Performance Evaluation of Solar Radiation for Food and Agriculture Dryer

Sriwichai Susuk[1]*, *Weerayuth* Promjan[1], *Natsacha* Inchoorun[1], *Rewadee* Meesat[1], *Wannee* Suttivattanavet[1], *Kusol* Iamsub[2], and *Soravit* Jamjumroon[2]

[1]Expert Center of Innovative Health Food (innoFood), Research and Development Group for Bio-Industries, Thailand Institute of Scientific and Technological Research (TISTR), Pathumtani, Thailand
[2]Expert Center of innovative Agriculture (innoAg), Research and Development Group for Bio-Industries, Thailand Institute of Scientific and Technological Research (TISTR), Pathumtani, Thailand

Abstract. This paper is attempt to utilize the solar radiation in a solar dryer for saving the day-light, energy, and environment. Solar dryer was designed based on thermal analysis heat transfer equations, then it was constructed and tested in Thailand (on a latitude 14ºN. and longitude of 100ºE). The main three stages were carried out in order to test solar dryer performance. Initially, solar energy consumption data was recorded from 8:00 a.m. to 5:00 p.m., then thermal analysis without load condition was conducted and and tested with fresh fruit sample. In the final stage, the data was compared with an electrical oven. Recording results for the system showed that the solar energy consumption was 313 W/m^2 - 493 W/m^2 (horizontal irradiance), ambient temperature was at 29.5 ºC - 40.3 ºC, and relative humidity was at 36.2% - 52.2%, respectively. The calculated thermal energy of solar dryer was approximately 41 m^3/h with the rate to remove moisture content out of the system at 0.21 kg/h in average. The average temperature inside the dryer is 47.4 ºC. According to the Psychrometric chart, the constant volume is approximately 0.92 m^3/kg. Experimental drying test with fresh fruit in the solar dryer showed that a moisture content of fresh fruit was recorded to be at 81.2% and reduced to 8.4%. Comparatively, under the similar temperature condition, drying with electrical oven is faster for dehumidifying than solar dryer about 21%. However, solar dryer is considered to be more environmentally-friendly than electrical oven. It is also found that the result showed no more differences in dehumidity when testing with the other agricultural samples at the similar drying rate. The results also revealed CO_2 mitigation through a solar dryer system was 2.6 kg/day, energy-saving was 5.63 kWh/day. Therefore, solar dryer system is demonstrated to be an alternative saving sustainable method for all.

Keyword. CO_2 mitigation, Dry-air, Electricity-oven, Environmentally-friendly, Heat transfer coefficient, Solar dryer

1 Introduction

Concerns over climate change energy and food security are among the current major challenges in the global perspective. The need to minimize the utilization of fossil fuels as a mitigation measure in curbing the extent of greenhouse gas emission has brought about extensive research on renewable energy applications [1]. Solar energy is a clean energy source that is very popular, especially in drying process. The sun is the primal energy producer of our solar system and energy is generated. A small fraction of the energy produced by radiation causes all natural cycles and activities such as photosynthesis. The solar surface temperature of the sun is 6,000 celsius, which corresponds to 70,000 - 80,000 kW/m^2 radiation intensity. Earth receives only a very small portion of this energy. Despite this, the incoming solar radiation energy in a year is 2x10^{17} kWh; this is more than 10,000 times of the yearly energy demand of the whole world. The solar radiation intensity outside the atmosphere is nearly 1,360 kW/m^2. When solar radiation penetrates through the atmosphere, some of the radiation is lost. On a clear sky sunny day in summer, 800 - 1,000 W/m^2 (global radiation) can be obtained on the ground [2]. The global radiation and the path length of the beams through the atmosphere. Duration of the sunshine as well as its intensity depend on the time of the year, weather conditions and naturally also on the geographical position as shown in Figure 1. Solar energy is a highly attractive and renewable source of energy as compared to other fossil fuels that pollute the environment [3].

The sun is the central energy producer of our solar system. It has the form of a ball and nuclear fusion takes place continuously in its center. A small fraction of the energy produced in the sun hits the earth and makes life possible on our planet. Solar radiation drives all natural cycles and processes, such as rain, wind, photosynthesis, ocean currents, and several others, which are important for life. The world's energy need has been based from the very beginning on solar energy. All fossil fuels (oil gas and coal) are converted indirectly from solar energy. Among food preservation technologies, cold storage is the best way to conserve its nutritional value, on the contrary, drying is the most suitable option to preserve fruit and

* Corresponding author: sriwichai@tisir.or.th

vegetable for a long time and reduced postharvest loss, increase shelf life, preserve its quality attributes, and reduce transport weight and cost [4]. Drying process is comprised of a heat and mass transfer occurrence where moisture leaves the inside of the product to be dried on to the exterior surface from which it evaporates (mass transfer). Heat energy transfers from the hot drying air into the exterior surface of the food and agricultural product, and the remaining amount of heat energy is functioned in the evaporation of the water from the exterior surface of the product, constituting water vapor. The moisture from the inside migrates into the outside surface in order to restore the loss of moisture occurred by evaporation [5].

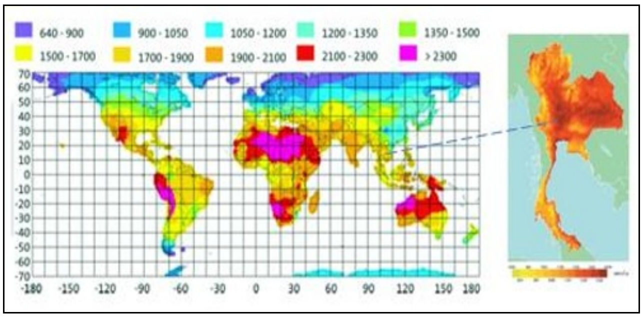

Fig. 1. Global solar radiation[6,7].

The food chain is one of the major contributors to greenhouse gas (GHG) emissions, and global food waste accounts for one-third of produced food. For drying agricultural and marine products, several types of dryers are also being developed. They require a large amount of energy supplied conventionally from pollutant energy sources. The environmental concerns and depletion risks of fossil fuels persuade researchers and developers to seek alternative solutions. Greenhouse dryers (GHDs) are simple facilities that can provide large capacities for drying agricultural products.

The experiment using Particle Image Velocimetry (PIV) technique results were obtained. Fresh apples of moisture content 81.2% (wet basis) were dried to moisture content 8.4% (wet basis) for 8 h 40 min, overall efficiency 16.49% [1]. Recent advancements in the technical design of solar greenhouse dryers are demonstrated as follows;

- Greenhouse dryer includes solar air collector. Efficiency of the solar thermal collector was reported between 29.36% and 88.52% during the drying process. Drying air temperature was reported between 28.08 °C and 55.94 °C during the experiments. Moisture content was reduced from 5.5 g water/g of dry matter to 0.22 g water/of dry matter during 128 h. The product was Grape (Sultana).
- Greenhouse dryer includes photovoltaic (PV) modules (including Flate-plate solar air collector for dried Tomato product). Best efficiency was obtained at a maximum drying period of 28 h. Useful heat gain was ranged between 6.45% and 26.62%. Average overall was between 6.14% and 17.96%.
- Greenhouse dryer includes solar thermal collector. Three drying air's mass flow rates (0.0275, 0.0551 and 0.0826 kg/s) were used. Drying process took 17 h with the optimum airflow rate of 0.0551 kg/s. The average efficiency of the GHD was 19.7% when the air mass flow rate was 0.0551 kg/s. The product was Bitter gourd flakes [8].

Another experiment involving a natural convection solar dryer was conducted at location of 17.115°N. and 74.33°E, India. the environmental parameters taken into consideration during the analysis covered energy, energy payback time and CO_2 emissions, mitigation and carbon credits earned by the dryer. The embodied energy of the solar greenhouse dryer consideration all components of the dryer is 238.137 kWh, the energy payback is 0.588 years and CO_2 emissions are 24.327 kg per year, the carbon dioxide mitigation is 2.024 kg/kWh [9].

2 Equations and mathematics

Determination of convective heat transfer (h). The present focus on evaluating the convective heat transfer coefficient was investigated for the convection flow on the ambient air and moisture content. The convective heat transfer calculations, air moisture and temperature are always a constant in convective drying, and mean convective heat transfer coefficient values are calculated for the lamina flow Figure 2 [10,11].

Reynolds Number (Re)

$$\mathrm{R}_e = \frac{D\bar{V}\rho}{\mu} \tag{1}$$

Nusselt Number (Nu)

$$N_u = h\frac{d}{k} \tag{2}$$

$$N_u = 0.68 + \frac{0.67 R_a^{1/4}}{\left(1 + \left(0.492 / \mathrm{Pr}^{9/16}\right)\right)^{4/9}} \tag{3}$$

; For vertical plate analysis

$$R_a = \mathrm{P_r} \times G_r \ ; \leq \ 10^9 \tag{4}$$

Prandtl Number (Pr)

$$\mathrm{P_r} = \frac{C_p \mu}{k} \tag{5}$$

Grashof Number (Gr)

$$G_r = \frac{d^3 g \beta \rho^2 \Delta T}{\mu^2} \tag{6}$$

Heat transfer coefficients in free convection from water or air

$$h_c = C\left(\frac{\Delta T}{L}\right)^{0.25} ; C_{air} = 1.3683, C_{water} = 217.1 \tag{7}$$

Heat transfer by convection and energy required

$$q = h_c A \Delta T \tag{8}$$

$$\dot{q} = \dot{m} \times h_{fg} \tag{9}$$

The Re, Pr, Gr and Nu numbers used in the drying process to calculate the heat transfer coefficient of the product were calculated as a result of the different physical properties of the humid air determined by the formula No.1 - No.6 and all equation analyses shown in scenario according to Figure 2 and Figure 3.

$$\rho = \frac{353.44}{(T_{av} + 273.15)} \quad (10)$$

$$k = 0.0244 + 0.6773 \times 10^{-4} T_{av} \quad (11)$$

$$C_p = 999.2 + 0.1434 T_{av} + 1.101 \times 10^{-4} T_{av}^2 - 6.7581 \times 10^{-8} T_{av}^3 \quad (12)$$

$$\mu = 1.718 \times 10^{-5} + 4.620 \times 10^{-8} T_{av} \quad (13)$$

$$\eta_{ad} = \frac{(T_1 - T_2)}{(T_1 - T_a)} \times 100 \quad (14)$$

$$v = \frac{m}{\rho x a} \quad (15)$$

$$V = a \times v \quad (16)$$

$$CO_2 = 0.58 \times Electricity(kWh.) \quad (17)$$

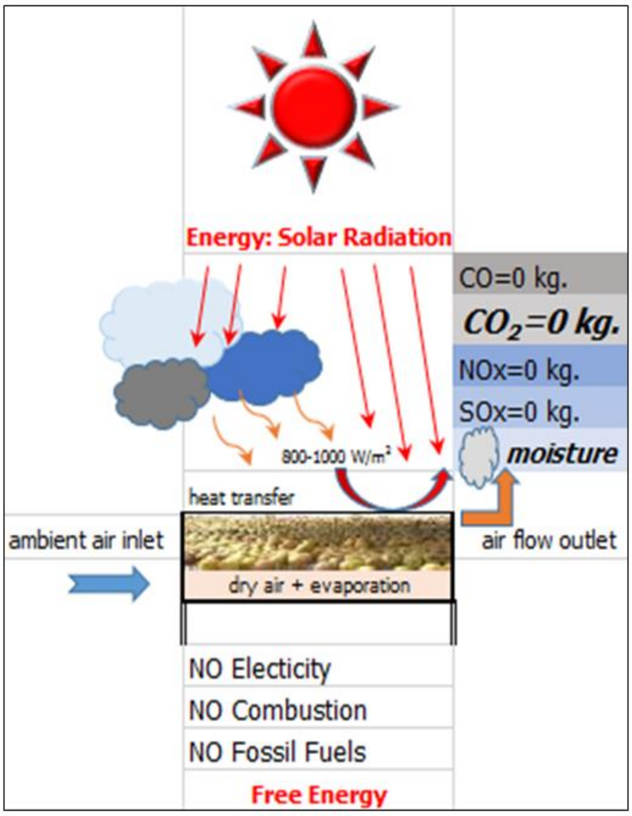

Fig. 2. Illustration chart of global solar radiation, air flow, moisture heat transfer utility and emission (equation analysis).

3 Materials and methods

3.1 Materials

The cross-sectional view of the solar dryer vertical cylindrical shape using materials that are easily obtainable from the local market. Figure 3 shows the schematic of the solar dryer, it consists of main parts, Polycarbonate-bright white color plate (thickness of 8 mm., diameter of 1.5 m., length of 2 m.). Air flows enter the dryer at the lower side and then pass up to the upper side (exhaust). Solar radiation has absorbed by surface areas (cylindrical shape). This process provides effective air heating because airflow passes through all surfaces inside areas.

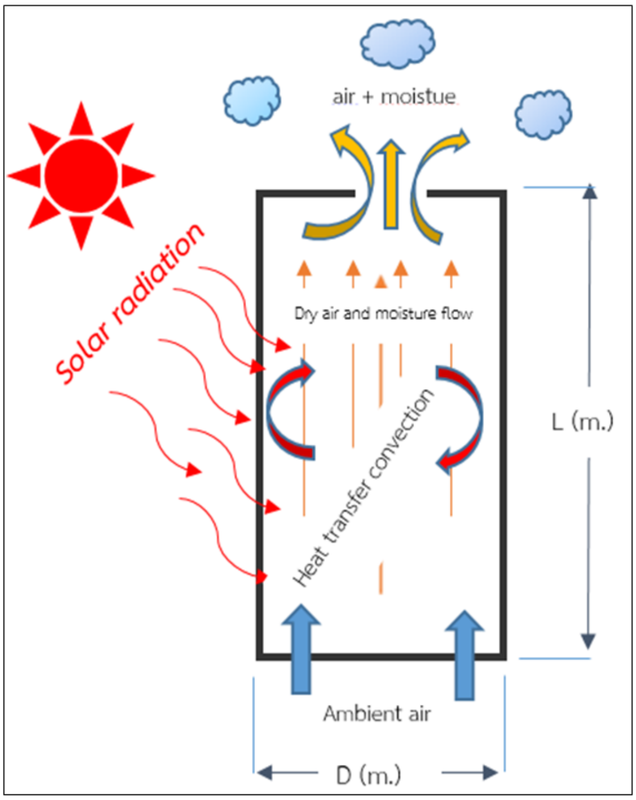

Fig. 3. Illustration of solar dryer diagram.

The external structures can receive sunlight in all directions and helps to distribute heat through all inside areas evenly and thoroughly, internal structure consists of 10 raw material trays (width 1 m., length 1 m) representing a drying area maximum of approximately 10 m². It is made of SUS304 stainless steel mesh material. The upper part of the dryer is equipped with a ventilator, it is rotated by wind and sucked all moisture out of the system. The lower part is equipped with an air vent hole to add up new airflow into the system and circulate within the dryer.

Drying schedule record data from January to June 2023 from 8:00 a.m. to 5:00 p.m. The solar collector was tilted and oriented in such a way that it receives maximum solar radiation during operation. The best stationary orientation is located in Tambon Khlong Ha, Amphoe Khong Luang, Pathum Tani, with a latitude of 14°0'48.46"N and a longitude of 100°31'49.76"E. The angle of tilt (θ) of the solar collector is given by Eq.18 [12].

$$\theta = 10^{\circ} + Lat\phi \quad (18)$$

Where; $Lat\phi$ = the latitude of the collector location 14° for Thailand, PathumTani Provence.

3.2 Experimental set-up

Most solar energy in the dryer was started by solar radiation at day-light. The main experiment was carried out in three stages, under conditions without load and with load and the final stage compared with utilities electric-oven. In order to evaluate the performance of the solar dryer vertical cylindrical shape, the temperature profile of the dryer was determined by measuring the hourly temperatures of the solar collector, drying and ambient between 8:00 a.m. to 5:00 p.m., a thermometer was placed through the wall dryer (Table 1).

Table 1. Solar radiation and moisture content

Local time (h.)	Energy Solar (W/m^2)	Ambient Temp. (ºC)	Average dryer Temp. (ºC)	Surface of dryer Temp. (ºC)	Ambient Relative Humidity (%R.H.)	Average Relative Humidity In dryer (%R.H.)
8:00 a.m.	313	29.5	39.7	43.6	52.2	42.6
9:00 a.m.	371	33.0	43.4	48.8	46.7	38.7
10:00 a.m.	419	35.7	46.4	53.3	44.1	36.8
11:00 a.m.	455	37.6	48.8	56.8	41.0	34.3
12:00 a.m.	477	39.2	50.5	59.0	39.9	33.5
1:00 p.m.	493	40.3	51.8	60.8	36.2	30.5
2:00 p.m.	484	39.6	51.0	59.7	38.0	31.9
3:00 p.m.	456	40.3	50.3	57.8	39.5	33.1
4:00 p.m.	416	39.6	47.9	54.2	42.6	35.4
5:00 p.m.	356	32.8	43.8	48.7	47.3	38.8

The ambient temperature was measured from a maximum and minimum thermometer and the relative humidity was obtained from a psychrometric chart (Figure 4). The heat transfer natural convection, thermal efficiency and dry-air flow rate was calculated as Eq. 1-16 and the carbon dioxide (CO_2) emissions were calculated using Eq. 17. All equations were considered by steady-state for performance evaluation of solar dryer before fruits have tested by drying. The photovoltaic (PV) modules have added up for suitable dry-air flow rate. In the final experiments, solar dryers are compared with utility electric-oven and then consider emissions of gas carbon dioxide equivalent.

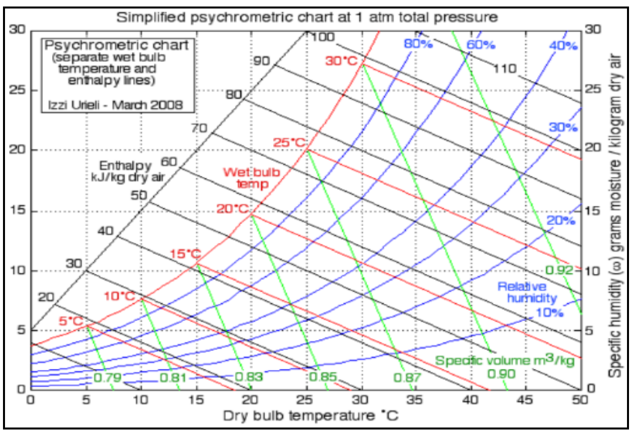

Fig. 4. Illustration of Psychrometric chart [12].

4 Results and Discussion

4.1 Solar radiation and all equations

The solar collector was shown in more detail by the following Table 1 and Figure 5 - Figure 12. Heat is achieved from direct solar radiation through the transparent walls. As shown in Figure 3, the temperature profile of the dryer on the solar collector at 8:00 a.m. to 5:00 p.m. for 6 months (January to June 2023) was shown. All average information was recorded as follows; solar radiation energy maximum of approximately 493 W/m^2 mean 424 W/m^2, ambient temperature maximum of approximately 40.30 ºC, mean of 36.34 ºC inside dryer temperature maximum of approximately 51.80ºC, mean of 47.37 ºC, and surface dryer temperature maximum approximately 60.80 ºC, mean 54.27 ºC, relative humidity maximum approximately 52.23%, mean 42.74%, respectively.

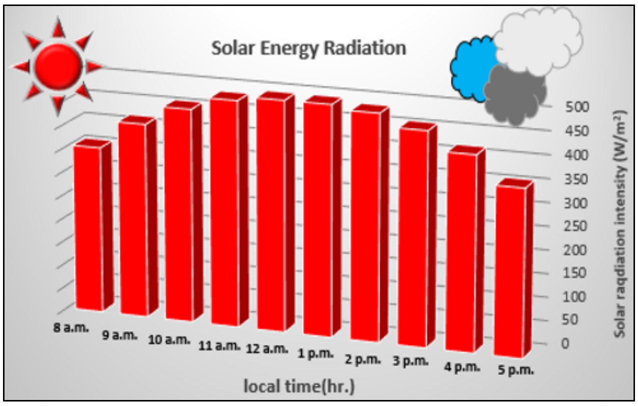

Fig. 5. Solar radiation profile at 8:00 a.m.- 5:00 p.m

Figure 5 shows an hourly variation of the temperatures in solar radiation incidents. In order to evaluate the performance of the solar dryer, the temperatures profile of the dryer was determined by measuring the hourly temperatures of collector between the hours 8:00 to 17:00 solar radiation is hot about mid-day (11.00 a.m.-2.00 p.m.) when the sun is usually overhead, that is highly temperature and energy for good drying process consequently energy saving sustainable and without fossil fuels. However, the performance of solar dryer vertical cylindrical shape has an average of temperature information according to Table 1.

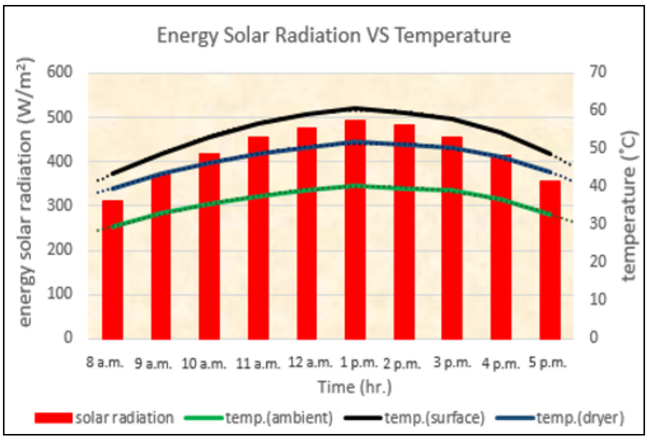

Fig. 6. Profiles of solar energy and temperature.

Figure 6 shows an hourly variation of solar energy and different temperatures. Inside the dryer are much higher than ambient temperatures during day-light. It indicates the prospect of better performance than open sun drying. Additional temperatures are achieved from direct solar radiation incoming through the transparent walls. The higher temperature observed inside the dryer is due to the direct solar radiation. Also, the profiles were recorded as follows; ambient temperature 29.5 ºC - 40.3 ºC, inside dryer 39.7 ºC – 51.8 ºC and dryer's surface (inside) 43.6 ºC – 60.8 ºC, respectively.

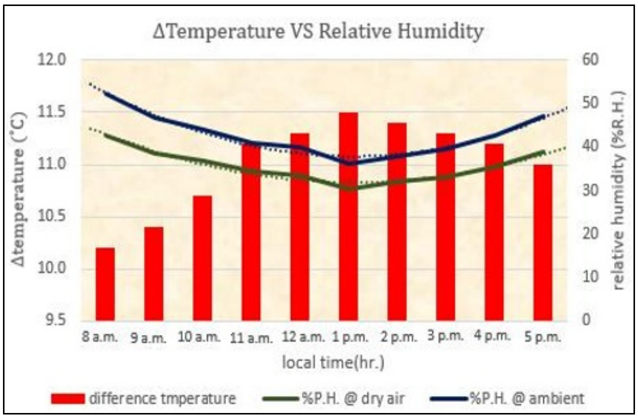

Fig. 7. Profiles of temperature and relative humidity.

Figure 7 shows an hourly variation of difference temperature and relative humidity of dry-air process drying between ambient temperature and inside temperature. Information of recorded temperature is 10.2 ºC - 11.5 ºC and ambient relative humidity is 36.2% - 52.2%, relative humidity inside dryer is 30.5% - 42.6%, respectively. Information indicated more difference in temperatures (most at 1 p.m.), which means more moisture was removed out of the dryer.

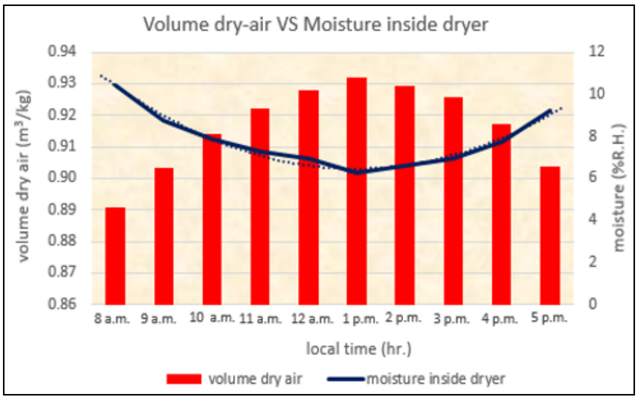

Fig. 8. Profiles of volume dry-air and moisture content.

Figure 8 shows an hourly variation of volume dry-air and moisture content of dry-air process drying between volume dry-air and difference moisture content. The results showed that volume of dry-air flow increase (most is at 1 p.m.) that means dry-air could absorb more moisture. Also, a consequence of moisture inside the dryer decrease. The constant volume of dry-air according to Psychrometric chart Figure 3 and Eq.10 is approximately 0.92 m³/kg.

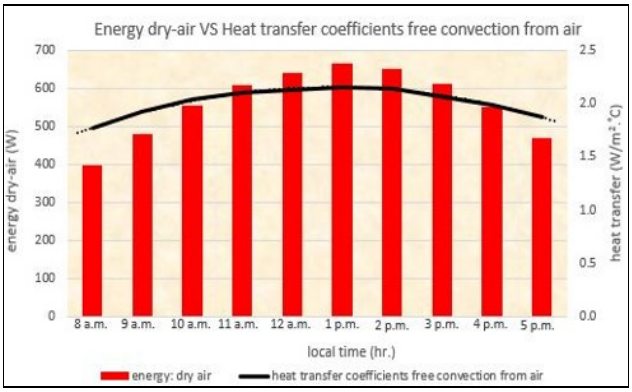

Fig. 9. Profiles of energy and heat transfer coefficients in free convection

Figure 9 showed hourly thermal heat transfer coefficients and free convection values of the dry air process. It can be indicated that the drying system is high or low level. The thermal heat transfer coefficients are high level, which means the energy of dry-air is high level also. The high energy can achieve more volume of dry-air that leads to dehumidification (moisture removed out of the dryer). The value of heat transfer coefficients is the highest that means the highest solar radiation also. Analysis of mathematical equations were solved using suitable initial lamina flow, the heat transfer coefficient natural convection 2.02 W/m².ºC - 2.15 W/m².ºC. Simultaneously, energy solar radiation created a dry-air system at 396 W - 666 W.

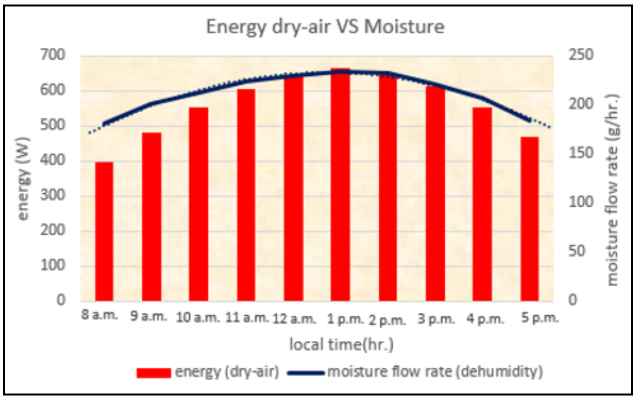

Fig. 10. Profiles of energy transfer to moisture (mass flow rate) or dehumidify

Figure 10. showed hourly energy transfer to moisture (mass flow rate) or dehumidification of the dry air process that is similar to Figure 9. Energy of solar radiation created dry-air system. High energy can remove more moisture out of the dryer also. When the solar radiation or sun's ray is perpendicular to the location between 11 a.m. and 2 p.m. where the highest energy, and highest dry-air lead to removal of moisture at the average of 212.78 g/h.

Figure 11. showed hourly moisture per dry-air and difference of temperatures. The maximum moisture content per dry-air from 8:00 a.m. to 5:00 p.m. is approximately 0.0048 $kg_{water}/kg_{dry\text{-}air}$ according to Psychrometric Chart (Figure 4), and the maximum difference of temperature also is also measured at this point. In this process before the test with drying product, the activation moisture system is increased in the high temperature.

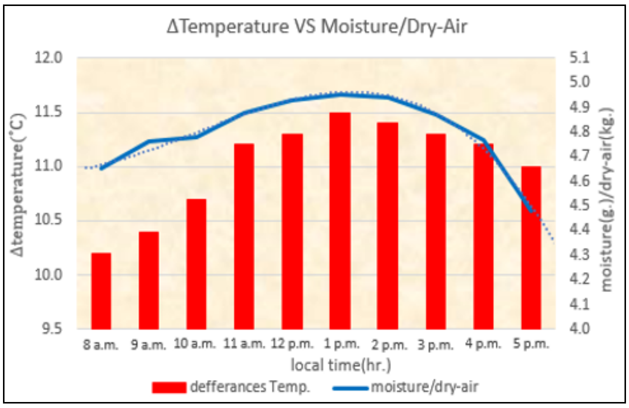

Fig. 11. Profiles of temperature and moisture per dry air ratio

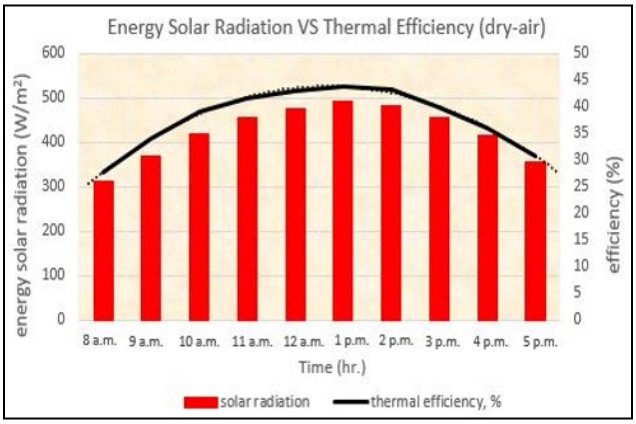

Fig. 12. Profiles of energy solar radiation and thermal efficiency

Figure 12. showed an hourly variation of solar energy and thermal efficiency. Based on the profile of solar radiation from 8:00 a.m. to 5:00 p.m., the maximum of solar energy is approximately 493 W/m^2 at 1 p.m. with the mean at 424 W/m^2, and the maximum thermal efficiency of 44% with the mean of 38%, respectively (Eq.14). The performance of solar dryer can consider at this graph. High efficiency of the solar dryer indicated high moisture removal out of the dryer. Usually, solar dryer systems, the highest performance is observed between 11 a.m. and 2 p.m.

4.2 Experimental drying; fruit (Indian Goosebery) Product compared with electric-oven

The drying test of Indian Goosebery fruit (Figure 13), in a solar dryer, was compared with an electrical oven with the the weight of fruit in the range of 81.2% - 8.4%. Comparatively, the electrical oven showed the better moisture removal out of the dryer than the solar dryer. The electric-oven setup temperature (capacity 3 kWh) was 47 ºC (Figure 13). Its drying time was 11 days and solar dryer drying was 14 days. This experiment showed solar dryers spent time more than electrical oven about 36 h and the difference in drying time was 21%. However, drying by solar dryer has not utilized electricity current. Therefore, CO_2 was mitigated throughout the system by approximately 2.6 kg/day (Eq.17) with energy saving approximately 5.63 kWh/day.

The averages moisture removal by electrical oven is at 0.81 kg_{water}/h (areas for testing is 5 m^2, 81.2%R.H-8.4%R.H.) and solar average dryer drying rate is 0.58 kg_{water}/h (areas for evaporated is 10 m^2, 81.2%R.H-8.4%R.H.). Comparatively, testing results of Indian Gooseberry was compared with other agricultures (Table 2) [13]. It was found that Indian Goosebery as well as Ginger and Butterfly pea have a similar drying rate.

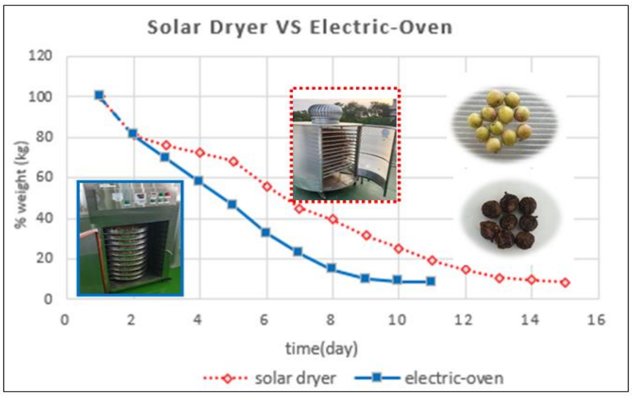

Fig. 13. Demonstration of the relationship between solar dryer vs electrical oven.

Table 2. Example drying test with other agricultures

Products	Ginger	Turmeric	Gotu Kola	Butterfly pea
Initial moisture content (% w. b.)	82.1	86.4	91.5	85.6
Final moisture content (% w .b.)	8.8	7.2	9.1	8.2
Mean ambient temperature (◦C)	34.7	36.1	37.2	36.3
Ambient relative humidity (%)	68.4	59.1	57.5	65.2
Average product temperature (◦C)	45.5	48.2	49.8	48.4
Drying time (h)	36	27	16	14
Drying rate (kg_{water}/h)	0.6	0.7	0.4	0.6

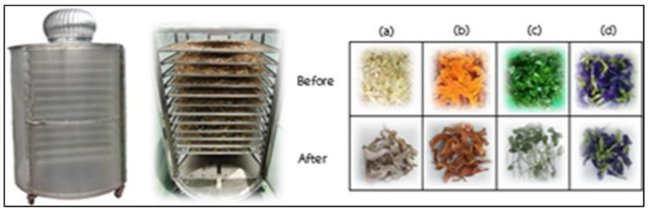

Fig. 14 . Appearances of (a) Ginger (b) Turmeric (c) Gotu Kola and (d) butterfly pea before and after of drying

5 Conclusions

In this research, a practical way of cheap and sanitary preservation of food and agriculture items by using solar dryer (vertical cylindrical shape) is developed. It does not require high technology and electricity current, also the installation and the maintenance cost are low. The drying test results showed that the maximum solar radiation is approximately 493 W/m^2, with the mean of 424 W/m^2, ambient temperature maximum of approximately 40.30 ºC, mean of 36.34 ºC, average inside dryer temperature maximum of approximately 51.80 ºC, mean of 47.37 ºC. The relative humidity maximum is approximately 52.23%, mean is 42.74%, respectively. The heat transfer coefficient natural convection maximum is approximately 2.15

W/m².ºC, mean 2.02 W/m².ºC. The Reynolds Number is 1,195 < 2,100 (Lamina flow), and velocity of airflow through the dryer is natural convection with flow rate at approximately 0.011 m3/s. The volume of dry-air required approximately 41 m^3/h and moisture removed out of the drying system was at 212.78 g/h. Simultaneously, energy solar radiation created dry-air system was 563 W and maximum air-drying thermal efficiency was approximately 44%. Analysis of Psychrometric chart according to dry-bulb constant temperature line against constant humidity relationship curve line can be found at absolute humidity at 4.8 $kg_{water}/kg_{dry\text{-}air}$ and constant volume approximately at 0.92 m^3/kg. Carbon dioxide (CO_2) mitigation is approximately 5.51 kg/day and dryer systems without electricity current. Therefore, solar dryer was environmentally friendly. The solar drying performance was compared with electrical oven by using agricultural items. Comparatively, drying with the solar dryer showed better results than electrical oven in terms of saving electricity current and without release of carbon dioxide (CO_2). When other samples were tested in this solar drying system, the similar drying rate for dehumidification were observed.

Nomenclature

Re	=	Reynolds Number
Nu	=	Nusselt Number
Pr	=	Prandtl Number
Gr	=	Grashof Number
L	=	Length, m.
ΔT	=	Temperature difference,ºC
μ	=	Dynamic viscosity, kg/m.s
ρ	=	Density, kg/m^3
β	=	Temperature difference,ºC
k	=	Thermal conductivity, W/mºC
v	=	Velocity, m/s
η_{ad}	=	Air-drying efficiency, %
D,d	=	Diameter, m.
h_{fg}	=	Enthalpy, kJ/kg
C	=	Constant value
V	=	Volume of the material m^3/h.
m	=	Mass, g.
A	=	Area, m^2
E	=	Energy, W or J/s
T_1	=	Inside dryer surface Temperature, ºC
T_2	=	Inside dryer center Teperature, ºC
T_a	=	Ambient Teperature, ºC
T_{av}	=	Average dryer Temperature, ºC
CO_2	=	Carbon dioxide, kg.

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. N.M. Maundu, K.S. Kiptoo, K. Eliud, D. Kindole, Y. Nakajo, Air-flow distribution study and performance analysis of a natural convection solar dryer, American Journal of Energy Research, **5**,1 (2017): 12-22
2. A. Tiwari, A review on solar drying of agricultural produce, Journal of Food Processing & Technology, **7**,9 (2016): 1-12
3. E. Getahun, M.A. Delele, N. Gabbiye, S.W. Fanta, P. Demissie, M. Vanierschot, Importance of integrated CFD and product quality modeling of solar dryers for fruits and vegetables: a review, Solar Energy, **220** (2021): 88-110
4. Aee Intec, www.aee-intec.at
5. S. Abdellatif, Y.M. El-Hadidi, G. Abdell Razik, D. EL-Sayed, Comparative study for two types of solar dryers (Modified-Quonset and Lean-to) for drying stevia plants (Rebaudiana bertoni), Journal of Soil Sciences and Agricultural Engineering, **9**,8 (2018): 313-320
6. Sigma tec, Systemes & installations photovoltaic ques, www.sigma-tec.fr
7. Department of Alternative Energy Development and Efficency Ministry of Energy, Areas with solar power potential, www.weben.dede.go.th
8. S. Gorjian, B. Hosseingholilou, L.D. Jathar, H. Samadi, S. Samanta, A.A. Sagade, K. Kant, R. Sathyamurthy, Recent advancements in technical design and thermal performance enhancement of solar greenhouse dryers, Sustainability, **13**,13 (2021): 7025
9. A.A. Yadav, P.A. Prabhu, J.S. Bagi, Life cycle assessment and economical valuation of a natural convection solar greenhouse dryer in Western Maharashtra, India, Journal of Mechanical and Energy Engineering, **6**,1 (2022): 99-106
10. R.T. Toledo, R.K. Singh, F. Kong, *Fundamentals of food process engineering* (Springer, New York, 2007)
11. M. Daş, E. Alıç, E.K. Akpinar, Numerical and experimental analysis of heat and mass transfer in the drying process of the solar drying system, Engineering Science and Technology, an International Journal, **24**,1 (2021): 236-246
12. Chapter 10: Air - Water Vapor Mixtures, www.ohio.edu
13. N. Inchurat., Drying Herbs with Vertical Cylindrical Solar Incubator. 14th National Science Research Conference, 25-26 May 2023, Bangkok, Thailand.