content of solar dried product may be due to an inactivation of chlorophyllase enzyme which may be responsible for degradation of chlorophyll (5).

5. Conclusion

Dehydrated bitter gourd have the potential to become an important value added product because of relatively inexpensive, easily and quickly cookable and rich in several nutrients, which are essential for human health (5). The Evacuate Tube Collector assisted dryer used in the present study reduces the drying period of bitter gourd considerably. Solar drying of bitter gourd takes nearly half the time as compared to natural sun drying (1). The minimum drying period of 6 hours is required for bitter gourd to achieve equilibrium moisture in evacuated tube solar dryer, whereas the time taken by sun drying is 10 hours. The Evacuated tube solar drier collector efficiency varied from 26.68% to 54.72%. The drying process is controlled in evacuated tube solar drying. This drier can be used to dry different products simultaneously and products that cannot be dried in natural sun drying. The most important advantage of using evacuated tube solar dryer is that it can be used to dry products even during no sunshine and winter season as it makes use of evacuated tube collector (1). Evacuated tube solar dried product retained the minerals of phosphorous 446.55 mg/100g, iron of 5.91mg/100g and the chlorophyll retention was 53.41 mg/kg. The sun dried product the minerals of phosphorous 457.16 mg/100g, iron of 6.68mg/100g and the chlorophyll retention was 139.58 mg/kg.

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