ENERGY AND EXERGY ANALYSIS OF GREENHOUSE DRYING OF IVY GOURD AND TURKEY BERRY

by

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This study deals with the performance evaluation of a simple low-cost greenhouse dryer using energy and exergy analysis. Drying experiments were conducted under the open Sun and in greenhouse dryer with two different cover sheets of ultra violet polyethylene and drip lock under passive mode and active mode for two vegetables with medicinal values: ivy gourd (coccinia grandis) and turkey berry (solanum torvum). Thermal efficiency, exergy efficiency, and improvement potential were evaluated and presented. The experiment showed that performance of the greenhouse dryer was better than the open sun drying. Thermal efficiencies were up to 30.64% and exergy efficiency values were up to 0.09% and the maximum values were obtained during the drying of ivy gourd with the drip lock sheet under active mode. The results showed that this dryer could be used for drying agricultural products at low cost by the farmers in order to produce value added products from their harvested products.

Key words: *drying process, exergy analysis, greenhouse dryer*

Introduction

The population of the world is projected to increase to 9.6 billion by 2050. The increase in population will lead to a growth in economic prosperity of the big part of population [1]. There will be a great demand for food, but due to conversion of agricultural lands to residential purposes, deforestation, changing climatic conditions, shortage of rain fall, and scarcity of water, the production of food materials will not be sufficient to meet the demand. Hence there is a need for efficient using of our resources for the better future. The challenges before the food industries are the need for efficient production, post harvesting methods, less utilization of water, and energy and reducing the wastage of food. Around 30-40% of the vegetables and fruits are being wasted during their processing time in developing countries [2]. So, the future designs of the food industry should avoid or minimize wastage and should use renewable energy sources instead of fossil fuels [1].

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Drying or dehydration of food products decreases the moisture in the products to reduce weight, for easy transportation and increase shelf life. Traditionally agricultural products have been dried under the open Sun. It is a simple and economic process but has a lot of disadvantages, like depending on weather, slow process, loss due to birds, dust and other contamination. Best quality of dried products can be achieved with industrial hot air dryers, but it requires a huge amount of energy. Approximately 9.25% of the available energy in the developed countries is being consumed by drying process [3]. So, new cost and energy effective systems are essential to reduce the energy consumption. The objective of a drying system is to supply more heat to the product than available in the ambient [4]. It needs a proper thermodynamic analysis of a drying system.

Energy and exergy analysis using First and Second law of thermodynamics should be performed for finding out the energy interactions and thermodynamic behavior of a drying system [5]. The analysis of a dryer should provide a quantitative measure of inefficiencies for a designer to design better systems [6]. The exergy analysis delivers suitable information to select the appropriate design and operational procedure for better performance [7].

Exergy is the maximum work attained from a stream of matter, heat or work as it comes to equilibrium with a reference environment [8]. By carrying out exergy accounting in smaller and smaller subsystems, we are able to draw a map of how the destruction of exergy is scattered over the engineering system [9]. The lesser thermal efficiency of drying systems, higher price of fossil fuel and electricity and the GHG emitted from drying systems increase the importance for exergy analysis of drying systems [10]. Various exergetic indicators used in food industry are absolute exergy loss, exergetic efficiency, improvement potential, exergy destruction ratio, entropy generation, and cumulative exergy loss. Grassmann diagram is also used by the researchers [1]. Solar dryers can reduce the use of fossil fuels and the carbon emission and also make the process a sustainable one which is one of the prime needs of the society [11].

Greenhouses working on the concept of greenhouse effect have been used for a long time for the cultivation of the crops. For the past two to three decades, greenhouse structure is also being used for solar drying of agricultural products at low temperatures [12]. Many researchers have been working in the area of greenhouse dryers [6, 13, 14]. Few recent articles have reviewed the developments in solar greenhouse drying [15] and the applications of greenhouse drying [16]. A modified greenhouse dryer with thermal energy storage was analyzed for its performance.

A good quantity of vegetables harvested by the farmers is spoiled due to lack of proper post-harvesting processes. Some of the vegetables are having medicinal values and often seasonal. A huge market share of the medicinal species and herbals in the globe has been contributed by Asian region. Recently the usage of certain herbal based food supplements is increasing day by day throughout the world [17]. For example, ivy gourd is a creeping plant that grows widely in many parts of the India subcontinent, which is used to treat urine sugar. The herb has insulin-mimetic properties [18]. Turkey berry belonging to *Solanaceae* family is a bushy, erect, and spiny perennial plant. It is one of the significant medicinal plants in tropical and sub-tropical countries. It is widely used as food and medicine in many parts of the world [19]. It is also used for treating anemia and diabetes. Drying can be used for processing such medicinal, value added and lifesaving products like turkey berry, ivy gourd, adamant creeper, neem, turmeric, *etc.*

Some studies have been recently carried out on the drying of medicinal vegetables like mint [20-22], medicinal ginger, javanese pepper [23], momordica cha [1], murraya koenigii [24], chilli pepper, ginger [25], coconut [26], curcuma zedoaria [17], and valeriana jatamansi [27]. However, only a few reports are available in the literature for the drying of medicinal vegetables. In the present study ivy gourd and turkey berry were dried using a simple low-cost solar greenhouse dryer with two different cover sheets and under passive and active modes. Energy and exergy analysis have been conducted to find out the significance of various drying conditions on the performance of the dryer.

Experimental facility

Experimental set-up

The photographs of the experimental greenhouse dryer under passive and active modes are shown in fig. 1. A greenhouse solar tunnel dryer of even span roof type with 1.2 $m^2 \times 1.2$ m^2 floor area and ceiling 1 m height has been designed and fabricated for drying. The dryer is covered with transparent plastic sheet. This plastic sheet transmits the observed solar radiation into green house.

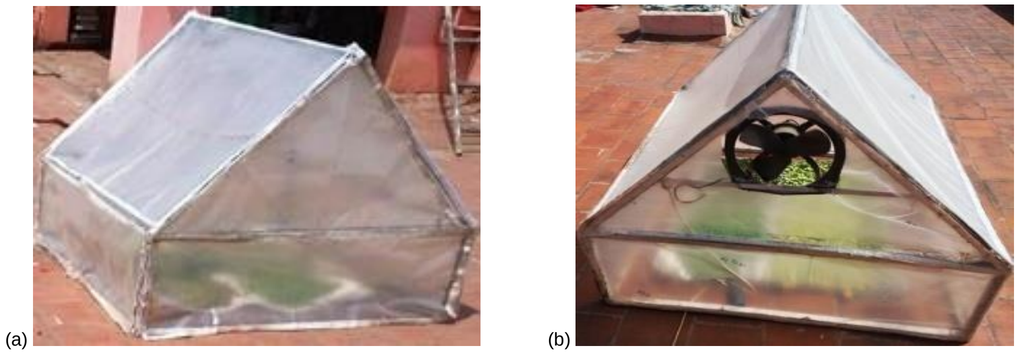

Figure 1. Solar greenhouse dryers; (a) passive mode, (b) active mode

Some amount of the solar radiation available was partly observed by the vegetable to be dried, floor and tray, the left out solar radiation would heat the air inside the greenhouse dryer. The greenhouse dryer was kept under east-west orientation to have more exposure to solar radiation. For active mode greenhouse drying, a fan with air velocity of 2.8 m/sec was placed at upper end of the side wall of the greenhouse, fig. 2. For passive greenhouse drying a vent of 0.40 $m^2 \times 0.40$ m^2 was provided on the upper end of the roof for natural ventilation to facilitate air movement. Two different cover materials UV polyethylene and drip lock sheets had been used in the dryers. The drip lock sheet or anti drip sheet was used in this experiment as it had certain advantages. Due to the condensation of the water vapour evaporated from the products being dried, water droplets were created inside the superficial of the greenhouse sheets. This affected the drying quality of the vegetables, since it reduces the light transmission by 15-30%. Also, incidents of diseases might happen due to the water particles.

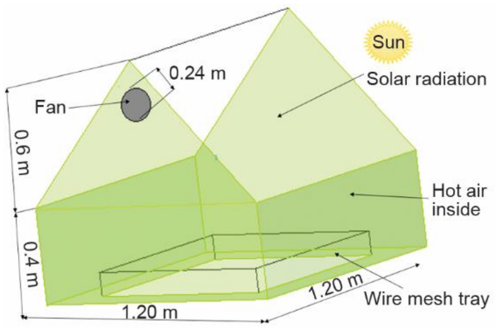

Figure 2. Schematic view of a active mode greenhouse dryer

The individual droplets were converted into continuous thin layer of water by the anti-drip films, since it contained special additives. The thin layer of water fell down the sides of the roof and wall of the greenhouse.

Experimentation

The vegetables ivy gourd and turkey berry were dried in the greenhouse dryer for increasing the shelf life of the products. Fresh ivy gourds of almost equal sizes were cut into slices of 4 to 5 mm thickness. Fresh turkey berry of almost equal size was used for the drying. A steel wire mesh tray of 0.85 m × 0.85 m size was used for drying of vegetables under passive and active mode of the greenhouse dryer. Vegetables were organized in a single layer in the steel wire mesh tray. The drying process took place at isobaric condition when heat and mass transfer occurred simultaneously. Experiments were conducted in the month of April 2018 between 9 a. m. to 4 p. m. For active mode a fan was placed on the east wall to enhance the air movement. Various thermal data were recorded from the system. The data were collected for several measurements and the average of the values was considered for the evaluation of the performance parameters. The photographs of fresh and dried samples of turkey berry and ivy gourd are shown in figs. 3 and 4, respectively.

Figure 3. Turkey berry; (a) fresh product, (b) dried product

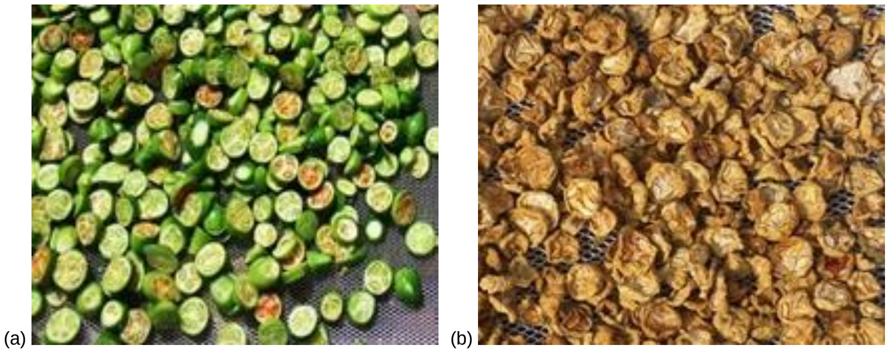

Figure 4. Ivy gourd; (a) fresh product, (b) dried product

Instrumentation

A halogen moisture analyzer HR83 was used to determine the initial moisture content of ivy gourd and turkey berry. A solarimeter was used for measuring the solar radiation (range 2000 W/m^2) with an accuracy of ±5%. A non-contact type infrared thermometer was used for measuring temperature up to 380 °C with an accuracy of ±1.5 °C. An anemometer (Model: Benetech, range 0-30 m/s) was used to measure the wind speed range 0 to 30 m/sec.

Energy and exergy analysis

Assumptions

To analyze the system and to record the performance parameters, the following assumptions had been arrived at [28]:
– greenhouse heat capacity and wall material was neglected,
– greenhouse air temperature stratification was neglected, and
– heat capacity and absorptive of enclosed air was neglected.

Analysis

The performance of the drying system was analyzed using the data collected with experimentation. Various performance parameters like moisture ratio, thermal efficiency, overall thermal efficiency, instantaneous exergy efficiency, and improvement potential had been calculated with the experimental readings.

Moisture ratio

Moisture ratio is an important parameter to analyze and compare the performance of solar dryers. It is given by [29]:

$$MR = \frac{M_{\text{int}} - M_{\text{eq}}}{M_{\text{in}} - M_{\text{eq}}} \tag{1}$$

where M_{int} is the instantaneous moisture content, M_{in} – the initial moisture content, and M_{eq} – the equilibrium moisture content.

Thermal efficiency

Thermal efficiency of dryer, η_{th}, is the ratio of energy essential to evaporate the moisture from the product to the total energy given into the drying system on daily basis. It is given [25]:

$$\eta_{\text{th}} = \frac{\dot{m}_w h_{fg}}{E_t} \tag{2}$$

where E_t is the energy input, $\dot{m}_w$ – the mass of moisture evaporated during a period, and h_{fg} – the enthalpy of evaporation.

Overall thermal efficiency is the ratio of the energy consumed for the drying and total energy received by the dryer for the full drying period.

Instantaneous exergy efficiency

The instantaneous exergy efficiency, $\eta_{\text{i,ex}}$, of the dryer is the ratio of the product exergy (desired output exergy) to exergy input as given [28]:

$$\eta_{\text{i,ex}} = \frac{\dot{Ex}_{\text{evap}}}{\dot{Ex}_{\text{Sun}}} = \frac{\dot{Q}_{\text{ex}}}{U_{eev} \Sigma I A_{\text{p}}} \tag{3}$$

where $\dot{Q}_{\text{ex}}$ is the exergy of products:

$$\dot{Q}_{\text{ex}} = \left[m_w \lambda \left(1 - \frac{T_\text{a} + 273}{T_\text{r} + 273} \right) \right] \tag{4}$$

where λ is the latent heat of water, T_a – the ambient temperature, T_r – the greenhouse room temperature, U_{eev} = 0.95 [28], and A_p – the area of products.

Improvement potential

Improvement potential, is a measure of how much improvement can be possible to increase the exergy efficiency. Lower exergy efficiency would lead to higher improvement potential [30]. Improvent potencial is given [31]:

$$IP = (1 - \eta_{\text{i,ex}}) \dot{E}x_{\text{loss}} \tag{5}$$

where

$$\dot{E}x_{\text{loss}} = \dot{E}x_{\text{Sun}} - \dot{E}x_{\text{evap}} \tag{6}$$

Uncertainty analysis

In the analysis of systems, there are some independent parameters. They were measured, like temperature, mass, time, *etc.*, and some dependent parameters such as efficiency, power, *etc.* The uncertainty in the measured parameters was due to errors like sensitivity, calibration, reading, *etc.* Let x_1, x_2, x_3,…, x_n are independent variables with uncertainty w_1, w_2, w_3, …, w_n. The result, R, is a dependent function of independent variables. The uncertainty in the R is given by w_R [32]:

$$\left[\left(\frac{\partial R}{\partial x_1} w_1 \right)^2 + \left(\frac{\partial R}{\partial x_2} w_2 \right)^2 + \left(\frac{\partial R}{\partial x_3} w_3 \right)^2 + \ldots + \left(\frac{\partial R}{\partial x_n} w_n \right)^2 \right]^{1/2} \tag{7}$$

The uncertainties in the measured and calculated parameters are given in tab. 1.

Table 1. Uncertainty in the measured and calculated parameters

Parameters	Uncertainty
Temperature, [°C]	±1.5
Solar radiation, [Wm^{-2}]	5%
Wind velocity, [ms^{-1}]	2%
Mass of the products, [kg]	0.1%
Moisture ratio, [%]	2%
Heat flow rate, [kJs^{-1}]	3%
Energy input, [kWh^{-1}]	1%
Thermal efficiency, [%]	2.5%
Instantaneous exergy efficiency, [%]	5%

Results and discussion

Drying experiments had been conducted in the open sun dryer and in greenhouse dryer with two different cover materials UV polyethylene under passive mode (UVPM) and active mode (UVAM) and drip lock sheets and under passive mode (DLPM) and active modes (DLAM). Two vegetables with medicinal values *Ivy Gourd* and *Turkey Berry* were dried. Different performance parameters during the drying process under various modes have been elaborated in this section.

Solar radiation and dryer temperatures

Environmental properties such as solar radiation, atmospheric temperature, greenhouse temperature, and air velocity, *etc.* influence the drying performance. Solar radiation is an important parameter. At higher solar radiations, the temperature of the dryer, the temperature of the products to the dried ones increases and the moisture evaporation will be easier and the drying time will be lower.

The hourly variation of the solar radiation recorded and temperature of the greenhouse dryer under various modes for ivy gourd and turkey berry are presented in the figs. 5(a) and 5(b), respectively. The solar radiation increases from 650 W/m^2 at 9.00 a. m. and reaches the maximum values of around 980 W/m^2 at 1.00 p. m. and decreases afterwards. Dryer temperatures have higher values in active mode drying with drip lock sheet.

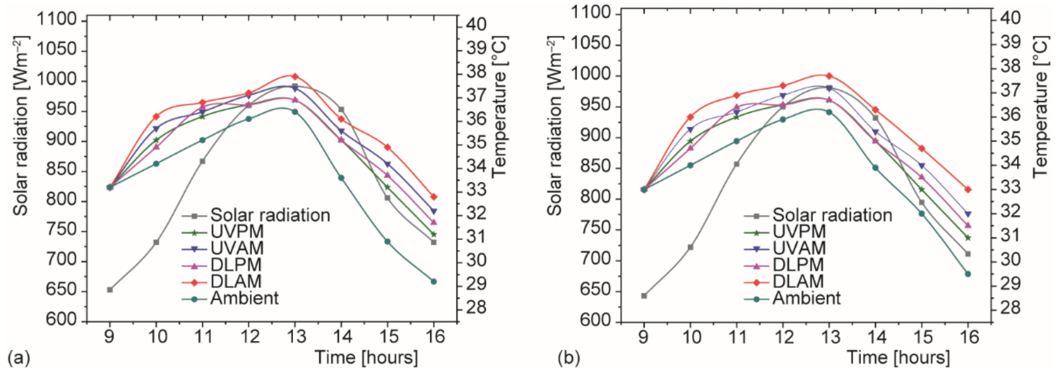

Figure 5. Solar radiation and dryer temperatures; (a) ivy gourd drying, (b) turkey berry drying

Moisture ratio

The variations of moisture ratio with time obtained using experimental data are shown in fig. 6 for ivy gourd and turkey berry. For ivy gourd the final moisture content of about 9% and final moisture ratio of around 0.1 had been achieved in less than 3 days with DLAM, 3 days with UVAM, 3.5 days in DLPM, 4 days with UVPM, and 5 days with open Sun mode. For turkey berry the final moisture content of about 10% and final moisture ratio of

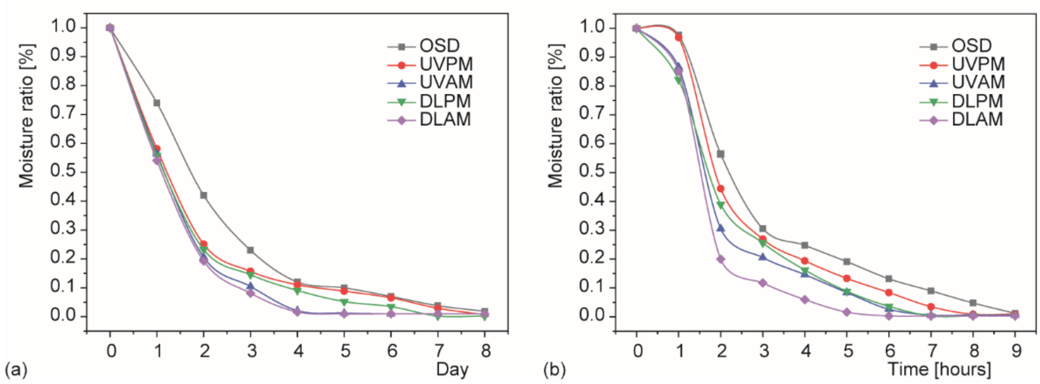

Figure 6. Moisture ratio; (a) ivy gourd drying, (b) turkey berry drying

around 0.1 had been achieved in 3.5 days with DLAM, 5 days with UVAM, 5 days in DLPM, 6 days with UVPM, and 7 days with open Sun mode. The time taken for turkey berry was more as the vegetable was not cut and also the turkey berry was found to have a thicker skin which prevented the evaporation of moisture from the surface.

It was observed from the figure that during the initial period the rate of moisture removal was more and decreased as the time increased. This was because of the evaporation of moisture from the surface initially and then the heat supplied was used for bringing the moisture from the inner part of the product to the surface. In general, the moisture ratio in drying decreased exponentially and in open Sun the rate of decrease of moisture ratio was slower than greenhouse drying as the time consumed was more in the case of open Sun drying.

Thermal efficiency and overall thermal efficiency

The variation of thermal efficiency on hourly basis and overall thermal efficiency for the total drying period for ivy gourd and turkey berry are depicted in figs. 7(a) and 7(b), respectively. The thermal efficiency for the drying of ivy gourd with drip lock active mode was around 31% on the first day of drying and decreased on the subsequent days. The thermal efficiency of turkey berry drying was 27% with drip lock active mode and afterwards decreased. The higher values of thermal efficiency during initial days were due to more evaporation of moisture and effective utilization of the energy available during those periods. The type of variation of thermal efficiency was same as reported by [25].

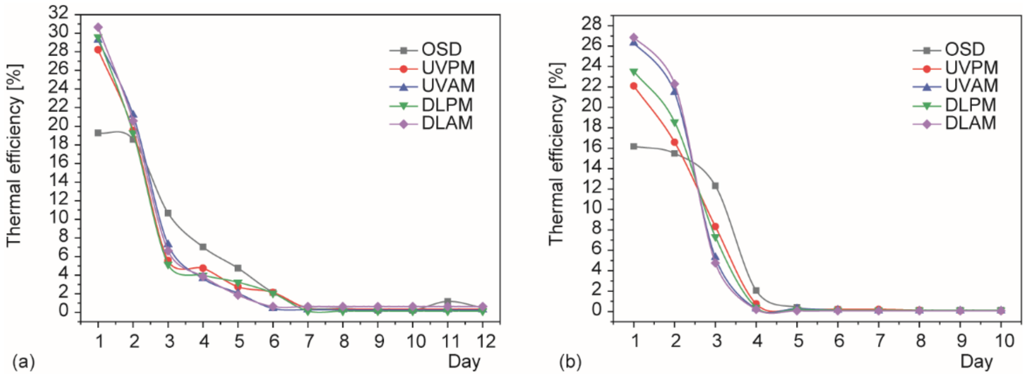

Figure 7. Thermal efficiency; (a) ivy gourd drying, (b) turkey berry drying

Comparing to ivy gourd, turkey berry had lower thermal efficiency values as the rate of moisture removal in turkey berry was lower. The thermal efficiency of open sun drying was initially lower, higher at intermediate periods and coincided with greenhouse dryer afterwards. This was due to the lower evaporation of moisture initially compared to the greenhouse dryer and higher moisture evaporation at intermediate periods than greenhouse dryer. Figure 8(a) shows the overall thermal efficiency of the drying processes of ivy gourd. While drying ivy gourd the overall thermal efficiency varied from 6.7% for open Sun drying to 10.84% for greenhouse drying with drip lock sheet under active mode. The values of overall thermal efficiencies for the drying of turkey berry are shown in fig. 8(b). For open Sun drying it was 5% and drip lock active mode greenhouse drying it was 9%.

As long time was taken in drying with the open Sun, drying the overall efficiency was the lowest. The drying of turkey berry took more time compared to the ivy gourd. So, the overall thermal efficiency for turkey berry was lower than that of the ivy gourd.

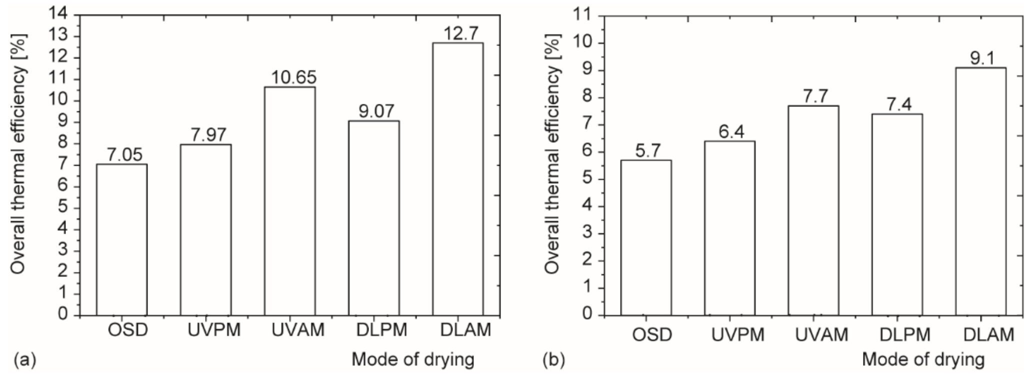

Figure 8. Overall thermal efficiency; (a) ivy gourd drying, (b) turkey berry drying

Exergy efficiency

Exergy efficiency is the real measure of how the resources are effectively used. Figure 9 represents the exergy efficiency of the drying of ivy gourd and turkey berry with various modes. It was clear from the figures that the values of exergy efficiency for drying with drip lock active mode were the highest among the different modes. Exergy efficiency values had been found to range between 0.001% and 0.09% for ivy gourd and turkey berry. The highest exergy efficiency was during the drying of ivy gourd under DLAM. Comparing with thermal efficiency, exergy values were lower for all the modes of drying of ivy gourd and turkey berry. This was due to some of the exergy supplied to the system was destroyed due to irreversibility. The trend in the variation of exergy with time is same as reported by earlier research [28].

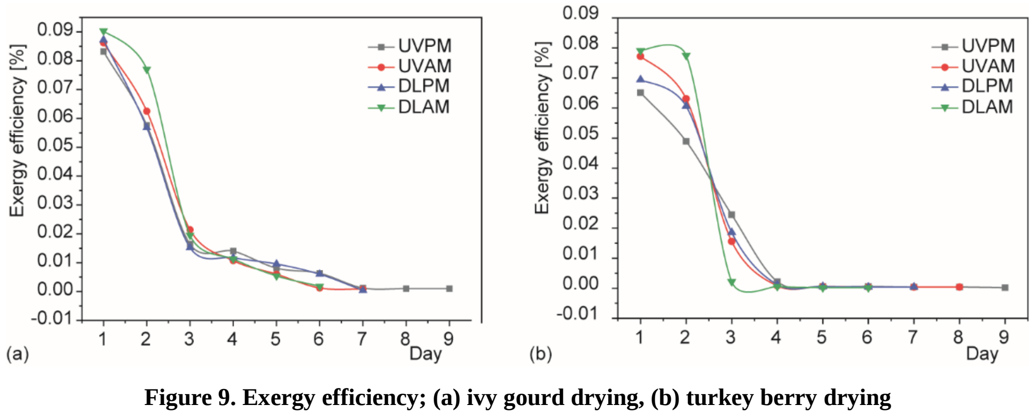

Figure 9. Exergy efficiency; (a) ivy gourd drying, (b) turkey berry drying

Improvement potential

Most frequently used exergetic indicators were exergy efficiency and exergy loss. Next important parameter was improvement potential. It was used for comparing the various processes and various sizes in different fields, although the maximum value of improvement for a process was its total exergy loss [33].

Exergy improvement potential evaluation was necessary in order to improve the exergy efficiency, because at lower exergy efficiency provided higher opportunities for improvement [30]. Figures 10(a) and 10(b) represent the improvement potential while drying ivy gourd and turkey berry, respectively, with various modes.

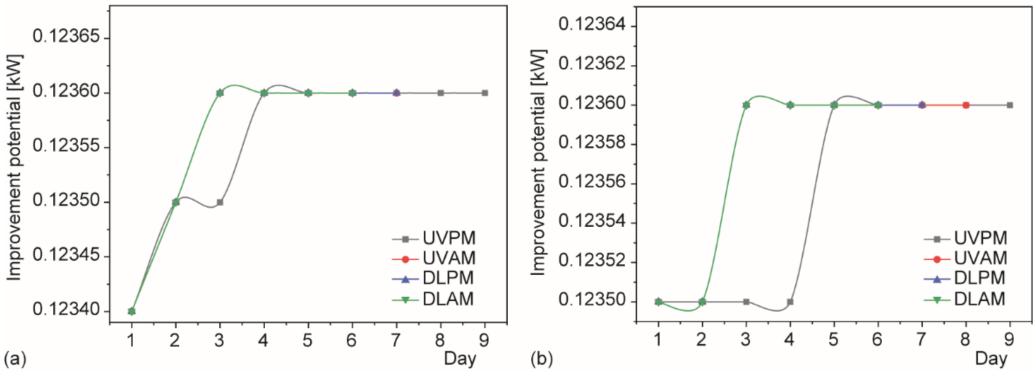

Figure 10. Improvement potential while drying; (a) ivy gourd, (b) turkey berry

The improvement potential in drying of ivy gourd varied from 0.1235 kW to 0.1236 kW and became constant. Similar pattern could be seen in drying turkey berry also ranging from 0.1234 kW to 0.1236 kW. The values of improvement potential were similar [31]. The type of variation of improvement potential with time was also similar [30].

Conclusions

Every year there is an increase in the loss of food products due to poor post-harvesting processes and improper storage facilities. Simple solar dryers are appropriate for economical drying of fruits, vegetables and other agricultural products and can be used by rural farmers and rural women specifically in developing countries. In this study the performance of simple low-cost solar greenhouse dryer has been investigated. Drying experiments have been conducted in open Sun and in greenhouse dryer with two different cover materials ultra violet polyethylene and drip lock sheets and under passive mode and active mode. Two vegetables with medicinal values ivy gourd and turkey berry have been put to dry. Moisture ratio, thermal efficiency, exergy efficiency and improvement potential have been evaluated and presented. The present study brings the following conclusions.

- Performance of greenhouse dryer is better than the open Sun drying. Thermal efficiency of solar dryer is higher than that for open sun drying.
- Thermal efficiencies are up to 30.64% and maximum thermal efficiency could be realized during drying of ivy gourd with drip lock sheet under active mode. Overall thermal efficiency of 12.7% and 9.1% was obtained during the drying with drip lock active mode for ivy gourd and turkey berry.
- Drip lock sheet or anti drip sheet shows a better performance than UV polyethylene sheet.
- Exergy efficiency values ranged between 0.001% and 0.09% and highest exergy efficiency was witnessed during the drying of ivy gourd under DLAM.
- Improvement potential for the drying processes were evaluated and reported. The performance values were in the same range or little more than the values reported in the literature.
- The results showed that this dryer could be used for drying agricultural products at low cost by the small farmers to make value added products from their harvested products.

- This dryer was useful in remote places even without electricity. Also, this dryer could be used for industrial drying with low cost at reasonable time frame without compromising quality.
- Further design modifications would be possible based on the improvement potential to improve the performance.
- Present study would be useful for engineers and researchers working in the field of post-harvesting processes such as drying and it could be applied for developing alternate designs for rural and industrial drying.

Nomenclature

A – area, [m^2]
E – energy input, [kWh^{-1}]
$\dot{E}x$ – exergy, [kJkg^{-1}]
h – enthalpy, [kJkg^{-1}]
I – solar radiation, [Wm^{-2}]
M – moisture content, [kg]
$\dot{m}$ – mass flow rate, [kgs^{-1}]
U – constant
$\dot{Q}$ – heat flow rate, [kJs^{-1}]

Greek symbols

η – efficiency
λ – latent heat of water, [kJkg^{-1}]

Acronyms

DLPM – drip lock passive mode
DLAM – drip lock active mode
IP – improvement potential, [kW]
OSD – open sun drying
MR – moisture ratio
UVPM – ultra violet passive mode
UVAM – ultra violet active mode

Subscripts

A – ambient
eev – efficiency expression value
eq – equilibrium
evap – evaporation
ex – exergy
int – instantaneous
in – initial
i, ex – instantaneous exergy
loss – loss
p – product
r – greenhouse
Sun – solar
t – time
th – thermal
w – water

References

[1] Vijayan, S., *et al.*, Mathematical Modelling and Performance Analysis of Thin Layer Drying of Bitter Gourd in Sensible Storage Based Indirect Solar Dryer, *Innovative Food Science and Emerging Technologies, 36* (2016), Aug., pp. 59-67
[2] El-Sebaii, A. A., Shalaby, S. M., Solar Drying of Agricultural Products: A Review, *Renewable and Sustainable Energy Reviews, 16* (2012), 1, pp. 37-43
[3] Hall, C. W., Handbook of Industrial Drying, *Drying Technology, 6* (1998), 3, pp. 571-573
[4] Dincer, I., Sahin, A. Z., A New Model for Thermodynamic Analysis of a Drying Process, *International Journal of Heat and Mass Transfer, 47* (2004), 4, pp. 645-652
[5] Ozgener, L., Ozgener, O., Exergy Analysis of Drying Process: An Experimental Study in Solar Greenhouse, *Drying Tech., 27* (2009), 4, pp. 580-586
[6] Srinivasan, R., *et al.*, Computational Fluid Dynamic Analysis of Missile with Grid Fins, *Journal of Applied Fluid Mechanics, 10* (2017), Special issue, pp. 33-39
[7] Midilli, A., Kucuk, H., Energy and Exergy Analyses of Solar Drying Process of Pistachio, *Energy, 28* (2003), 6, pp. 539-556
[8] Dincer, I., On Energetic, Exergetic and Environmental Aspects of Drying System, *International Journal of Energy Research, 26* (2002), 8, pp. 717-727
[9] Bejan, A., Fundamentals of Exergy Analysis, Entropy Generation Minimization, and the Generation of Flow Architecture, *Int. J. of Energy Research, 26* (2002), 7, pp. 545-565
[10] Aghbashlo, M., *et al.*, A Review on Exergy Analysis of Drying Processes and Systems, *Renewable and Sustainable Energy Reviews, 22* (2013), June, pp. 1-22
[11] Tiwari, S., Tiwari, G. N., Energy and Exergy Analysis of a Mixed-Mode Greenhouse-Type Solar Dryer, Integrated with Partially Covered N-PVT Air Collector, *Energy, 128* (2017), June, pp. 183-195

[12] Prakash, O., *et al.*, Performance of Modified Greenhouse Dryer with Thermal Energy Storage, *Energy Reports, 2* (2016), Nov., pp. 155-162
[13] Fudholi, A., *et al.*, Performance Analysis of Solar Drying System for Red Chili, *Solar Energy, 99* (2014), Jan., pp. 47-54
[14] Beigi, M., *et al.*, Exergetic Analysis of Deep-Bed Drying of Rough Rice in a Convective Dryer, *Energy, 140* (2017), Dec., pp. 374-382
[15] Prakash, O., Kumar, A., Solar Greenhouse Drying: A Review, *Renewable and Sustainable Energy Reviews, 29* (2010), Jan., pp. 905-910
[16] Sahdev, R. K., *et al.,* A Review on Applications of Greenhouse Drying and its Performance, *Agricultural Engg Int.: CIGR J., 18* (2006), 2, pp. 395-412
[17] Lakshmi, D. V. N., *et al.*, Performance Comparison of Mixed Mode and Indirect Mode Parallel Flow Forced Convection Solar Driers for Drying Curcuma Zedoaria, *Journal of Food Process Engg., 42* (2019), 4, pp. 1-12
[18] Saravankumar, P. T., *et al.*, Ecological Effect of Corn Oil Biofuel with SiO_2 nanoaditivies, *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 41* (2019), 23, pp. 2845-2852
[19] Sarathkumar, A., *et al*., Evaluation of Physiological Seed Treatments on Seedling Quality parameters in Turkey Berry (Solanum torvum Sw.). *Int. J. of Current Microbiology and Applied Sciences, 6* (2017), 6, pp. 212-219
[20] Boukadoum, A. B., Benzaoui, A., Energy and Exergy Analysis of Solar Drying Process of Mint, *Energy Procedia, 6* (2011), June, pp. 583-591
[21] Colak, N., Hepbasli, A., Performance Analysis of Drying of Green Olive in a Tray Dryer, *Journal of Food Eng., 80* (2007), 4, pp. 1188-1193
[22] Colak, N., *et al.*, Exergetic Assessment of Drying of Mint Leaves in a Heat Pump Dryer, *Journal of Food Process Engg., 31* (2008), 3, pp. 281-298
[23] Tambunan, A. H., *et al*., Freeze Drying Characteristics of Medicinal Herbs, *Drying Technology, 19* (2001), 2, pp. 325-331
[24] Vijayan, S., *et al*., Thin Layer Drying Characteristics of Curry Leaves (Murraya Koenigii) in an Indirect Solar Dryer, *Thermal Science, 21* (2017), Suppl. 2, pp. S359-S367
[25] Vivekanandan, M., *et al.*, Pressure Vessel Design using PV-ELITE Software with Manual Calculations and Validation by FEM, *Journal of Engineering Technology, 8* (2019), 1, pp. 425-433
[26] Ayyappan, S., Performance and CO_2 Mitigation Analysis of a Solar Greenhouse Dryer for Coconut Drying, *Energy & Environment, 29* (2018), 8, pp. 1319-1337
[27] Bhardwaj, A. K., *et al*., Experimental Investigation of the Performance of a Novel Solar Dryer for Drying Medicinal Plants in Western Himalayan Region, *Solar Energy, 177* (2019), Jan., pp. 395-407
[28] Tiwari, G. N, *et al.*, Energy and Exergy Analyses of Greenhouse Fish Drying, *Int. J. Exergy, 6* (2009), 5, pp. 620-636
[29] Chauhan, P. S., *et al.*, Drying Kinetics, Quality Assessment, and Economic Analysis of Bitter Gourd Flakes Drying Inside Forced Convection Greenhouse Dryer, *Journal of Solar Energy Engg., 140* (2018), 5, pp. 1-10
[30] Dhandayuthabani, M., *et al.*, Investigation of Latent Heat Storage System using Graphite Microparticle Enhancement, *Journal of Thermal Analysis and Calorimetry*, On-line first, https://doi.org/10.1007/s10973-019-08625-7, 2019
[31] Akpinar, E. K., The Effects of Some Exergetic Indicators on the Performance of Thin Layer Drying Process of Long Green Pepper in a Solar Dryer, *Heat and Mass Transfer, 55* (2019), 2, pp. 299-308
[32] Holman, J. P., *Experimental Methods for Engineers*, McGraw-Hill, New York, USA, 1994, Vol. 6
[33] Zisopoulos, F. K., *et al.*, The Use of Exergetic Indicators in the Food Industry – A Review, *Critical Reviews in Food Science and Nutrition, 57* (2017), 1 , pp. 197-211

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