Green drying of Tomato by designed Air solar heater

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ABSTRACT

Drying the agricultural products is considered one of the most immemorial and efficient method that is used in food preservation. This work adopted solar energy system to reduce the moisture content of these agricultural products in a way that increases the shelf-life and improves product quality. A great amount of energy is consumed during drying process due to the high latent heat of water, originally contained in the product.

Solar energy like other sources of energy is underutilized in Jordan. The aim of this work is to utilize the enormous solar energy potential which is available in Jordan in the process of drying the agricultural products (Tomato).

A suggested model for a solar dryer with creative design of a double glass container and a solar heat collector had been tested for several weeks during spring (March ,April and May) in drying Tomato's slices.

The results show the efficiency of the adopted model and the good quality of the dried agricultural product (Tomato). The time spent for this process was about seven and half hours. The heating capacity of the system was about 0.82 kW.

Key words: Dry food, solar dryer, tomato preservation, heat gain, container, solar collector.

1. Introduction

Throughout the history food preservation is essential to increase the shelf-life and prevent deterioration in the quality of agricultural products. This process is accomplished by preventing the growth of microorganisms, as well as slowing the oxidation of fats that causes rancidity [1].

Moreover, dehydration process is considered a sophisticated process with simultaneous heat and mass transfer, which are well known as a very complex thermo-chemical because of the differential structure of the products. In fact, a food dryer is considerably more complex than a device that simply removes water, and many effective models are essential for process design, optimization, energy integration, and control[2].

Arguably, drying is considered one of the most old and efficient method that is used in food preservation. It involves the application of heat to the food material which results in the transfer of moisture within the material to its surface and then water removal from the material to the atmosphere. It's thus a combined heat and mass transfer operation. This process results in preventing the growth and reproduction of microorganisms like yeast, bacteria and molds which cause degradation and many of the moisture- mediated deteriorative reactions [3].

Additionally, drying process brings about a remarkable reduction in volume, weight, packing, storage and transportation cost and enables storability of the processed food under ambient temperature.In drying process 50% of the energy is consumed due to the high latent heat of water. An also the major part of energy consumption occurs during evaporation of liquid wat(2258J/ kg at 101.3 kPa) [4]. The water may be contained in solid in various forms like free moisture or bound form which directly affects the drying rate.

Moisture content is expressed either on dry or wet basis. That is moisture content in wet (W) basis is the weight of moisture per unit of wet material:

$$W = \frac{mw}{mw+md} \text{ Kg per Kg of mixture.}$$

and on dry basis (X), is expressed as the ratio of water content to the weight of dry material:

$$X = \frac{mw}{md} \quad \text{kg of water per kg of dry material .}$$

Where are: $\boldsymbol{mw}$ mass of water and $\boldsymbol{md}$ is amass of dry solid. The most convenient way to express moisture for mathematical calculations is on dry basis but for agricultural products moisture content normally is expressed in wet basis. Figure (1) shows the relationship between wet- weight and dry-weight basis [5] .

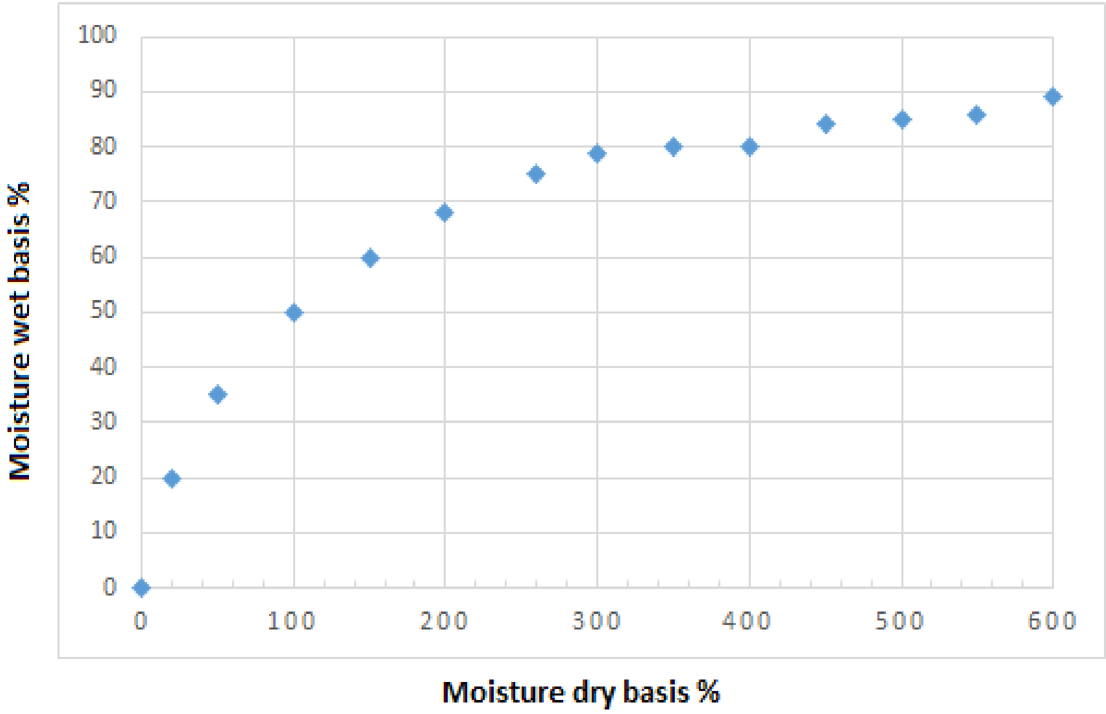

Figure 1.wet- weight Vs dry-weight basis

The main principle for solar dryer is to concentrate the available heat more than the ambient heat at a given humidity. This process will increase the vapor pressure of the trapped in the foodstuff and decrease the relative humidity of the drying air which will in turn increase the carrying capacity of the air with solar dryer the material can be heated by air and sometimes directly by the sun.

Sun, Solar, or open-air solar drying is considered one of the oldest methods of drying. Using this method the foodstuff is placed outside on tray to dry in sun. Sometime this drying process can be accomplished by covering the foodstuff with a transparent cover to protect partially the food from deterioration due to rain, insects and other natural factors. In addition to that during drying process just part of the solar radiation is absorbed depending on the foodstuff color and the rest is reflected back to the atmosphere, so it's a very slow rate operation. Moreover, scientific observations do not exist during the long period of drying.

On the other hand, indirect solar drying techniques range from simple, dessert or remote communities up to very sophisticated industrial installations. Even these techniques are not yet standardized and widely commercialized, but they have almost only advantages regardless of their high initial capital cost.

By indirect solar drying, the drying rate is high which increase the productivity of the system and the process can be controlled scientifically. Furthermore, foodstuff is not subjected to any natural phenomena. So there are no losses at all. The flexibility of most indirect solar drying systems makes it possible to use them for drying similar seasonal crops.Over and above these advantages, indirect solar modes have a high capacity due to trays accommodations which are stacked inside the dryers[6].

There are different classifications for drying equipment. Two of the most practical classifications are according to the following criteria firstly, the method which is used to transfer heat to the wet material,and secondly, yhe handling characteristics and physical properties of the wet material.

Solar energy dryers can broadly be categorized into direct, indirect and hybrid solar dryers. The method of solar energy collection and its conversion to useful thermal energy for drying is determined by the working principle of these dryers.

Jordan is a poor country that imports nearly 96% of its energy, Jordan can adopt the world experiencesand utilize its enormous solar energy potential in various sectors one of them food preservation sector.

Sukhmeet and et al**.,** introduced a multi-shelf design with intermediate heating, passive, integral, direct/indirect portable solar dryer. With this dryer the foodstuff can be dried under shade or otherwise as per requirement. This cheap design makes it economically available. A semi-continues mode of loading had been studied to avoid the problem of reduction the efficiency on the second and third day. The results shows that the efficiency almost remains the same over the drying period [7].

A domestic solar dryer with a transparent external surface was designed and investigated by A.saleh, I.badran(2009). In order to predict the drying period for different products a thin- layer models that simulate the drying process in a unified way, regardless of the controlling mechanisms was proposed. Moreover an exponential model that predicts the drying rate constant was checked through this work. two local herbs; Jew`s herbs and mint leaves were used to test the proposed design. The results showed a reasonable agreement between the experimental results and the exponential model under different tests.[8]

Abhay hing ayat, [2017] introduced a solar dryer that consists of solar flat plate air collector with V-corrugated absorption plates, insulated drying chamber with chimney for exhaust air. This model was used for drying banana. The results show that the moisture content dropped from 356% (db) to final moisture content of 16.3292%, 19.4736%, 21.1592%, 31.1582%, and 42.3748% (db) for Tray1, Tray2, Tray3, Tray4, and open sun drying respectively. The average thermal efficiency of the collector was found to be 31.50% and that of drying chamber was 22.38%. [9].

Essalhi hajar .and et al. [2017] introduced a new concept of a solar absorber. The new absorber consists of two corrugated plates which are fixed to form parallel cylinders. This configuration allows the air to circulate a long the collector. The drying experiments were carried out on pear. the results revealed that the mass of samples were reduced to 135.13 g from 997.3 g with an average thermal efficiency of the drying chamber about 11.11%.[10]

A mixed solar dryer with forced convection prototype was proposed and tested by M.Fterich..et [2018]. In this work the system consists of air collector (PV/T) and drying room. Tomatoes were divided into two trays and dried using forced convection mixed solar dryer. The final results revealed that the moisture content reduced from 91.94% to 22.32% for tray 1, and to 28.9% for tray 2. Comparing with dry in open sun which has a moisture content of 30.15%. [11]

On the basis of the above- mentioned literature, a model for a solar dryer with creative design of a double glass container and a solar heat collector had been tested for several weeks during spring (March ,April and May 2017) in drying Tomato's slices.

2.Theoretical Analysis:

2.1 Heat loss due to (wall, ceiling, floor, chimney and nozzle)

$$\mathbf{Q = UA(T_i - T_o)} \qquad 2.1$$

Where
Q : Heat loss { Watt }
U : Overall heat transfer coefficient { $W/m^2.K$}
A : Area { m2 }
T_i : Inside temperature { °C }
T_o : Outside temperature { °C }

2.2 Heat loss due to infiltration

$$\mathbf{Q_f = (1250/3600)\ (T_i - T_o)\ V_f} \qquad 2.2$$

where
Q_f : heat loss due to infiltration { W }.

T_i : inside temperature { °C }.

T_o : outside temperature { °C}

V_f : volumetric flow rate of infiltrated air { m^3/h }.

2.3. Heat gains due to double glass:

$$\mathbf{Qtr. = A(SHG)(SC)(CLF)} \qquad 2.3$$

where
Q_{tr} : heat gain due to solar transmission through glass {W}
A : area m_2
SHG : solar heat gain rate factor {W/m2} [table9.7 Appendix A]
SC : shading coefficient factor [table9.8 Appendix A]
CLF : cooling load factor [table9.10 Appendix A]

2.4 Heat gains due to collector:

$$\mathbf{Q_u = Q_i - Q_o = I\ell\alpha.A - U_L A\,(T_c - T_a)} \qquad 2.4$$

where

Q_u : useful energy gain { W}

Q_i : collector heat input { W}

Q_o : heat loss { W}

I : intensity of solar radiation { W/m^2}

Transmission coefficient of glazing. : .ℓ

α : absorption coefficient of plate.

A : area of collector. { m^2}.

U_L: collector glass overall heat loss coefficient { W/m^2. K }.

T_c : collector average temperature { ^oC }.

Ta : ambient temperature {^oC}.

2.5.Mass flow rate due to the collector

$$\mathbf{Q_u = \dot{m}\, C_p(T_o - T_i)} \qquad 2.5$$

where

$\dot{m}$: mass flow rate of air { Kg/s }.

C_p : specific heat { J/Kg. K }.

T_o : exit temperature of air { °C }.

T_i : inter temperature of air { °C }.

2.6.The efficiency of the collector

$$\mathbf{\eta = (Qu/IA) * 100\%} \qquad 2.6$$

η : collector efficiency {%}.

2.7. Time of drying process

Amount of moisture to be removed from a given quantity of wet tomato slices MW in kg was calculated using the following equations:

$$\mathbf{M_w = \frac{mp(Mi-Mf)}{100-Mf}} \qquad 2.7$$

where

m_p : is the initial mass of product to be dried{ Kg }.

M_i : is the initial moisture content, { % }. wet basis.

M_f : is the final moisture content, { % }. wet basis.

2.8. Quantity of heat needed to evaporate the H_2O:

$$\mathbf{Q = M_w * h_{fg}} \quad 2.8$$

where

Q : The amount of energy required for the drying process { KJ }.

M_w : mass of water { Kg }.

h_{fg} : Latent heat of evaporation { KJ/Kg H_2O }.

Latent heat of vaporization was calculated using equation by Yousef – ali et al (2001) as follow :

$$\mathbf{h_{fg} = 4.186*103(597-0.56T_{pr})} \quad 2.9$$

T_{pr} : product temperature °C, and in this project 55 °C

2.9.Quantity of energy from the collector and double glass gain:

$$\mathbf{E = Q_u + Q_{gain} - Q_{loss}} \quad 2.10$$

2.10. Time of drying process:

$$\mathbf{Time = \frac{Q}{E}} \quad 2.11$$

heat gains calculations:

ṁ=0.0165Kg/s

$$\mathbf{\eta = (Qu/IA) *100\%} \quad 2.12$$

$$\eta = \frac{443.7}{1000*1.14*0.75} * 100\%$$

η= 51.9%

$$M_w = \frac{mp\ (mi - Mf)}{100 - Mf} = 9.375 \text{ Kg} \quad 2.13$$

Quantity of heat needed to evaporate the H_2O:

Q = 22110 KJ

Quantity of energy from the collector and double glass gain

$E = Q_u + Q_{gain} - Q_{loss}$ 2.14

$= 443.7+700-324$

$= 820$ W.

$E = 0.82$ KW.

Time of drying process:

$$\text{Time}= \frac{Q}{E} \quad 2.15$$

$$= \frac{22110}{0.82} = 7.5 \text{ hours.}$$

3.Experimental setup

In the present study the solar dryer model is consist of two parts, a container and solar collector as shown in figure (2). A simple solar air collector is used to capture radiation and transfer this thermal energy to air. The container is designed using double glass that can absorb the heat from surrounding (solar radiation) and keep it in, so we can benefit from this to increase the heat inside the container that is required in the drying process.

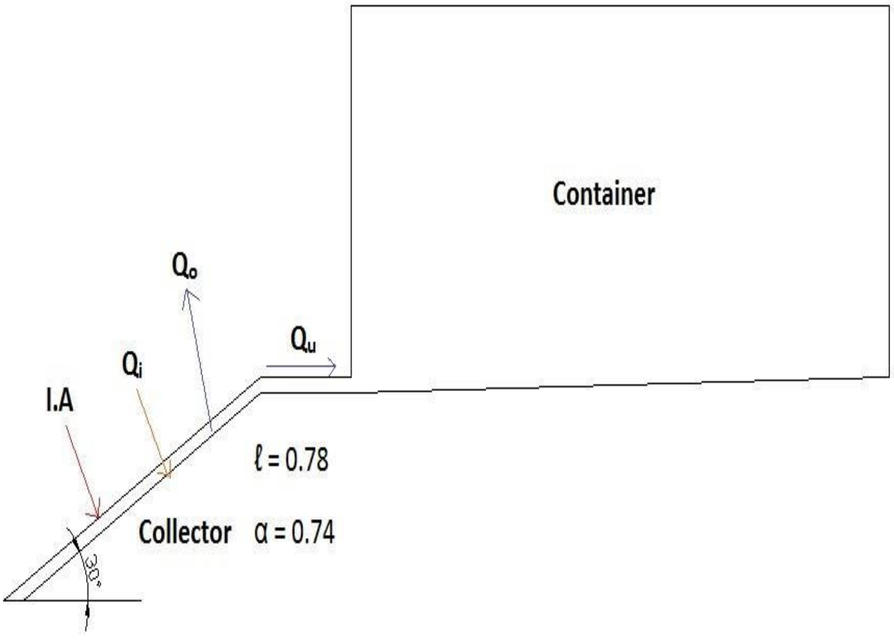

Figure (2) :Main parts of the drying system

The solar dryer was tested at Zarqa (32° 04' 21.90" N, 36° 05' 16.66" E).

In order to maximize the incident solar radiation, the solar collector was oriented toward south. With a tilt angle of 30^o .In preparation for the drying process, the tomatoes sample was washed to remove dust and undesired foreign material. The water which remained after washing process was removed by a cotton cloth.

After that the tomatoes were chipped in to slices. Table (1) summaries the basic data and conditions of this work.The following figures 3 through 5 show the built system and drying process of tomato.

Items	Conditions
Location	Zarqa
Crop	Tomato
The a mount to be dried	10 kg
Outside average temperature	33.4 °C
Temperature of the air dryer	60 °C
Temperature of the air enters the collector	33.4°C
Temperature of the air exists the collector	60 °C
Initial moisture content	94 %
Final moisture content	4 %

Figure 3. The photo of the built system

Figure 4. The photo of the built system and the measurement devices

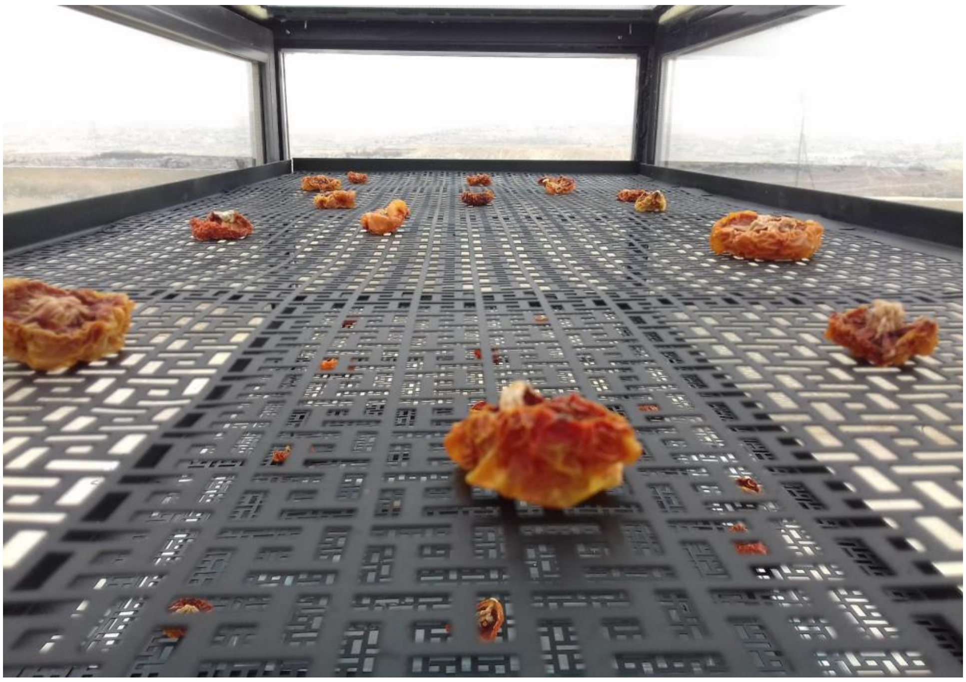

Figure 5. The photo of the built system with the tomato fruit

5.Results and conclusions

The solar air system was designed built, tested, and all measurement were carried out.

Results are summarized and shown in tables 2 and 3.

Container heat losses (W)				
Item	Area m^2	U ($W/m^2 K$)	DT [K]	Q(W)
S.Wall	0.3286	2.5	26.6	21.85
N.Wall	0.3286	0.75	26.6	6.6
W.wall	0.958204	2.4	26.6	60.07
E.Wall	0.958204	2.3646	26.6	60.27
Floor	0.724086	1.0753	26.6	20.7
Ceiling	0.724086	2.5	26.6	41
Chimney	0.4215	5.5	26.6	62.3
Nozzle	0.4223	1.075	26.6	12.1
Infiltration				39
Sum				324

Table 2. Container heat losses

Container Heat gain (W)	
Item	Heat gain (W)
S. Wall	40.24
W.Wall	151.84
E. Wall	1.51.84
Ceiling	325.81

Collector	443.7
Sum	961.59

Table 3. Container heat gain

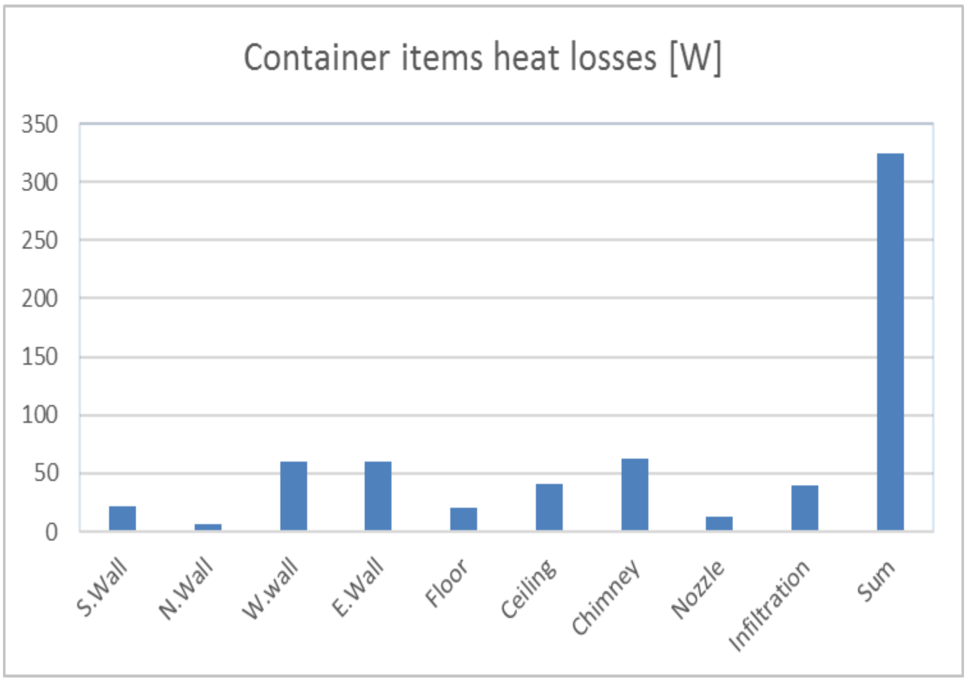

Figure 3. Items of container heat losses

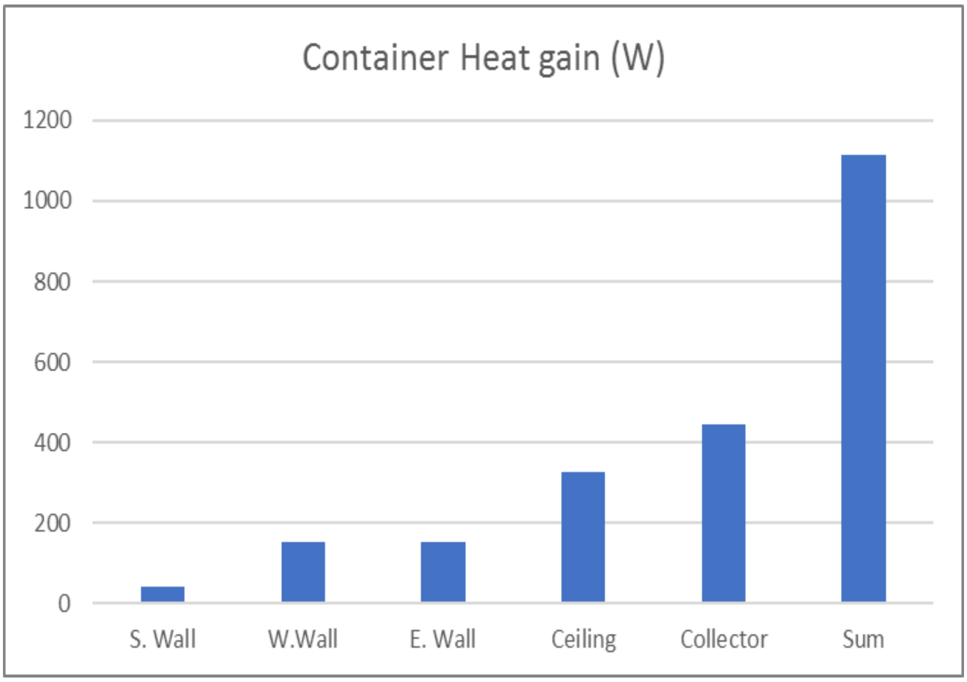

Figure 3. Items of container heat gain

During the experiments in the four months, the system was effective to handle 10 kg of tomato to be dried. The time spent for this process was about seven and half hours. The heating capacity of the system was about 0.82 kW.

As well as solar energy is the solely source of energy to power the designed and built system, Therefore, it is concluded from this study that it is useful enough to adopt such as these system to get green and effective drying process.

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