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DRYING ANALYSIS OF DOUBLE-STAGE PV/T DRYING SYSTEM FOR MULBERRY LEAVES TEA PRODUCTION

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Abstract- Analysis of drying characteristics, drying efficiencies and economic evaluation in drying of the Burirum-60 mulberry leaves under the double stage PV/T drying system (D-SPV/TDS) are the aims of this study. The drying system has been constructed as a small size in order to promote renewable energy use for the small household drying application. The experiment was conducted during the winter season at Mahasarakham University, in Northeastern Thailand. In the experiment, 700 g of mulberry leaves were used as the drying material. The parameters, e.g., solar irradiation, temperatures, weight losses of material and solar irradiation were measured from 8.00 AM- 4.00 PM. The data were analyzed and performed mathematical models of the system drying rates. The study result shows that the model has high confidence with R^2 is 0.964, and low values of χ^2 and *RMSE*, which is 0.027003 and 0.146977, respectively. The *DR* and D_{eff} value of the system are 1.33 g/min and 2.54047E-10 m^2s^{-1}, respectively. The $\eta_{th,O}$ and $\eta_{E,PV/T}$ of the D-SPV/TDS in drying the mulberry leaves are 11.07% and 10.84%, respectively. In addition, the *IRR* and *PBP* of the system are 45.0% and 2.16 years, respectively.

Keywords: Drying Analysis, PV/T, Efficiency, Drying Model.

1. INTRODUCTION

The mulberry leaves have been consumed as herbal tea and healthy beverage in numerous regions in the world [1, 2, 3]. Strict drying temperature at lower than 60 °C has significance in the production quality of the mulberry leaf products, i.e., in terms of the antioxidant activity and the polyphenolic medical compounds [4, 5, 6]. Moreover, the mulberry tea product needs clean and guaranteed quality production [7]. Electricity from fossil fuels must be replaced by alternates sources [8]. The source of renewable energy that possible to compete with conventional energy is solar energy due to its high potential, practical, free and environmentally friendly [9]. Therefore, various traditional drying methods have been instead by the low-temperature solar drying process. However, the solar drying system needs active airflow to increase the thermal efficiency [10, 11, 12], which requires electricity for the air ventilator. For the reason above, the PV module is popularly used for that purpose [13].

Solar drying has been classified by the drying methods as: (1) the open sun drying method (OSD), (2) the direct solar drying method (DSD), sunlight is directly incidents on the front cover of the drying compartment for heating the air and products, (3) indirect solar drying method (ISD), which sunlight incident through the front cover of the air heating section only, then the hot air flows to the drying compartment for drying of products and (4) the mixed solar drying method (MSD), which the sunlight incident on both of the air preheating section and the drying compartment [14].

Recently, the solar module that simultaneously produces electricity and heat, as so-called "the photovoltaic/thermal (PV/T) module", is adapted into the solar drying system. Kong et al. (2021) have been studied the drying of turnips by using the ISD system by adding a PV/T air solar module [15]. They found that the solar dryer has a drying period shorter than when using typical drying. Çiftçi et al. (2021) have been studied the vertical hybrid PVT in the ISD system, which has the purpose to do space-saving, as well as efficiency improvement of the solar dryer. The research shows that the vertical module can improve the drying air flow rate, resulting in the system efficiency being in the range of 48.46-58.16% [16].

Tiwari and Tiwari have been studied the MSD greenhouse-type. The N-PVT air collector which has partially covered is integrated on top of the drying compartment. The study found that equivalent thermal efficiency changes from 42.2-61.56% [17]. Fterich, et al. (2018) have been studied of a forced flow in the MSD system which is added with a PV/T module on top of the drying compartment, for tomatoes drying. The result shows that the tomatoes dried well in the MSD than in the OSD [18]. Jadallah, et al. (2020) have been studied the hybrid (PVT) double-pass system with an MSD system for drying bananas [19]. The study used the PVT module as the air preheating for the main drying compartment. The MATLAB program provided them that the best thermal performance of the system is 52.98%. Poonia, et al. (2018) have been studied the drying of the local fruit, people (Gypsies Mauritius), by using the PV/T module integrated at the left side of the drying compartment [20].

They have evaluated the drying system performance, and the study revealed that even if the system efficiency is 16.7% but the *IRR* is at a high rate (which is 54.5%) and the payback period is low, making the dryer unit cost is efficient and has a possibility to invest in the system.

The literature surveys discovered that the PV/T module can assist in improving the solar drying's thermal efficiency. However, most of the previous studies mentioned heat at the backplate of the PV/T module for air pre-heating. The MSD system, which separated the air preheating section and drying compartment, previously, requires information on the front heat recovery of the PV/T module for the drying purpose. This study is focused on heat from both sides of the PV/T module. The PV/T module is integrated inside the air preheating section (the 1st stage), below the cover sheet, as shown in Figure 1 (a). With this method, heat gained from the PV/T module to the air is from the backside and front sides of the PV/T module, as shown in Figure 1 (b). Moreover, the inlet air temperature can also increase by heat from light incidents through the cover sheet of the 1st stage, then flowing into the drying compartment (the 2nd stage), this system configuration is so-called, the double stage PV/T drying system (Figure 1). The study has been done to figure out the thermal efficiencies, electrical efficiency and economic viability of this system configuration.

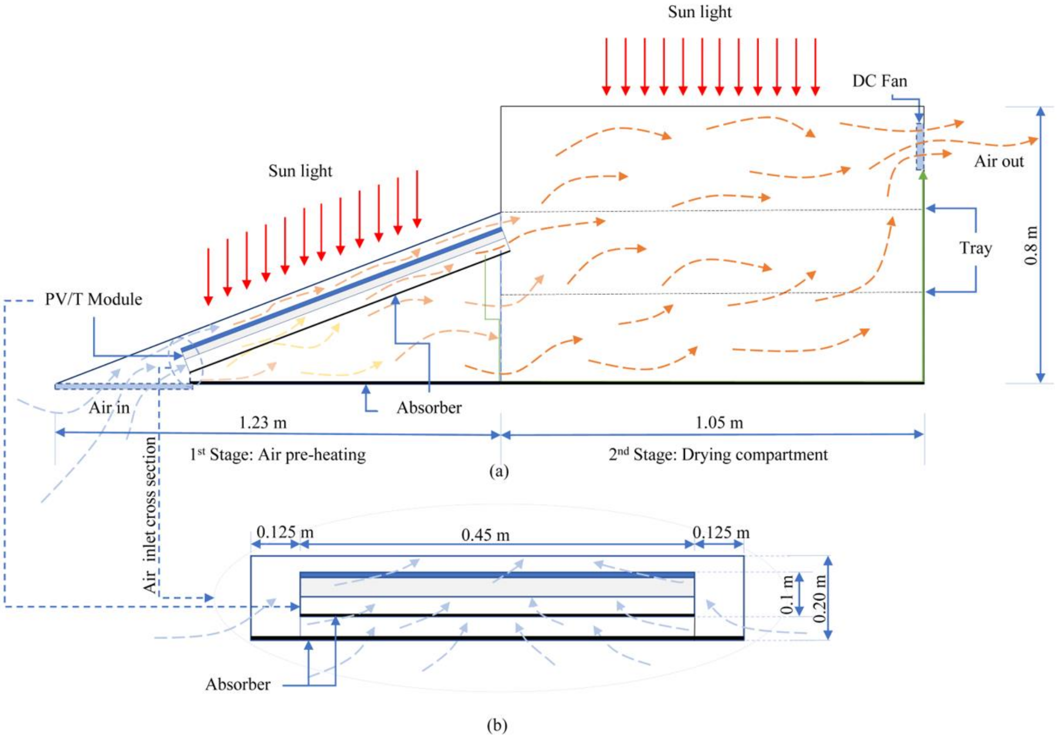

Figure 1. The D-SPV/TDS diagram: (a) side view of the system, (b) Air inlet cross-section

2. MATERIAL AND METHODS

Due to the PV/T module in this study being placed inside the air preheating section, then the module size has to fit in the section, also provides sufficient energy supply to the air ventilators, and be available in the market. The system construction is described as follows.

2.1. Design and Construction

The air preheating area and drying compartment area have been designed by 0.7×1.23 m and 0.7×1.05 m, respectively. The height of the drying system is 0.8 m, as shown in Figure 1(a). The drying system cover is made of an acrylic sheet. The 80 Wp, 0.45×0.98 m of mc-Si PV module has been adapted to be the PV/T module, it was covered by the black aluminum plate at 5 cm separated from the backside of the module. Then, the PV/T module was integrated inside the first stage of the system, for collecting heat and generating electricity supplied to the three DC fans, each fan having 12 V and 0.5 A.

The total 18 W DC fan is located at the end of the drying compartment, which can deliver maximum airflow rates up to 0.137 kg/s. The tilt angle of the PVT module in the system is 20 degrees, with references to the floor. Comparing PV module and DC fan specifications revealed that there is approximately 70% of the rest of the power can deliver to the heater, to dry up the mulberry leaves. The constructed system is shown in Figure 2, in which (a) is the air preheating section and (b) is the mulberry drying compartment section.

2.2. Experiment Methods

Three consecutive days of experiments were done during winter at Mahasarakham University, where the latitude and longitude are 16˚12′N and 103˚16′E, respectively. The solar irradiances on the system were measured using the SP-215 Alpogee pyranometer. The type-K thermocouples were used to measure the temperature signals of the PV/T module, ambient air, air inlet, air outlet and drying air in the drying stage.

The pyranometer was set up on the cover sheet of the 1st state (Figure 2), and temperature sensors were set up in many locations in the drying system. The sensors were connected to the Agilent data locker to measure, record and store drying air temperature, the PV/T module temperature and solar irradiation to the computer. All parameters were measured and recorded every 15 minutes, from 8.00 AM- 4.00 PM. The system was experimented with to dry up the 700 grams of mulberry leaves. The measurement of the weight loss in products was done every two consecutive hours during the experiment. Once the experiment is carried out, then the data is analyzed and performed mathematical models of drying parameters. Finally, the thermal and electrical efficiency is calculated, as well as the economic performance of the PV/T module is evaluated and analyzed.

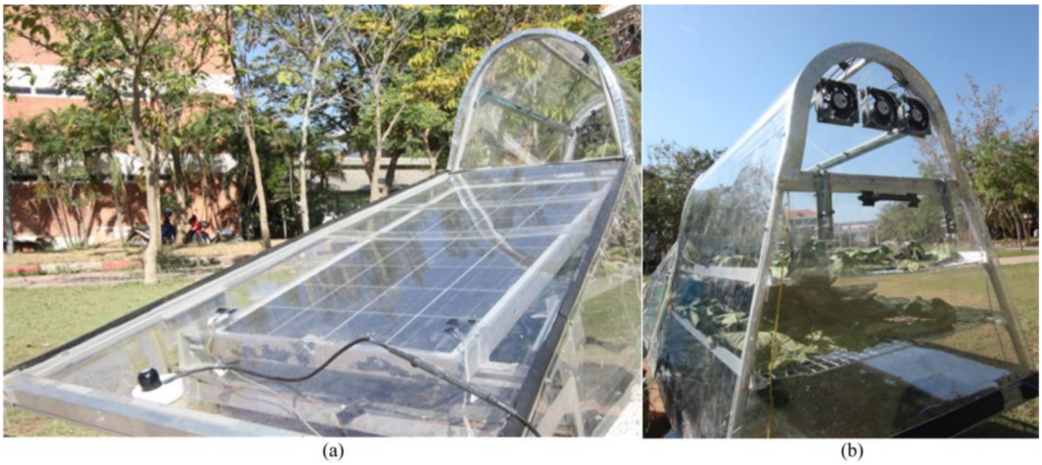

Figure 2. The constructed of the D-SPV/TDS: (a) air pre-heating section (1st stage), (b) drying compartment section (2nd stage)

3. THEORY/CALCULATION

The theoretical used for analyze the D-SPV/TDS in this work related to: (1) the statistical theory, for calculation and describes the accuracy of the drying model, (2) the thermal efficiencies theory, for point out the thermal performance, (3) the PV/T electrical efficiency theory, for evaluated electrical performance and (4) the economic theory, for calculate and describes the economic visibility of the D-SPV/TDS.

3.1. Statistical Calculations

The statistical parameters concerning the testing of the model accuracy in this study are the R^2, χ^2 and $RMSE$. To find out these parameters, the experimental and predicted data are given in Equations (1)-(3) [21]:

$$R^2 = 1 - \frac{\sum_{i=1}^{N}\left(MR_{exp,i} - MR_{pre,i}\right)^2}{\sum_{i=1}^{N}\left(MR_{exp,i} - (ln)\sum_{i=1}^{N} MR_{pre,i}\right)} \tag{1}$$

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(MR_{exp,i} - MR_{pre,i}\right)^2}{N - z} \tag{2}$$

$$RMSE = \left(\frac{1}{N}\sum_{i=1}^{N}\left(MR_{pre,i} - MR_{exp,i}\right)^2\right)^{1/2} \tag{3}$$

The model with high accuracy must be dominant in the R^2 value (close to 1), but least in the χ^2 and $RMSE$ values (close to 0) [22, 23]. To point out model accuracy, the value of the R^2, χ^2 and $RMSE$ is analyzed by the SPSS program.

3.2. Drying Model

In the experiment, the M_i on the wet basis of the mulberry leaves was calculated by using Equation (4)[20].

$$M_i = \left(\frac{W_i - W_f}{W_i}\right) \times 100 \tag{4}$$

The drying curve of the mulberry leaves drying in the D-SPV/TDS was plotted by using the recorded moisture contents. The DR represents the rate that which humidity is evaporated from the product. The calculation of the DR of mulberry leaves was done by using Equation (5)[20].

$$DR = \frac{\Delta M}{\Delta t} \tag{5}$$

For the MR, which represents the ratio of moisture content at any instantaneous drying time (M) to the M_i, Equation (6) is used to calculate the MR of the Burirum-60 mulberry leaves [20].

$$MR = \frac{M - M_e}{M_o - M_e} \tag{6}$$

Generally, the M_e is insignificant compared to M and M_o (due to M_e being very small), then MR is shortened to M/M_o [24, 25].

3.3. Effectiveness of Moisture Diffusivity

The effectiveness of moisture diffusivity (D_{eff}) reflects the mulberry leaves dehydration capability under a drying environment and it is significant in the modeling. The equation below shows a simple linear equation for long drying times which is shown in a logarithmic function, in which the natural logarithm is taking on the function [20].

$$\ln(MR) = \ln\left(\frac{8}{p^2}\right) - \frac{p^2 D_{eff} t}{4r^2} \tag{7}$$

The D_{eff} in the model for this study was calculated using the linear regression analysis in the graph of ln *(MR)* versus time (*t*), with a significance level of 0.05. With a slope from Equation (7), i.e.:

$$slope = \left(\frac{p^2 D_{eff}}{4r^2} \right) \tag{8}$$

by using the method of slope in the linear fitting method, then the D_{eff} was calculated. Typically, the D_{eff} value of mulberry leaves is in the range of 1.032E-10 - 3.01E-10 m^2s^{-1} [26].

3.4. Electrical Efficiency Evaluation

The $\eta_{E,PV/T}$ of the silicon-based PV/T module, with the function related to the module temperature can be calculated by using Equation (9)[27].

$$\eta_{E,PV/T} = \frac{P_m}{GA_{PV}} = \frac{I_m V_m}{GA_{PV}} = \frac{(FF) I_{sc} V_{oc}}{GA_{PV}} \tag{9}$$

While PV module temperature rises during the day, that consequences to decrease of the open circuit voltage and the fill factor due to the electron being excited by heat, then the electrical properties of the semiconductor have control by the electrons. This is opposite to the short-circuit current, it is slightly increased with temperature. So, the η_{PV} as in the function of module temperature can express as Equation (10):

$$\eta_{PV} = \eta_{T_{ref}} \left[1 - \beta_{ref} \left(T_c - T_{ref} \right) + \gamma \log_{(10)} G \right] \tag{10}$$

in which η_{Tref} is the module efficiency at T_{ref} of 25 °C and at G of 1,000 W/m^2. The β_{ref} and γ of crystalline silicon modules are concerning to properties of the material, having the value of 0.004 K^{-1} and 0.12, respectively. However, the right term in the bracket is generally given as zero [27].

Then, for the PV/T module, the $\eta_{E,PV/T}$ that changes with the module temperature is calculated by the equation as follows:

$$\eta_{E,PV/T} = \eta_{Tref} \left(1 - \beta_{ref} \left(T_{PV/T} - T_{ref} \right) \right) \tag{11}$$

where, the η_{Tref} is 0.12, β_{ref} is 0.0045 and T_{ref} is 25 °C [28, 29, 30].

3.5. Thermal Efficiency Calculation

The solar energy utilization efficiency of the D-SPV/TDS (ratio of energy used in removing the mulberry leaves moisture to the global solar energy incident into the drying system), or so call drying efficiency has been calculated using the following relation [20].

$$\eta_{th,D} = \frac{M_{ev} L}{A \int_0^{\theta} G d\theta} \tag{12}$$

However, the $\eta_{th,D}$ can increase with converting electricity from PV/T to be the heat. The overall drying efficiency, in this case, was calculated as:

$$\eta_{th,o} = \eta_{th,D} + F_n \, \eta_{th,D} \left(\frac{\eta_{E,PV/T}}{\eta_e} \right) \tag{13}$$

where, F_n is in this study is 0.7 and η_e is 0.35 [31, 32].

3.6. Economics Efficiency Calculation

The economic efficiency of the application of the drying system for the production of mulberry leaves tea has been done under the assumption that the average price of the mulberry leaves is 0.4 THB/g, interest rate (*i*) is 0.075 and there are 3 months a year for productions. The economic efficiency is represented in terms of the PBP and IRR, which are calculated by the equation as follows:

$$IRR = DL + \left(\frac{DD \times NPW_{DL}}{NPW_{DL} - NPW_{DU}} \right) \tag{14}$$

where, *DL*, *DD*, *NPWDL* and *NPWDU* are the lower discount values, the difference of upper discount rate (*DU*) and *DL*, the net present worth (*NPW*) at *DL* and *NPW* at *DU*, respectively. The *DL* and *DU* are considered at the point that *NPW* changes from plus to minus value [20]. The *NPW* is calculated by:

$$NPW = LCB - LCC \tag{15}$$

where, the *LCB* is calculated by Equation (16):

$$LCB = R \left(\frac{X \left(1 - X^n \right)}{1 - X} \right) \tag{16}$$

where, *R* is 3,000 THB for this study. The *X* value in Equation (16) is defined by:

$$X = \frac{1+e}{1+i} \tag{17}$$

where, *e* and *n* are 0.01 and 10 in this study, are the annual escalation in cost and the lifetime of the dryer (year), respectively. In case of the *LCC*, it is calculated by Equation (18):

$$LCC = P_i + P_w \frac{X \left(1 - X^n \right)}{1 - X} - SV \left(1 + i \right)^{-n} \tag{18}$$

where, the P_i, P_w and *SV* in the study are 6,000, 500 and 600 THB, respectively [20]. And finally, the *PBP*, which is the value of year for *LCB* equal to *LCC*, is calculated by using Microsoft Excel Program.

4. RESULTS

The drying characteristics results of mulberry leaves under the double stage PV/T drying system are represented in terms of the reduction in moisture content and moisture ratio in each observing time. The experimental data, the mathematical modeling and the performance study results are described below.

4.1. Drying Parameters

The experiment data of drying parameters are shown in Figure 3, in which the maximum global solar incident on the D-SPV/TDS is 742 W/m^2. The ambient temperature, drying temperature and PV/T temperature are directly varying with the solar irradiation, which average values are 32, 36 and 46 °C, respectively. The measurement result shows that the drying temperature in the 2nd stage is 12.5% higher than the environment temperature. Moreover, the drying temperature reaches the maximum value of 39.72 °C, which is in the recommended range of the mulberry leaves drying temperature.

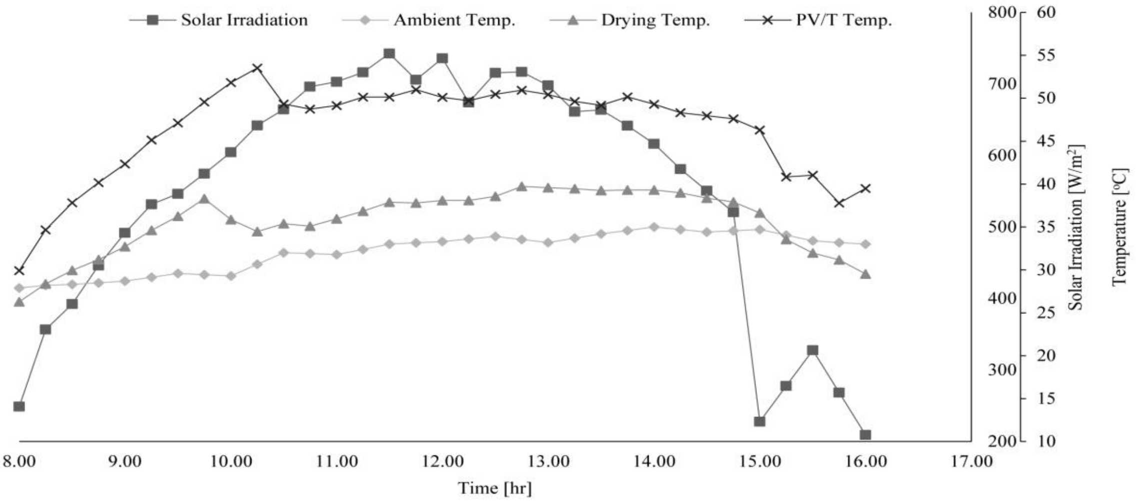

Figure 3. Temperatures and solar irradiation variation with time

4.2. Drying Model

The results analyzed in Equations (4) and (5) are shown in Figure 4. The figure shows that high drying rates are in the initial duration of the experiment, and then the values decrease with time. The *DR* average and M_i are 1.330 g/min and 91.1%, respectively.

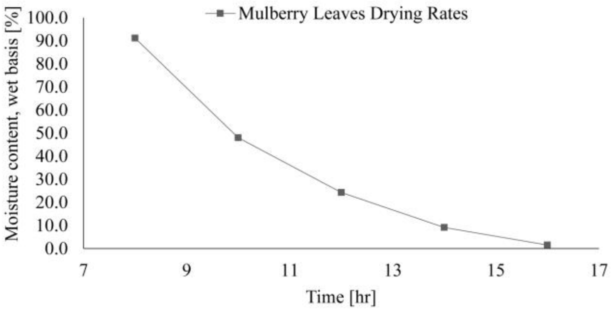

Figure 4. Drying rates of mulberry leaves by using the D-SPV/TDS

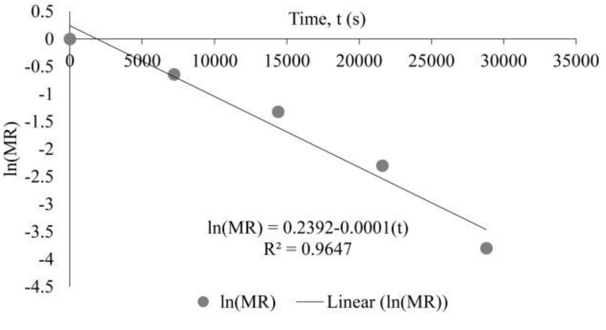

Figure 5. Plotting of drying experiment data in, ln(*MR*) versus time

Figure 5 shows the calculation results of *MR* by using Equation (6) and then plotting and fitting versus time in form of function in Equation (7). The model has statistically significant. The R^2, χ^2 and *RMSE* are 0.964, 0.027003 and 0.146977, respectively. The D_{eff} is calculated by using the method of slop in Equation (8), and it has a value of 2.54047 E-10 m^2s^{-1}. The mulberry leaves D_{eff} value drying by this system is in the range of drying by the other technique, as mentioned above.

Figure 6 shows plotting of the *MR* which gained from the experimental data and the *MR* which obtained by the log-linear model. As the data points in graph were on the line of 45°, or R^2 close to 1, it revealed that the mathematical model has high accuracy to predicted *MR* values of mulberry leaves in this study.

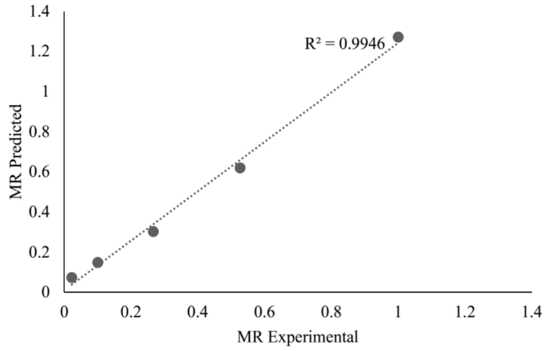

Figure 6. Plotting of the *MR* experimental and the *MR* predicted

4.3. Electrical Efficiency of PV/T Module

The $\eta_{E,PV/T}$ curve in Figure 7 has been calculated by using Equation (11). The $\eta_{E,PV/T}$ curve in the graph shows that the module's electrical efficiency is slightly higher value during the morning and late afternoon, while the lower value of efficiency is in during the noon. The maximum and minimum efficiencies are 11.73% and 10.45%, respectively. The average $\eta_{E,PV/T}$ is 10.84%. The $\eta_{E,PV/T}$ of the system is lower than the previous scholarly studies (13.6%-14.1% of electrical efficiency) due to the PV/T module being inside the drying system [33, 34, 35]. However, electricity is sufficiently provided to the fan and the rest of the electricity can convert to heat.

4.4. Thermal Efficiency of Drying System

The $\eta_{th,D}$ and $\eta_{th,o}$ of the D-SPV/TDS have been calculated by using Equations (12) and (13), which are shown in Figure 7. The data shows that the efficiencies are continuously reduced from morning to the end of the afternoon. The $\eta_{th,D}$ of the system is 8.94%, however, when considered to convert surplus electrical energy from PV/T module to be thermal energy, to drying mulberry leaves, the $\eta_{th,o}$ is 11.07%, which is a 23.87% increase from $\eta_{th,D}$.

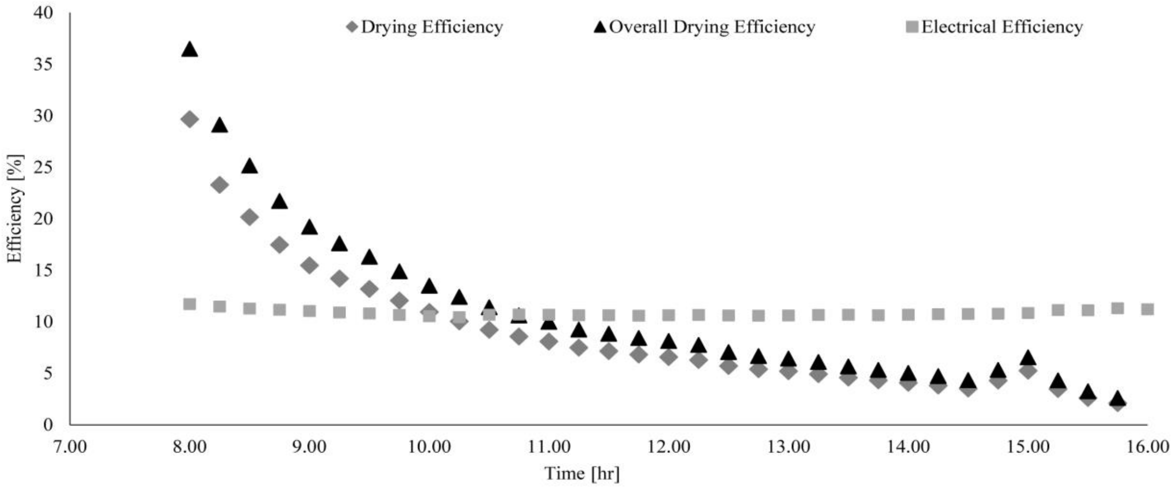

Figure 7. Drying efficiency ($\eta_{th,D}$), overall thermal efficiency ($\eta_{th,o}$) and the PV/T module electrical efficiency ($\eta_{E,PV/T}$) variation with time

4.5. Economics Efficiency

The calculation result of economic parameters in Table 1 shows that the *IRR* and *PBP* of the D-SPV/TDS are 45.00% and 2.16 years, respectively. The high value of IRR and less value of *PBP* represent that the system has high economic performance, which is the application of this drying configuration to the mulberry leaves drying can be potentially economically viable.

Table 1. Values of economic parameters

Attributes Economics	Values
LCB	36,052.70
LCC	10265.60
NPW	25787.00
IRR	45.00%
PBP	2.16 years

5. DISCUSSION

The drying efficiency of the D-SPV/TDS is lower than previous scholarly studies due to the thermophysical property of the acrylic cover sheet being weaker than glass for this purpose. In addition, the lack of heat insulation at the sides and bottom of the DPV//TDS consequently occurring heat loss as well. However, by keeping the extended PV module form the dryer, to be inside the solar dryer, the D-SPV/TDS can reduce the total area of the drying system. Moreover, the system has high economic viability and it has a solid point on providing the costless electricity from PV/T to DC fan, which causes D_{eff} value to be in the range of generally drying mulberry leaves.

6. CONCLUSION

The D-SPV/TDS for drying the Burirum-60 mulberry leaves has benefits for improving the $\eta_{th,o}$ of the system by converting electricity to heat and removing evaporated vapors from the product by DC fans without cost. The drying model has been developed by using the linear regression analysis of *ln (MR)* and time in the SPSS program, for predicting *MR* and D_{eff} of the system. The D_{eff} from the study is 2.54047E-10 m^2s^{-1}, which shows that, even if the D-SPV/TDS has the PV/T inside the dryer, it can dry mulberry leaves like as being in the other drying system.

The model has been approved at a significance level of 0.05. By, converting electrical to heat by PV/T module, the overall drying efficiency has the potential to be 23.8% increased. Moreover, *IRR* and *PBP* of the system are 45.0% and 2.16 years, respectively, which is high economic viability. In future studies, the cover sheet should be replaced by glass due to the deficiency of acrylic cover. The heat insulation should be installed for improving system efficiencies.

APPENDICES

Appendix 1. Experimental Data

The average of three consecutive days of experimental data of solar irradiation, PV/T module's temperature, ambient temperature and drying air temperature every 15 minutes shows in Table 2.

Table 2. Average experimental data

Time	Solar Irradiation, G (W/m2)	Ambient Temp. (°C)	PV/T Temp. (°C)	Drying Temp. (°C)
8:00	249.09	27.90	29.91	26.29
8:15	356.63	28.20	34.68	28.38
8:30	392.27	28.30	37.84	29.95
8:45	446.33	28.50	40.17	31.2
9:00	491.83	28.70	42.35	32.72
9:15	531.76	29.15	45.14	34.61
9:30	546.35	29.60	47.14	36.26
9:45	574.71	29.45	49.56	38.29
10:00	604.39	29.30	51.83	35.85
10:15	641.89	30.65	53.52	34.47
10:30	664.54	32.00	49.33	35.39
10:45	696.31	31.90	48.74	35.09
11:00	703.11	31.80	49.16	35.94
11:15	716.12	32.40	50.14	36.84
11:30	742.48	33.00	50.12	37.88
11:45	705.78	33.15	50.99	37.79
12:00	735.95	33.30	50.11	38.08
12:15	674.17	33.60	49.72	38.09
12:30	715.41	33.90	50.47	38.57
12:45	716.99	33.55	50.94	39.72
13:00	697.86	33.20	50.44	39.58
13:15	661.23	33.70	49.62	39.45
13:30	663.82	34.20	49.17	39.26
13:45	641.79	34.60	50.15	39.32
14:00	616.32	35.00	49.31	39.32

Time	Solar Irradiation, G (W/m2)	Ambient Temp. (°C)	PV/T Temp. (°C)	Drying Temp. (°C)
14:15	581.12	34.70	48.32	38.98
14:30	550.68	34.40	47.97	38.36
14:45	520.65	34.55	47.62	37.92
15:00	227.86	34.70	46.29	36.65
15:15	277.78	34.05	40.83	33.56
15:30	327.69	33.40	41.04	31.97
15:45	268.47	33.20	37.81	31.17
16:00	209.24	33.00	39.48	29.52

Whereas the mulberry leaves weight (W), the moisture content on a wet basis and the moisture ratio from the experiment are shown in Table 3.

Table 3. Mulberry leaves weight, moisture content and moisture ratio.

Time	Mulberry Leaves Weight (g)	Moisture Content, Wet basis (%)	Moisture Ratio Experiment (%)
8:00	700.00	91.14	100.00
10:00	398.00	48.00	52.66
12:00	232.00	24.29	26.65
14:00	126.00	9.14	10.03
16:00	62.00	1.50	2.24

NOMENCLATURES

1. Acronyms

PV	Photovoltaic
PV/T	Photovoltaic/Thermal
DC	Direct Current

2. Symbols / Parameters

A	Drying Area(m^2)
D_{eff}	Effectiveness of moisture diffusivity (m^2/s)
DD	The difference between DU and DL (%)
DL	Lower discount rate (%)
DR	Drying Rate
DU	Upper discount rate (%)
F_n	Fan factor
G	Global solar irradiation (W/m^2)
I_m	Current at maximum power
I_{sc}	Short circuit current
IRR	Internal Rate of Return (%)
LCB	Life cycle benefits (THB)
LCC	Life cycle cost (THB)
M_e	Equilibrium moisture content ($kg_{water}/kg_{dry\ matter}$)
MR	Moisture Ratio
$MR_{\exp,i}$	Experimental Moisture Ratio at order i
$MR_{pre,i}$	Prediction Moisture Ratio at order i
M_i	Initial moisture content (%)
M_o	The initial moisture content ($kg_{water}/kg_{dry\ matter}$)
M_{ev}	The evaporated moisture mass (kg)
N	The observation number
NPW	Net present worth (THB)
P	The predictive constant
P_i	The Initial cost of investment (THB)
P_w	Operational and maintenance cost (THB)
P_m	Maximum Power
PBP	Pay-back Period (year)
r	The thickness of product at a half (m)
R	Annual benefit
R^2	The coefficient of determination
$RMSE$	Root Mean Square Error
SV	Salvage value (THB)
t	Time (s)
T_c	Solar cell temperature (°C)
$T_{PV/T}$	PV/T module temperature (°C)
T_{ref}	PV module temperature at STC (°C)
THB	Thai baht
V_m	Voltage at maximum power
V_{oc}	Open circuit voltage
W_i	The product's weight at initial state (kg)
W_f	The product's weight at final state (kg)
z	The numeral constants
ΔM	The mass loss of products ($kg_{water}/kg_{dry\ matter}$)
Δt	Interval of time (min)
β_{ref}	The thermal coefficient of PV module
γ	The solar radiation coefficient
$\eta_{th,D}$	The drying efficiency (%)
$\eta_{th,O}$	The overall drying efficiency (%)
η_e	The conventional power plants efficiency of (%)
$\eta_{E,PV/T}$	The PV/T module electrical efficiency (%)
$\eta_{T_{ref}}$	The silicon-based PV efficiency at STC (%)
θ	period of test (s)
χ^2	chi-square value

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