DRYING OF MINT LEAVES IN FORCED CONVECTION SOLAR DRYER

by

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In this present work, performance study on drying mint leaves under the metrological conditions. Intensity of radiation falls on the absorber plate which transfers heat to forced air-flow inside the galvanized iron tube. Drying experiment carried out with 1 kg of mint leaves taken for drying process under the different mass-flow rate of 0.75 m/s and 1.25 m/s in serpentine flow of air. Performance of the collector and drying efficiency were 30.33% and 1.63% in first day at 0.75 m/s mass-flow rate and in the second day collector, the drying efficiency were 29.41% and 1.89% at the mass-flow rate of 1.25 m/s. The mass-flow rate of air decreased with increasing collector and drying efficiency.

Key words: *solar dryer, system efficiency, collector efficiency in serpentine flow performance evaluation*

Introduction

The solar drying is an ancient method to preserve the food product in the low and moderate temperature. In this process the food products were prevented from spoiling due to climates condition, decaying from bacteria virus, *etc*., which can improve the quality and reduce the crop losses from the season plantation. Mint leaves are antiseptic, anti-asthmatic, refreshing and antispasmodic which is used as medicinal contains rich in calcium and phosphorus and sweet-smelling plant. It also helps in colds, poor digestion, and food poison and throat and sinus ailments [1]. The forced convection solar air heater was fabricated and the outlet of hot air left to room which act as room heater during the winter season. In this work, the highest second law efficiency was obtained during the experiment work. The efficiency is 9% during 8.00 a.m. and it increases to 85% at 14.45 p. m. and reduces to 40% at 16.00 p. m. at the mass-flow rate of 0.11 kg/s [2, 3]. The performance of triple pass solar air dryer was investigated. The moisture of sliced carrot was reduced from 87.5% to 10% in 6 hours at the mass-flow rate of 0.062 kg/s and thermal efficiency is 44% [4]. The experiment was conducted in prototype of glazed flat plate collector with sheet and tube roll-bond absorber plate with black coated and semi-selective coating. The efficiency was conducted under steady-state and quasi-dynamic condition. The efficiency of selective coating was 70.86% is high compare to standard coating was 69.34% [5]. The double pass solar air heater dryer integrated with paraffin wax based shell and tube heat storage unit was conducted with 20 kg of red chill was dried with final humidity of 9.7%. The

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weight is reduced to 14.1 kg in 35 hours in forced convection and 78 hours in open sun drying [6].The experiment conducted on indirect forced convection method integrated with phase change material. The blower connected with 0.035 m diameter pipe to flow air from collector to drying chamber. During dehydration using thermal storage process valeriana jatamansi medicine plant dries within 8 days with efficiency is 61.01% and under the shared drying process it took 14 day to dry plant with efficiency of shaded are 43.20% and 55.30% [7]. The experiment is conducted in novel indirect solar dryer using phase change material which consists of double pass *v*-corrugated plate as heat absorber. It found that after Sun set the temperature of drying air is greater the ambient temperature about 2.5 °C to 7.5 °C. As the result average temperature lies between 37.5 °C and 55 °C and the mass-flow rate is 0.0664 kg/s to 0.1204 kg/s [8]. The mint leaves was dried in two system forced and natural convection prototype solar air dryer with same dimension, where the drying rate in forced convection is higher than the natural convection and the effective diffusivity coefficient range lies between $1.2\cdot10^{-11}$ and $1.33\cdot10^{-11}$ m^2/s [9].

The main objective is to study performance of solar collector and system efficiency on galvanized iron sheet as heat absorber, characteristics of mint leaves under the forced convection drying.

Material and methods

The solar intensity radiation falls on the absorber plate which is constructed of galvanized iron sheet and its thermal conductivity 35 W/mK, emissivity is 0.28 and its absorptivity is 0.89. Solar collector is covered by 5 mm thickness glass sheet with absorptivity 0.84 is placed above the absorbing plate which increases the temperature between the glass and sheet. The galvanized iron tube of 18 mm diameter pipe id bonded below the absorbing sheet. The other end of galvanized iron (GI) tube is connected to drying chamber constructed with GI sheet. Polyethylene foam is used as insulation material with thermal conductivity of 0.033 W/mK. It is light weight, good vibration damping, high resistance in chemical reaction and good moister withholding, fig. 1 and tab. 1.

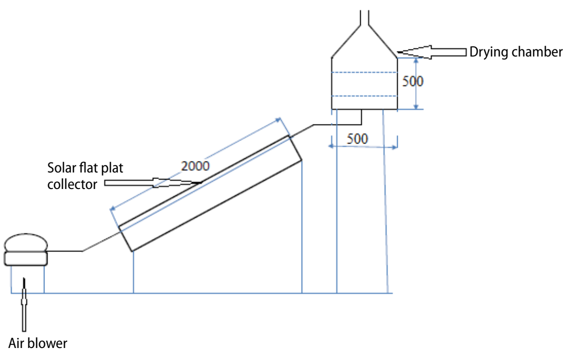

Figure 1. Schematic diagram of solar air dryer

Performance of solar dryer is evaluated with two different mass-flow rate of air by drying the mint leaves. During drying process, inlet and outlet temperature of air-flow inside GI tube and the inside cabinet temperature with different tray, quantity of product loaded, solar intensity, moisture in drying chamber and the wind flow were measure at time intervals in sunny day.

Instrumentation

The instrument selected for measuring temperature of inlet and outlet temperature of collector using HEATCON 8003/ USB Data-logger with accuracy of 1 °C. Regarding the solar intensity of radiation was measured by TES-1333 solar power with in accuracy of ±10 W/m^2. Six numbers of thermocouples are used to measure the temperature of different air-flow air in collector and in drying chamber, tab. 2.

Uncertainty analysis of experimental data

In order to establish the accuracy of experimental data, Uncertainty is required. It is based on precision and bias limits where precision error for each measured data is based on standard deviation as follows [10]:

$$U_B = \frac{\sigma}{\sqrt{n}}$$

where n is number of data and σ is the standard deviation:

$$\sigma = \sqrt{\frac{\Sigma(X - \overline{X})}{N}}$$

where X is athematic mean of measured data.

Table 1. Material selection and specification of solar collector and dryer

Element	Specification
Solar collector	Galvanized iron
Selective coating	Black paint
Dimension of collector	1 m × 2 m × 0.06 m
Absorbing tube	GI tube
Thermal conductivity of plate	35 W/mK
Density of plate	7850 kg/m^3
Glass cover emissivity/ absorptivity	0.88
Insulation	Polystyrene
Casing	GI sheet
Interbak duaneter	18 mm
Drying chamber	GI sheet
Dimension of chamber	0.5 m × 0.5 × 0.75
Insulation on thermal conductivity	0.06 W/mK

Table 2. Specification of measuring devices used in this study

Name of the device	Type	Accuracy	Percentage of error
Data logger	Type: HEATCON 8003/USB Eight channels. (Capable of recording temerature over a defined period of time	±1 °C	4.75%
Thermocouple	Type: K (A positive chrome wire and a negative alumel wire combination). It can measure up to 150 °C	±1 °C	0.4%
Solar power meter	Type: TES-1333	±10 W/m^2	0.38%
Digital hygrometer	Type: SG-Mart HTC-1 (capable to record humidity of air in chamber) Humidity range: 10%~99%PH	±5%RH	±1%

The bias error is assessed by fixed error magnitude and remains constant for experiment work, with mode of deviation from the mean assigned as bias error. The overall uncertainty is determined by each parameter (X) which is obtained from [10]

$$\frac{U_N}{X} = \sqrt{\left(\frac{U_B}{X}\right)^2 + \left(\frac{U_P}{X}\right)^2}$$

where U_p is total precision error which is included derives error and measurement error which was taken as 0.1 in this work. The uncertainty of experiment can determined using the temperature of inlet, outlet temperature intensity of solar radiation, efficiency of collector and drying chamber. The total value of uncertainty for calculated parameter such as inlet temperature, outlet temperature, and solar radiation, thermal efficiency of collector and system efficiency are about 0.974, 1.47, 41.023, 0.469, and 0.11%.

Experimental set-up

The pictorial diagram of solar collector is shown in fig. 2. The gross dimension of solar collector is 2 m × 1 m × 0.06 m. The solar collector is containing absorber plate with 1 mm thickness

Figure 2. Photographic view of experimental set-up

of Galvanized iron Sheet coated with black paint, which absorbs solar intensity of radiation. The drying chamber constructed from GI sheet with size of 0.75 m × 0.75 m × 0.75 m. The cabinet was insulated with foam sheet and covered by GI sheet and provide with two trays provided. The experiment performed in an indirect forced convection solar dryer installed at terrace of Mechanical Department of Engineering in Adhiyamaan College of Engineering Hosur, Tamil Nadu, India. The GI tube is bonded below the absorbing plate in serpentine flow direction. The inclined surface of collector is at angle of 22° with horizontal and place in north to south face direction to maximize exposure of solar radiation. To increase the temperature of air-flow 5 mm thick glass is placed above the absorbing plate. The air blower is connected at one end GI tube which air-flow inside in it, present below the collector and other end is connected to drying chamber. The mint leaves is dried in two days with two different mass-flow rate of air. The 1 kg of mint leaves as taken for drying kept on day during September, 2017. The drying was done at 35% initial moisture to 10% final moisture. The inlet temperatures, outlet temperature and surface temperature of solar collector, ambient temperature and solar radiation temperature were measured hourly intervals.

Data analysis

In many research paper the performance analysis of solar collector in define as the useful thermal energy to the sum of average incident solar radiation with same interval. The mathematical efficiency can expire by followed by Hottel-Whillier-Bliss equation reported by Duffie and Beckman [11].

$$\eta = \frac{Q_u}{A_c I_T} = F_R(\alpha\tau) - \left[\frac{F_R U_L \left(T_{p_o} - T_a\right)}{I_T}\right] \tag{1}$$

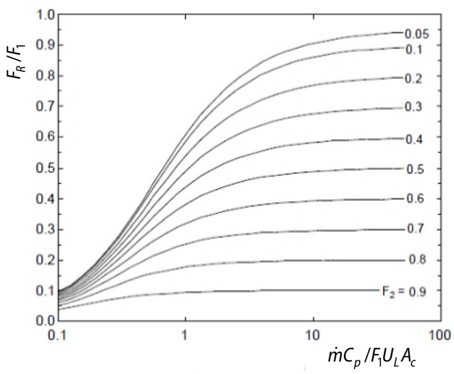

Figure 3. Chart for estimating heat removal factor FR for flat plat collector with serpentine tube by Abdel-Khalik [12]

where the collector heat removal factor, F_R, for the serpentine collector can be referred from the chart in figure and the F_2 on the x- and y-axis.

The F_R value was found in fig. 3. The value of $(\dot{m}C_p/F_1U_LA_c)$ taken along x-axis. The value of F_2 calculated and corresponding vale the curve has chosen, the intersection line from x-axis and the curve is drawn in horizontal that's value is:

$$\frac{F_R}{F_1} = 0.64 \tag{2}$$

The F_1 value is known. Then F_R is 0.65.

Collector overall heat loss transfer coefficients

The overall heat transfer coefficient [$Wm^{-2}K^{-1}$] is found by sum of heat loss of top, bottom and the edge loss [13].

$$U_L = U_B + U_T + U_E = U_T + U_B \equiv U_T + \frac{K_i}{D} \tag{3}$$

Due to insulate in edge and bottom U_B and U_E are neglected. The equation for U_T was developed by Klein and followed by Hotel and Woertz as:

$$U_T = \left[\frac{\frac{1}{N_g}}{\frac{C}{T_{P_o}}\left(\frac{T_P - T_a}{N_G + f}\right)^{0.33} + \frac{1}{h_w}} \right] + \left\{ \frac{\left[\sigma(T_{p_o}^2 + T_a^2)(T_{P_o} + T_a)\right]}{\frac{1}{\varepsilon_P + 0.05N_g(1-\varepsilon_P)} + \frac{2N_G + f - 1}{\varepsilon_g} - N_G} \right\} \tag{4}$$

where

$$f = (1 + 0.04h_w + 0.0005h_w^2)(1 + 0.091N_g) \tag{5}$$

$$C_{\text{air}} = 365.9(1 - 0.00883\beta + 0.0001298\beta^2) \tag{6}$$

The convective heat transfer, h_w, is depend on the wind flow over the surface of the collector. Then it become:

$$h_w = 2.8 + 3.0V \tag{7}$$

where V [ms^{-1}] in velocity of the wind and the unit of h_w is [$Wm^{-2}K^{-1}$]. The average value of heat transfer coefficient is 5.8 W/m^2K and 6.11 W/m^2K for mass-flow rate of air during 0.75, 1.25 m/s from eq. (9). The β is the solar collector tilt 20° and σ is Stephan Boltzmann constant.

For laminar flow $Re_D < 2100$ the Nusselt number I for flow in tube is estimated:

$$\text{Nu}_i = \frac{h_{f,i}D_{h,j}}{kf} = 3.6 \quad (i = 1,2 \; j = 1,2) \tag{8}$$

where $D_{h,j}$ is equivalent hydraulic diameter

Dryer efficiency

System efficiency indicates the total performance of system including collector efficiency and drying chamber efficiency.in this paper forced convection is taken in account using fan. The system efficiency written:

$$\eta_S = \frac{m_w L_w}{IA + p_f} \tag{9}$$

where the quantity of water can is calculated [14] is given:

$$m_w = \frac{m_p(M_i - M_f)}{100 - M_f} \tag{10}$$

where m_p is mass of dried product, M_i and M_f is the initial and final moisture of food product. The L_w is latent heat of evaporation of water, p_f is power developed by pump.

Result and discussion

The performance of solar dryer was conducted with two different mass-flow rates. The collector was fixed in angle of 22° which is facing to north and south direction in mechanical engineering department at Adhyiyamaan College of Engineering Hosur. The maximum solar radiation fall on top of collector, this is covered with glass of 5 mm thicknesses and the GI tube of 18 mm is fixed below the absorber plate in which air is flowed in it and heat is absorbed from collector plate. The measuring parameter where noted such as the temperature of air-flow out from collector, ambient temperature, drying chamber temperature, surface temperature, solar radiation, relative humidity, and drying chamber humidity. These values are employed for calculating the performance of solar dryer.

The experiment was conducted on drying the mint leaves at different mass-flow rate of air (0.75 and 1.25 m/s). During the experiment the solar radiation ranged from 524 to 1075.3 W/m^2, the outlet temperature of collector was 310 to 334 K, and average wind velocity was 08 to 1.31 m/s, respectively. The collector efficiency ranged from 29.54% to 31.28% with the average value of 30.33%.

The test was conducted at clear day in month of September. Figure 4 shows the temperature of different position inlet, outlet of collector, ambient and surface temperature of collector. The fig. 5 solar radiation and the wind flow above the surface of collector. Using blower the air is flow inside the tube with flow rate at 0.75 m/s which is kept constant in first day. The inlet temperature, outlet temperature of collector and surface temperature was notes with periodically from 9.30 a. m. to 5.00 p. m. using temperature indicator with K-type probe.

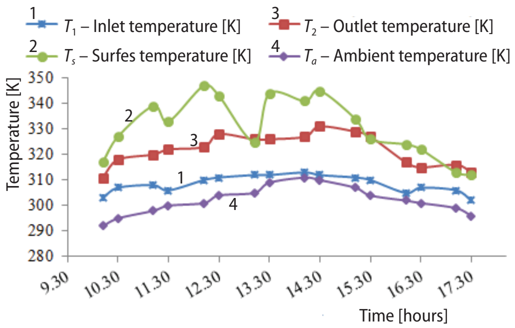

Figure 4. Variation of ambient temperature at 0.75 m/s flow rate

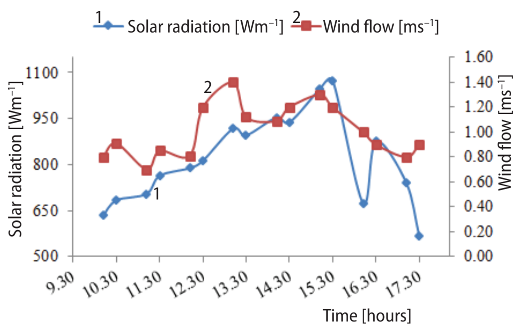

Figure 5. Variation of solar radiation and wind flow at 0.75 m/s flow rate

The variation of inlet air temperature, outlet air temperature, and surface temperature of solar collector, surface wind flow and solar radiation for typical experiment are noted with time intervals were shown figs. 4 and 5. The average outlet temperature of solar flat plate collector is 321.8 K, similarly the ambient temperature is 302.1 K, the wind flow on the surface of collector was 1.0133 m/s and solar radiation was 817.33 W/m^2. The decrease in temperature is due to decrease due to fall of solar radiation which cause heat loss in solar collector.

The variation of moisture content during the drying the mint leaves with different mass-flow rate of air is relative humidity varied from 64% to 10%. During the experiment the maximum temperature is 344 K, the solar radiation is 954 W/m and wind flow over the surface is less. So there is maximum temperature obtained during the outlet of solar collector. When solar radiation fall on the glass plate, due to this, air-flow in GI tube is heated and hot air is come out from collector and delivered to drying chamber. Thus collector is working at high efficiency with low heat loss and extract more heat energy from it. The drying rate increase with increasing more solar intensity of energy.

About 1 kg of mint leaves was taken for drying purpose, finally after 5.30 hours the relative humidity reached at 10% and the weight of mint leaves were reduced to 0.350 kg. The efficiency was calculated and shown in fig. 6. The maximum efficiency is 31.37% during 2 p. m. and minimum efficiency is 29.15% at high effective area which made to increase the heat removal factor F_R. Value was 0.65 was taken from chart shown in fig. 3. Similarly 0.420 kg mint leave is obtained during 1.25 m/s mass-flow rate air.

In fig. 7 show the variation of inlet, outlet, surface and ambient air temperature of collector for next day at mass-flow rate of air (1.25 m/s). In this average inlet air temperature lies 310.5 K, the outlet temperature of collector is 325 K. The ambient temperature is 302.1 K at 1.065 m/s with the average wind velocity on the surface of collector. During the process the maximum outlet temperature of collector lies is 334 K at 1.30 p. m. with the solar radiation is 860 W/m during clear sky, fig. 8. During this the system efficiency was 2.31%. Due to more solar intensity of radiation and the wind flow is less at 0.98 m/s is show in fig. 9. The minimum collector efficiency is 27.45% at 11.00 a. m. with system efficiency 2.43%. The average collector efficiency is 29.38% and the system efficiency is 1.89%.

In figs. 10 and 11 show the variation of instantaneous collector efficiency *vs.* reduced temperature parameter $(T_i - T_a)/I_T$ for air with various two types flow rates representing experi-

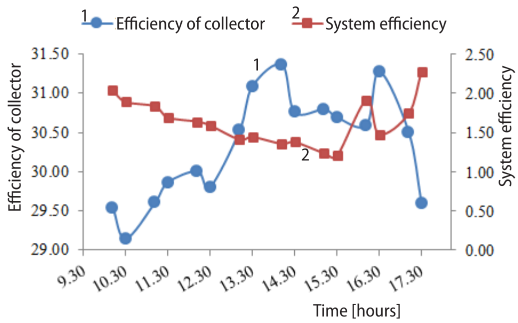

Figure 6. Thermal efficiency and system efficiency at air-flow rate of 0.75 m/s

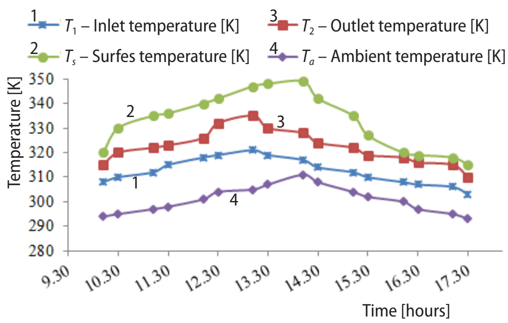

Figure 7.Thermal efficiency and system efficiency at air-flow rate of 0.75 m/s

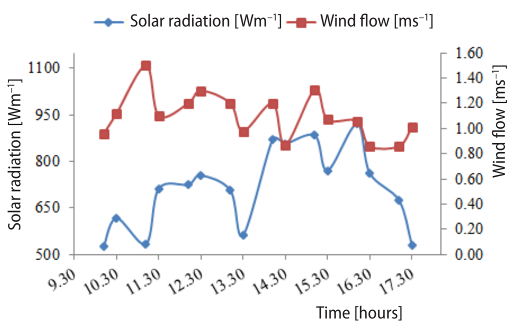

Figure 8. Variation of solar radiation and wind flow at 1.25 m/s flow rate

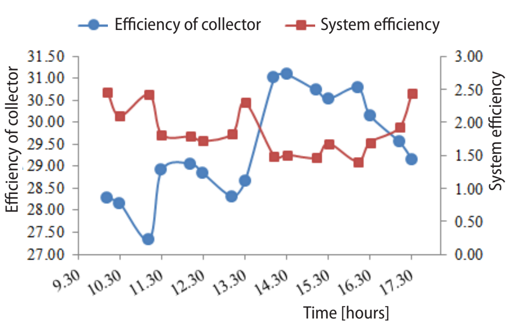

Figure 9. Thermal efficiency and system efficiency at air-flow rate of 1.25 m/s

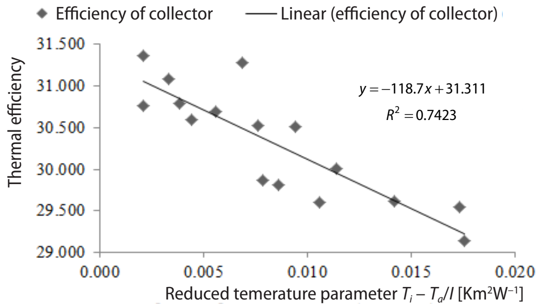

Figure 10. Thermal efficiency and system efficiency at air-flow rate of 1.25 m/s

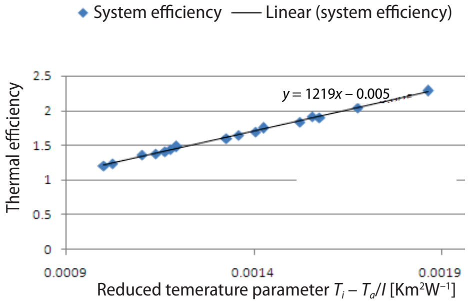

Figure 11. Thermal efficiency of air-flow rate of 0.75 m/s

mental and theoretical analysis, respectively. The experimental and theoretical data which have all the flow rates are fitted with linear trend line equations for describing characteristic parameters of solar air collector. It seem that air-flow in 0.75 m/s gives maximum efficiency of 30.2% for experimental study whereas 31.75% in case of theoretical analysis. Slimily that air-flow in 1.25 m/s gives maximum efficiency of 30.5% for experimental study whereas 31.8% in case of theoretical analysis. The experiment was conducted to dry valeriana jatamansi thus the moisture was dried from 89% to 9%, the valepotriates obtained is 3.47% in solar pump drying system and 3.31% in share drying process. These systems obtain this efficiency using phase change material [7]. But in my present work the system efficiency 1.63% at 1.25 m/s flow rate and 1.98% during 0.75 m/s flow rate. The efficiency is increase with decrease the flow of air-flow rate.

Conclusion

In this present work the system efficiency was investigated to dry the mint leaves. Forced convection solar air dryer was fabricated with heat absorber sheet with galvanized iron tube. Drying experiment carried out with 1 kg of mint leaves taken for drying process under the different mass-flow rate of 0.75 m/s and 1.25 m/s in serpentine flow of air. Performance of the collector and system efficiency were 30.33% and 1.63% in first day at 0.75 m/s mass-flow rate and in the second day collector and drying efficiency were 29.41% and 1.89% at the mass-flow rate of 1.25 m/s. The mass-flow rate of air decreased with increasing collector efficiency and decreasing in system efficiency. The flow rate of air increase thus reduces the collecting efficiency with increasing the system efficiency. But the system efficiency depends on the maximum time to reduce the initial to final moisture in the mint leaf. If the flow rate is increase the system efficiency is reduces. If the increasing the length of serpentine tubes in the collector will increase the maximum temperature of air which can be used to increases the system efficiency. After all this work can put forward extension of renewable energy based drying technology in the field of drying so that small scale farmers can be economically benefited.

Nomenclature

A_c – area of collector, [m^2]
C_p – specific heat of air, [kJkg^{-1}K^{-1}]
D – outer diameter of copper tube, [m]
F_R – collector heat removal factor
h – heat transfer coefficient, [Wm^{-2}K^{-1}]
h_w – wind heat transfer coefficient, [Wm^{-2}K^{-1}]
I – solar radiation, [Wm^{-2}]
k – thermal conductivity, [Wm^{-1}K^{-1}]
L_v – latent heat of vaporization
M_f – final moisture content
M_i – initial moisture content
m_p – mass of the product
m_w – mass of water content removal, [kg]
$\dot{m}$ – mass-flow rate of air, [kgs^{-1}]
N_g – number of glass cover
p_f – fan energy delivered to solar dryer in time

Q_u – use full heat flux, [kJkg^{-1}K^{-1}]
T_a – ambient temperature, [K]
T_i – input temperature, [K]
T_p – plate temperature, [K]
U_B – bottom loss, [Wm^{-2}K^{-1}]
U_E – edge loss coefficient, [Wm^{-2}K^{-1}]
U_L – overall loss coefficient, [Wm^{-2}K^{-1}]
U_T – top loss, [Wm^{-2}K^{-1}]
V – velocity of air, [ms^{-1}]

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