JOURNAL OF RENEWABLE ENERGY AND SMART GRID TECHNOLOGY

Vol. 19, No. 2, July-December 2024

Thermal Evaluation of Solar Dryer's Curve-Front utilized Heat Transfer Analysis

Sriwichai Susuk[1*], Natsacha Inchoorrun[2], Weerayuth Promjan[2], Khanittha Chawananorasest[3], Soravit Jamjumroon[4]

[1]Biodiversity Research Center, Research and Development Group for Bio-Industries, Thailand Institute of Scientific and Technological Research (TISTR) 12120

[2]Expert Center of Innovative Health Food, [InnoFood], Research and Development Group for Bio-Industries, Thailand Institute of Scientific and Technological Research (TISTR) 12120

[3]Expert Center of Innovative Herbal Products, [InnoHerb], Research and Development Group for Bio-Industries, Thailand Institute of Scientific and Technological Research (TISTR) 12120

[4]Expert Center of Innovative Agriculture, [InnoAg], Research and Development Group for Bio-Industries, Thailand Institute of Scientific and Technological Research (TISTR) 12120

***Corresponding author's email**: sriwichai@tistr.or.th

Article info:

Received: 11 July 2024
Revised: 2 September 2024
Accepted: 13 October 2024
DOI:
10.69650/rast.2024.257468

Keywords:

Renewable Energy
Natural Convection
Laminar Flow
Solar Radiation
Heat Transfer Coefficients

ABSTRACT

The sun is most sustainable renewable energy, environmentally friendly and utilized for preservation of food and agricultural crops. The main objective of this experiment research work has focused on using renewable energy for evaporated moisture of foods fruit vegetables and herbs by drying system. The heat transfer equation are analyzed to effectively harness the temperature from the sun. Experimental data obtained were used to evaluate the properties of dry air on boundary region condition. Initial, testing was carried out under without load condition, and the result shows that the ambient and dryer's internal temperature range between 29.3-40.2˚C and 37.4-60.3 ˚C, respectively, in Thailand a latitude of 14°0'48.46" North and longitude of 100°31'49.76" East (recorded average solar radiations and temperature on January 2023 - June 2024), average solar radiations range between 312 W/m^2 and 513 W/m^2. The indirect natural convection was design and calculated energy base on average temperature not higher than 55˚C, utilized sun daylight at 08:00 a.m. to 04:00 p.m. local time and clear sky or partially cloudy. Second, determination of design parameters; heat energy equation and steam table analysis. Final, utilization of the design under local time, solar radiation and the climatic local conditions and test with ginger slices (represent product in order to examine weight loss). The solar dryer's curve front shape conduced on without load showed the heat transfer coefficient natural convections range between 3.7 and 4.5 W/m^2 ˚C, the energy of dry air analysis range between 54.7 and 155.2 J/s and performance of drying rate range between 0.06 and 0.82 g/s, under increasing and decreasing trends of solar radiations from the time, date and climatic local region condition.

1. Introduction

Concerns over fossil fuel impacts on climate, energy cost, and the need to minimize post-harvest losses, the fossil, which take more millions of years to fuels form, are being depleted faster than they are produced, leading to climate change like air pollution, and water contamination [1]. Solar radiation is the most common economical and environment friendly for preservation of agricultural crops and food. Because of continuous nuclear fusion taking place in its core. It is an essential process utilized all over the world for preservation of food and agriculture product, sun is the oldest preservation technique of those. Solar drying can simply be analysis as an elaboration of sun drying. As an alternative to open sun drying, with possibility of improved post-harvest that is sustainable for increased drying, free of energy and without any danger to the environment. Solar drying system have added advantages of savings cost, energy, time and space requirement during drying operations. It's also form a sustainable renewable energy resource that has a great potential for applications because it is abundant and accessible. It's overcome the drawbacks of open sun drying such as contamination from foreign material and infestation by insect birds and other animals, lack of control over heat drying condition, bring structural and physical changes in the product. The solar energy drying offers an alternative which can be preserved food and agricultural crops in clean and sanitary condition. Drying is commonly described as the operation of the process of removing excess moisture from products to meet standard specifications, which exerts a vapor pressure less than that of bound moisture, this process requires a certain amount of energy, The solar dryers are classified into two major groups, namely; an active solar-energy drying system and passive solar-energy drying system. Both the heat energy required for removing the moisture as well as the energy source necessary for driving the dry air flow are generated in the most cases by solar energy only.

The heat transfer on dryer depends on the operating parameter of heat transfer coefficient and dry air flow character. Heat transfer take place cover between solid and fluid surrounding it, and fluid move due to action of forces base on buoyancy regime called natural convection else it is forced convection, generally heat transfer coefficient natural convection are much smaller than forced convection. The temperature difference between surface and surrounding are important in the investigation [2-3].

The objective of this paper is to estimate the ability of solar dryer's curve front indirect mode used energy equation and compare the result with the experimental ones. An analysis of solar radiation at several main agriculture form in Thailand shows that solar radiation is possible to use in solar drying, traditional method are under the open sun drying with not so much reduction of moisture content and slowly even under condition high humidity. An alternative to the traditional techniques and contribution towards the solution of these problems could be using solar dryer. The objective of solar dryer's curve front was design and calculated energy base on the collector tilt for average collection of incident solar radiation for all year round operation of a collector is to be taken as the latitude of the site where it is located in practice (Tambon Khlong Ha, Amphoe Khong Luang, Pathum Tani, Thailand). Solar radiation, temperature inside dryer and ambient are measured to provide a understanding of the flow due to heat transfer by natural convection in the dryer, utilize design process to achieve product quality longer safe storage and reduction in an herb losses, temperature not higher than 55˚C for prevented nutrient and volatiles components of generally fruit vegetables and herbs. Focus on utilize renewable solar radiation on January 2023-July 2024 at 08:00 am to 04:00 pm local region. All experiments were conducted under climatic condition (a latitude of 14°0'48.46" North and longitude of 100°31'49.76" East), testing were carried out on solar drying of ginger slices (represent product in order to examine weight loss, 120 hours on July 2024) compare with heat transfer equation for ensure design's optimization utility.

2. Experimental detail

2.1. Description of solar dryer

Gross dimension of this solar dryer's curve front shape consists of the dimension of curve length approximately 1.885 m width 0.91 m and height 1.2 m. It is covered with a transparent material (Polycarbonate-bright white color plate) 6 mm thick, the materials that are easily obtainable from the local market. Fig. 1 shows the schematically of the prototype of solar dryer which consists of main contracture made by steel. The tray made by stainless steel 5 plates dimension was 0.8m x 0.8m x 0.8 m., area collector approximately 1.72 m^2 and volume approximately 1.03 m^3. It's capacity to accommodate 10 kg of material per batch. The air flowed enters dryer inlet at bottom and leaves upper side (exhaust).

2.2. Experimental set-up

The temperature profile of the dryer was calculated by measuring the hourly thermometer., testing under no load conditions (Fig.1) were carried out recorded measuring the hourly temperature, humidity, solar radiation and air velocity by Solar power meter model SM206-SOLA, Anemometer model CBzSGHJ001, Temperature & Humidity model L563A, Temperature model TM 1803 ,Weighting scale model VIGO and Moisture meter model OHAUS MB23. Experimental studies set-up under no-load and then drying test consists of the ginger slices 25 kg 82% to 12.5% wet basis (ginger moisture content of about 83% w.b.) [4], average temperature were measured about 9 hours per day, (Fig. 2) the small-scale system used in this study for dry-air process, experiment analysis sampling weight of the ginger slices at 08:00 a.m. to 04:00 p.m. local time in Thailand a latitude 14°0'48.46" North and longitude 100°31'49.76" East.

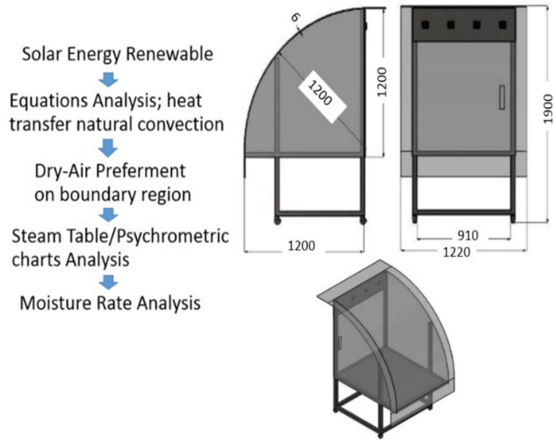

Fig. 1 Solar dryer's curve front and flow chart design.

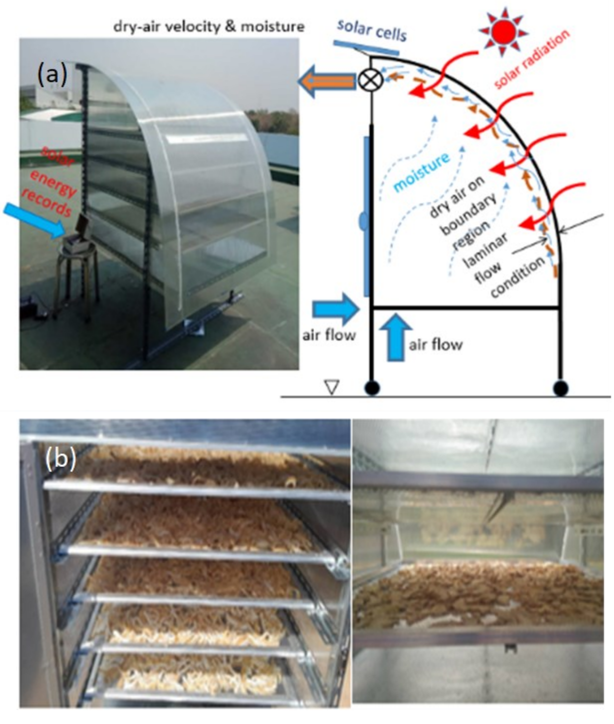

Fig. 2 (a) Experimental setup solar radiation record and (b) Experimental setup test load.

3. Equations and mathematics analysis

3.1. Mathematical equation analysis

Mathematical equations governing natural convection flow base on dimensionless quantities have been identified and utilized in correlations involving the heat transfer in solar dryer's curve-front shape (boundary condition) and energy equations. Major problem in heat transfer is the analysis of heat transfer coefficients to be used for design purposes, values of heat transfer coefficients (h_c) must be determined from the properties of the gas, fluid and the geometry of the system. The equations that describe different systems having similar characteristics can be superimposed on each other to form a single expression suitable for all systems. The following dimensionless quantities have been identified and used in correlations involving the heat transfer coefficient equation (3)-(8). The governing mean collector efficiency range of 30-50 % (*Sodha et al.,1987*) under assumptions as followed according to equations [5-7].

3.2. Equation of dimensionless

Nusselt Number (Nu)

$$N_u = 0274R_a^{1/4} \text{ ; for } 10^5 < Ra < 10^{10} \quad (1)$$

Rayleigh Number (Ra)

$$R_a = P_r \times G_r \quad (2)$$

Grashof Number (Gr)

$$G_r = \frac{d^3 g\beta\rho^2 \Delta T}{\mu^2} \quad (3)$$

Reynolds Number (Re)

$$R_e = \left(\frac{N_u}{0.664P_r^{1/3}}\right)^2 \quad (4a)$$

$$R_e = \frac{L.v.p}{\mu} \quad (4b)$$

Prandtl Number (Pr)

$$P_r = \frac{C_p\mu}{k} \quad (5)$$

Peclet Number (Pe)

$$P_e = R_e \times P_r \quad (6)$$

Heat transfer coefficient (h_c)

$$h_c = \frac{kN_u}{L} \quad (7)$$

Blasius's numerical solution for boundary-layer thickness

$$\delta = \frac{4.64L}{R_e^{1/2}} \quad (8)$$

3.3. Equation quantity of dry-air

Drying is the process of removing a liquid from a solid through evaporation (moisture). Mechanical methods for separating a liquid from a solid are not generally called drying

$$C_v = 999.2 + 0.1434T_i + 1.101\times10^{-4}T_i^2 - 6.7581\times10^{-8}T_i^3 \quad (9)$$

$$\mu_v = 1.718\times10^{-5} + 4.620\times10^{-8}T_i \quad (10)$$

$$K_v = 0.0244 + 0.6773\times10^{-4}T_i \quad (11)$$

$$\rho_v = \frac{353.44}{(T_i + 273.15)} \quad (12)$$

3.4. Energy of thermal collector

The energy input of the solar thermal collector can be determined equation:

$$E_i = I \times A \quad (13)$$

$$\eta_c = \frac{E_0}{E_i} \times 100 \quad (14)$$

$$\dot{q} = \dot{m} \times C_v \times \Delta T \quad (15)$$

$$\dot{q} = h_c \times A \times \Delta T \quad (16)$$

$$P_A V_A = m_a R_A (T + 273.15) \text{ Gas Laws, temperature in Kelvin} \quad (17)$$

$$P_S V_W = m_W R_W (T + 273.15) \text{ Gas Laws, temperature in Kelvin} \quad (18)$$

$$m_W / m_a = 0.622P_s / (P - P_s) \text{ Ps = enthalpy; saturate analysis} \quad (19)$$

The majority of energy consumed during drying is due to the evaporation of liquid water into vapors (2.258 MJ/kg at 101325 Pa), with an average specific heat capacity of 1.97 kJ/kg˚K. A phenomenon characterized by the separation of a liquid from a solid via evaporation; mechanical methods for separating a liquid from a solid are not commonly termed drying. Water can be present in the solid in a variety of forms, including free moisture and bound form, which has a direct effect on the drying rate. These ideas are generally applicable to mechanical conventional drying, but are particularly relevant to solar drying in this context. However, in general, conventional drying principles and occurrences are unaffected by the sort of energy used. [8-11].

4. Results and Discussion

4.1. No load test; definition of system (max. performance of dryer)

The first results described previously of prototype solar dryer's curve front shape utilized renewable energy source of heat energy continuously changed from hour to hour depending upon the time and sky cover of the day consequently so difficult to control. Preliminary evaluation, the air is a gas as if medium that can absorbed moisture facilitate from food or agriculture products during the drying process by using solar dryer (heats up the air within the collector, rising its temperature and increasing vapors pressure thus reducing its relative humidity) [12]. The information used for evaluation of the system are presented in Table 1-2. The general trend in the profiles of solar radiation and temperatures obtained shown increases from 09:00 a.m. to between 01:00 p.m. and 03:00 p.m. than decrease, on the other hand relative humidity decrease from 09:00 a.m. to between 01:00 p.m. and 03:00 p.m. local time, than increase, tested without trays and with no load. The hourly variation of the incident solar radiation is shown Fig. 3. During the period of test from 312 - 513 W/m^2. It is clearly seen that the dryer is hottest about mid-day when the sun is overhead.

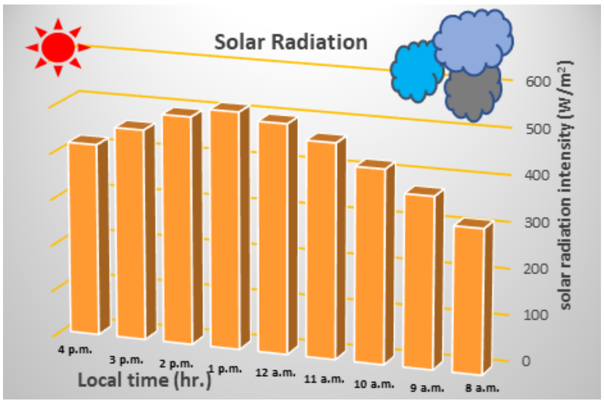

Fig. 3 variation of solar radiation and temperate.

Table 1 Variation of solar radiation and temperature: avg. 18 months.

Time	8:00 a.m.	9:00 a.m.	10:00 a.m.	11:00 a.m.	12:00 a.m.	1:00 p.m.	2:00 p.m.	3:00 p.m.	4:00 p.m.
Solar radiation (W/m^2)	312	371	419	465	497	513	494	456	416
Average ambient temperature.T_{am} (°C)	29.3	32.8	35.9	37.3	39.2	40.2	39.4	37.7	36.3
Average temperature. T_i (°C) inside dryer	37.8	43.8	48.9	54.2	56.8	60.3	57.8	53.7	46.3
%R.H. ambient outside dryer	52.2	46.7	44.1	40.0	39.9	36.2	38.0	39.5	42.6
%R.H. in dryer no load test	32.6	28.7	26.8	24.3	23.5	20.5	21.9	23.1	25.4

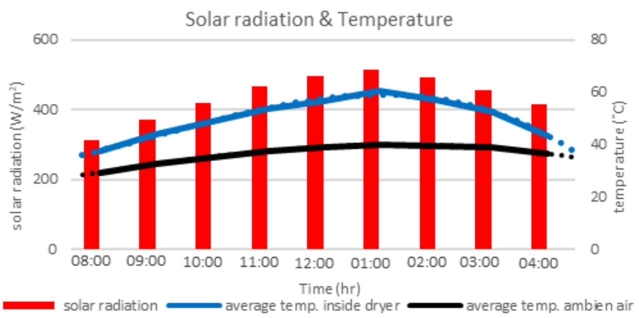

Fig. 4 Variation of solar radiation and temperature.

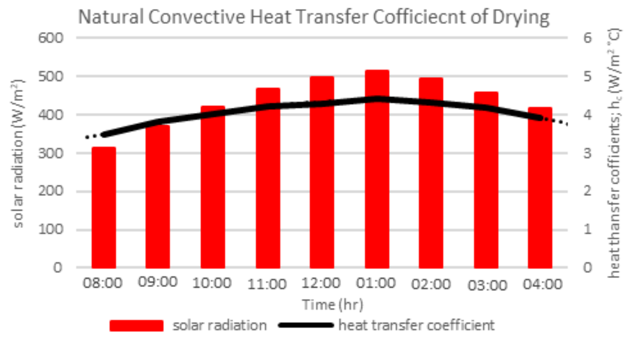

Fig. 5 Variation of natural convective heat transfer.

The maximum solar radiation is observed at around 01:00 p.m. local time, 497 to 513 W/m^2 and average 438 W/m^2 respectively (the dryer is hottest about mid-day when the sun is overhead). While, ambient and inside dryer temperatures varied from 29.3 to 40.2˚C and 37.3 to 60.3˚C respectively. Fig. 4, average temperature inside dryer 50.5˚C, which is in the range proposed fruits, herbs and vegetables [13]. It is also seen the inside dryer higher than ambient temperature during most hours of the day-light, this indicates prospect for better performance than open air drying.

The hourly variation of the heat transfer coefficient of drying in Fig. 5. The values very heat transfer coefficient natural convections are found to be 3.7 and 4.5 average approximately 4.2 W/m^2˚C respectively. It can be indicated that the drying system is high or low level dependent on the solar radiation and the temperature effect also. The high heat transfer coefficient can achieve high energy shown Fig. 5, with it can achieved more volume of dry-air lead to dehumidification (moisture removed out of dryer) shown Fig. 6. This is clearly seen that the maximum heat transfer coefficient similar solar radiation and temperature at around 01:00 p.m., the hourly variation of the mass flow rate (dry-air and water removed). Fig. 7 It was observed that energy highest in dryer can be dried faster at around 01:00 p.m. because the mass flow rate is strongly dependent on the solar radiation effect and the temperature. The effect of dry-air and water rate increase as heat transfer efficiency increase also, this clearly reveal the drying system dependent on solar radiation temperature, and heat transfer efficiency. The energy of dry-air between 54.7 and 155.2 J/s and energy of water (moisture) between 1.02 and 32.37 J/s. respectively.

The hourly variation of thermal (collector) efficiencies on the drying system. It increases as the solar radiation increases Fig. 8. This clearly reveals the dependence of the dryer performance on the solar radiation and temperature through the system. The efficiency of the solar dryer during the period of test was between 17.4 and 30.3 % [14] similar previously figure at 01:00 p.m. highest efficiency.

Table 2 Parameters condition for dry-air analysis.

Item	Average	Units	Equation
C_v	1006.8	J / kg ˚C	9
μ_v	0.0000195	kg/m.s	10
K_v	0.0278	W/m˚C	11
ρ_v	1.093	kg/m^3	12
β	0.003085	1/°K	-
I	438.1	W/m^2	measurement
P	101325	Pa	standard
T_i	51	°C	measurement
T_{am}	36.5	°C	measurement
L	1.885	m	-
A	1.72	m^2	-
Ei	605.2	W	12
g	9.81	m/s^2	standard
RA	287.1	J/kg°K	standard
V	1.03	m^3	-
Nu	235	dimensionless	1
Ra	6x10^9	dimensionless	2
Gr	9x10^9	dimensionless	3
Re	2x10^5	dimensionless	4
Pr	0.706	dimensionless	5
Pe	161365	dimensionless	6
v	2	m/s	1,4
h_c	4.2	W/m^2°C	7
δ	0.018	m	8

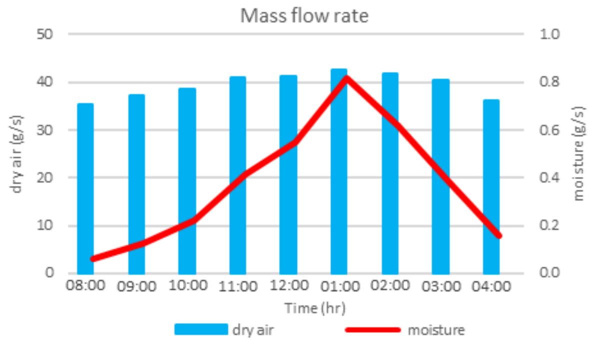

Fig. 6 Variation of mass flow rate (dry-air and moisture).

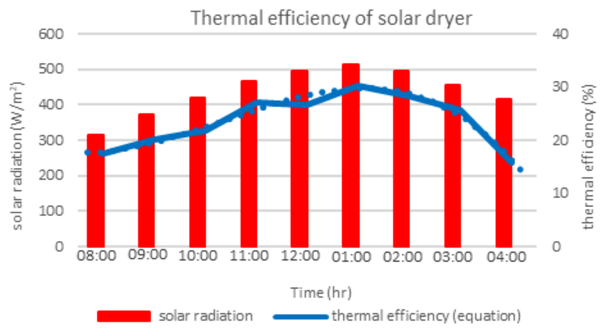

Fig. 8 Variation of thermal efficiencies (collector).

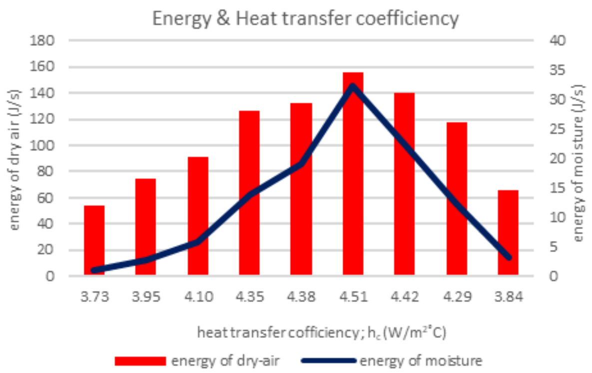

Fig. 7 Variation energy of dry-air and moisture versus heat transfer efficiency.

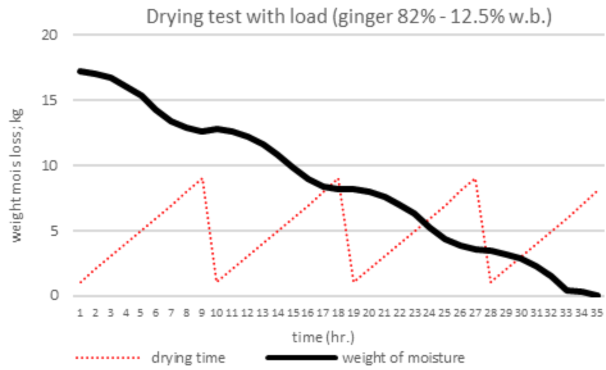

Fig. 9 Variation of experiments ginger slices drying.

Table 3 Evaluation performance of solar dryer according to standard steam table/psychometric chart and test with product (ginger slices).

Time	08:00 a.m.	09:00 a.m.	10:00 a.m.	11:00 a.m.	12:00 a.m.	01:00 p.m.	02:00 p.m.	03:00 p.m.	04:00 p.m.
Solar radiation (W/m²)	312	371	419	465	497	513	494	456	416
Average ambient temperature. T_{am} (°C)	29.3	32.8	35.9	37.3	39.2	40.2	39.4	37.7	36.3
Average temperature. T_i (°C), inside dryer	37.8	43.8	48.9	54.2	56.8	60.3	57.8	53.7	46.3
%R.H. ambient outside dryer	52.2	46.7	44.1	40.0	39.9	36.2	38.0	39.5	42.6
%R.H. in dryer no load test	32.6	28.7	26.8	24.3	23.5	20.5	21.9	23.1	25.4
Evaluation moisture removed; g/s	0.06	0.12	0.22	0.42	0.55	0.82	0.62	0.39	0.16
Energy of dry air (equation); J/s	54.7	74.9	91.7	126.5	131.9	155.2	139.2	117.4	65.6
Average temperature. °C, (test with load)	31.4	43.4	36.9	39.6	40.9	42.6	41.4	39.3	35.6
%R.H. (test with load)	31.3	41.9	49.6	56.3	59.4	63.3	60.6	55.7	45.7
Average moisture removed (test with load); kg/hr.	0.12	0.22	0.36	0.60	0.76	1.07	0.83	0.56	0.26

4.2. Test with load (ginger slices)

Compering the evaluation of mass flow rate between no load (maximum absorb moisture) and with load in order to verify performance all information, Experiments ginger slices were dried and the results obtained in drying a ginger slices sample, are shown in Fig. 9, It was observed that ginger slices products in dryer can be dried faster at around 01:00 p.m., testing were carried out drying of ginger slices 25 kg similar condition no load items. The test ginger slices spent drying time about 135 hours, beginning 82% was reduced to 12.5 % wet basis conditions. Weight loss or moisture rate between 0.12 and 1.07 kg/hr. according to Table 3.

5. Conclusions

The solar dryer's curve front process saves energy, time, occupies less drying area, improves product quality, it is very environment friendly and will enhance energy conversion. Both equation and experiment, simultaneously to ensure the utilization of drying system. A simple mathematical formulation was applied to evaluate the indirect passive solar dryer. In this design and experiment.

Practical way of comfortable movement, cheaply and sanitarily preserving fruit vegetables and herbs. items by carried out design and test system, use drying and had been demonstrated. It of the dryer does not require high technology and the maintenance cost is minimal. During the test, solar dryer had operated satisfactorily five hours between 10:00 a.m. and 01:00 p.m. local time, because of generated higher energy and performance effective transmittance of dryer (polycarbonate) lead to higher efficiency also. The experiment has provided useful information in drying process design for food, fruits, herbs vegetables and more agriculture which can assist in preservations. The dryer was tested and the following conclusions results obtained:

Maximum temperature of solar dryer's curve front shape was found to be 60.3 ˚C and average 50.5 ˚C (inside dryer) which interest is the temperature obtained in the prototype solar dryer, it optimum for drying fruits, herbs and vegetables. Heat transfer coefficient natural convections are found to be 3.7 and 4.5 average approximately 4.2 W/m^2˚C respectively obtained for buoyancy condition and the thermal efficiencies between 17.4 and 30.3 %, while a drying rate between 0.06 and 0.82 g/s (equation analysis).

Experiments were carried out drying of ginger slices 25 kg, weight loss or moisture rate between 0.04 and 0.36 g/s (0.12 and 1.07 kg/hr). Similar condition no load items. The information also revealed the weight of ginger slices decrease dependence on solar radiation and temperature through the system, the test ginger slices spent drying time average 34.5 hours. (08:00 a.m. - 04:00 p.m.)

Improvement in efficiency more than this design can add up solar collector or other renewable heat source utilized drying continuous during off-sunshine and the night time or rainy.

Acknowledgements

The research team would like to thank the Expert Center of Innovative Health Food, [innoFood] Thailand Institute of Scientific and Technological Research (TISTR) for supporting the budget, place, tools, and equipments for this research.

References

[1] Maundu, N. M., Kosgei, S. K. And Nakajo, Y., Design and Analysis of Solar Dryer for Mid-Latitude Region. *Energy Procedia*. 100(2016) 98 – 110, doi: https://doi.org/10.1016/j.egypro.2016.10.145.

[2] Çengel, Y. A. Heat transfer; A Practical Approach. 2nd edn., McGraw-Hill, 2002.

[3] Toledo, R. T. *Fundamentals of Food Process Engineering*. 2nd edn., Aspen Publishers, 1999.

[4] Olaoye, O. S. and Ogunleye, A. J., Experimental Study of Drying Parameters of Ginger at Different Temperature and Moisture Content. *European Journal of Engineering and Research and Science*. 3(9) 2018.

[5] Adelaja, A. O. and Babatope, B. I., Analysis and Testing of a Natural Convection Solar Dryer for the Tropics. *Journal of Energy*. (2013), doi: https://doi.org/10.1155/2013/479894.

[6] Mehmet, D., Erdem, A. and Ebru, K. A., Numerical and experimental analysis of heat and mass transfer in the drying process of solar drying system. *Engineering Science and Technology, an International Journal.* 24(1) (2021) 236-246, doi: https://doi.org/10.1016/j.jestch.2020.10.003.

[7] Houghton E. L., Carpenter, P. W., Steven H., Collicott, S. H. and Daniel, V. *Aerodynamics for Engineering Students*. 6th edn., Butterworth-Heinemann, 2013.

[8] Oko C. O. C. and Diemuodeke, E. O., Analysis of air-conditioning and drying processes using spreadsheet add-in for psychrometric data. *Journal of Engineering Science and Technology Review*. 3(1) (2010) 7-13, doi: https://doi.org/DOI:%2010.25103/jestr.031.02.

[9] Ji, Y. Y., Hee, J. K., Eun, J. W. and Chan, J. P., On Solar Energy Utilization for Drying Technology. *International Journal of Environmental Science and Development*. 8(4) 2017, 305-311, doi: https://doi.org/10.18178/ijesd.2017.8.4.968.

[10] Ekechukwu, O. V., Review of solar-energy drying systems I: an overview of drying principles and theory. *Energy Conversion and Management*. 40(6) (1999) 593-613, doi: https://doi.org/10.1016/S0196-8904(98)00092-2.

[11] Mujumdar, A. S. *Handbook of Industrial drying*. 4th edn., CRC Press; Taylor and Francis Group, 2007, doi: https://doi.org/10.1201/b17208.

[12] Eshetu, G., Mulugeta, A. D., Nigus, G. H., Solomon, W. F., Petros, D. and Maarten, V., Importance of integrated CFD and product quality modeling of solar dryers for fruits and vegetables: A review. *Solar Energy*. 220 (2021) 88-110, doi: https://doi.org/10.1016/j.solener.2021.03.049.

[13] Hussein, J. B., Hassan, M. A., Kareem, S. A, Filli, K.B.Design, Construction and Testing of a Hybrid Photovoltaic

Nomenclature

Nu	dimensionless	Nusselt Number
Ra	dimensionless	Rayleigh Number
Pr	dimensionless	Prandtl Number
Gr	dimensionless	Grashof Number
Re	dimensionless	Reynolds Number
Pe	dimensionless	Peclet Number
g	m/s^2	Acceleration due to gravity
β	1/°K	Coefficient of thermal expansion
ρ_v	kg/m^3	Density
ΔT	°C	Temperature difference
v	m/s	Velocity of air
δ	m	Boundary-layer thickness
μ_v	kg/m.s	Dynamic viscosity
L	m	Length
C_v	kJ/kg˚C	Specific heat of dry air, at constant pressure
C_{pw}	kJ/kg˚C	Specific heat of moisture 1.97, at constant pressure
K_v	W/m˚C	Thermal conductivity
T_i	°C	Temperature inside dryer
E_i	W	Solar energy
E_o	J/s	The rate of energy collection
t	s	Time
I	W/m^2	Incident insolation
A	m^2	Total collector area
η_c	%	Thermal efficiency
m_w	g	mass of water to be dried
h_{fg}	kJ/kg	Latent heat of water vaporization
T_{am}	°C	Ambient temperature
V_a	m^3	Volume of dry air
V_w	m^3	Volume of vapors
m_a	g	Mass of air
P	Pa	Pressure
P_s	Pa	Pressure of steam
R_A	J/kg°K	Gas constant t = 287.1
R_w	J/kg°K	Moisture constant = 461.5
$\dot{q}$	J/s	Energy, rate of heat flow
h_c	W/m^2°C	Convective heat transfer coefficient