Solar Drying of Polygonum minus Huds

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Abstract—The objective of this study is to design and fabricate a solar dryer to dehydrate medicine herbs. In addition, drying kinetics of solar drying was compared with natural sun drying. Average temperature and relative humidity of P.minus were 41 °C ± 5 °C and 30% ± 0.5% respectively. Lewis models, Henderson and Pabis models, Logarithm models, Page model and Midilli et. al model were used to determine the best fit models. The effective diffusivity for D_{ave}, D_{lhc}, D_{ave}, D_{ave} and NSD processes varied from 0.608E-10 m²/s to 1.722E-10 m²/s.

Keywords—thin layer modelling, indirect forced convection solar drying, moisture content, herbs

1. Introduction

Polygonum minus Huds (P.minus Huds) originated from Southeast Asia [1]. This plant belongs to the Polygonaceae family [1]. P.minus Huds leaves were widely used in Malaysia cooking as flavoring ingredient and can be used to treat digestive disorders and dandruff [1].

In recent years, solar energy was concerned as an alternative energy to replace the fossil fuel in energy consumptions. Solar drying using different solar dryer and natural sun drying would be studied [2]. The natural sun drying was abundant and free pollution whereas the solar drying improves the drying quality from hygiene and reduce drying time. Mathematical modeling and experimental studies had been conducted on thin layer drying process of mint, parsley leaves [2] by using different type of solar drying system.

The main objective of this study is to study and compare the thin layer drying characteristics of P. minus Huds leaves in the newly designed solar dryer and natural sun drying.

2. Materials and Experimental set – up

The drying chamber was constructed by aluminum sheet. In order to enhance radiation, the outer surface was painted matte black. One drying tray was placed inside the drying chamber. The circulate fan (12 V, 25W) which powered by two solar panel in parallel connection was located under the drying chamber in order to suck the hot air from solar collector to drying chamber. The solar panel and collector were oriented towards the sun with the angle of 20 °.

The solar collector constructed from aluminum tray with its interior layered with matted black painted stainless steel sheet (thickness 0.5 mm). A glass cover was placed on the aluminum tray, allowing a space of 0.5 mm above the stainless sheet in order to trap more heat in the collector due to greenhouse effect. Insulation material of calcium silicate (thickness 0.5 mm) was placed at the bottom of aluminum tray in order to minimize the heat loss from side of collector.

2.1. Experimental procedure

Solar drying experiments by indirect forced convection solar dryer and natural sun drying were performed in open area from 11 am to 2pm as shown in Fig.1. The experiment of natural sun drying of P.minus Huds was conducted on stainless steel sheets under direct sun. The oven — drying experiment of equilibrium weight samples was conducted on oven (Protech Model FAC-350) for 24h at 105 °C to determine the moisture content according to AOAC method [3].

The temperatures of tray, temperature of inlet collector, temperature of outlet collector were measured using Data Logger (Delta Ohm DO2003) with hot probe wire (Thermocouple type K). Both the relative humidity and air velocity were measured using the data logger with hot probe wire (capacitive Mk-33 sensor and NTC thermistor sensor respectively). The weight of the sample was measured every 5 minutes using weighing balance (AND Model EK-610).

2.2. Mathematical modeling of drying curves

The moisture ratio [4], moisture content [3] and drying rate [4] of P.minus Huds leaves were calculated as equations below:

\[
\text{Moisture content (dry basis)} = MC = \frac{M_e - M_d}{M_e} \quad (1)
\]

\[
\text{Drying Rate} = \frac{M_{1\text{st}} - M_{2\text{nd}}}{t} \quad (2)
\]

\[
\text{Moisture Ratio} = MR = \frac{M_e - M_r}{M_e} \quad (3)
\]

The thin layer drying equations which shown in Table 1 were used to select the best model for describing the drying curve equation of P.minus Huds using solar dryer and under natural sun .

<table>
<thead>
<tr>
<th>Model Name</th>
<th>Model</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lewis</td>
<td>MR = \exp(-kt)</td>
<td>[5]</td>
</tr>
<tr>
<td>Page</td>
<td>MR = \exp(-kt^n)</td>
<td>[6]</td>
</tr>
<tr>
<td>Henderson &amp; Pabis</td>
<td>MR = a \exp(-kt)</td>
<td>[7]</td>
</tr>
<tr>
<td>Logarithmic</td>
<td>MR = a \exp(-kt) + b</td>
<td>[8]</td>
</tr>
<tr>
<td>Midilli et. al.</td>
<td>MR = a \exp(-kt^b) + b</td>
<td>[9]</td>
</tr>
</tbody>
</table>

Data evaluation of drying curves based on the value of R², RMSE and \(x^2\) is calculated as equation below [4]:

\[
\text{Correlation Coefficient}\ R^2  = 1 - \frac{\sum_{i=1}^{n}(\text{MR}_{\text{exp}} - \text{MR}_{\text{pre}})^2}{\sum_{i=1}^{n} (\text{MR}_{\text{exp}} - \text{MR}_{\text{mean}})^2} \quad (4)
\]

\[
\text{Root mean square error }\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(\text{MR}_{\text{pre}} - \text{MR}_{\text{exp}})^2}{n}} \quad (5)
\]

\[
\text{Reduced Chi-square }\chi^2 = \frac{\sum_{i=1}^{n}(\text{MR}_{\text{exp}} - \text{MR}_{\text{pre}})^2}{n-2} \quad (6)
\]

2.3. Effective diffusivity

Fig 1. Schematic view of experimental set up: (1) Drying Chamber (1000 mm x 1000 mm x 800 mm), (2) Tray(1000 mm x 1000 mm), (3) Circulation Fan, (4) Solar Panel (290 mm x 385 mm) (355 mm x 700 mm), (5) Solar Collector (712 mm x 470 mm), (6) K – type thermocouple, (7)Thermistor sensor, (8) Capacitive Mk-33 sensor, (9) Weighing balance, (10) Natural Sun Drying.

Table 1. Thin layer modelling
Experimental moisture ratio was estimated from analytical solution of Fick's diffusion equation [4] and shown as equation below.

\[ MR = \frac{M - M_f}{M_0 - M_f} = \frac{8}{\pi^2} \exp \left( -\frac{\pi^2 D_{eff} t}{a^2} \right) \]  \(7\)

### 2.4. Efficiency of solar collector

The instantaneous efficiency in % for the application experimental was as shown below [10].

\[ \eta_{co} = \frac{q_{co} p c_p (T_{ambient} - T_{fin})}{G_{T} e_{co}} \]  \(8\)

## 3. Results and Discussion

### 3.1. Drying curves

The tray temperature for experiment Dabc, Dacb, Dnhc, Dnbc and NSD were 45.84°C, 43.07°C, 32°C, 44.62°C and 35°C respectively. Fig. 2 shows that experiment Dabc gives the highest drying rate as the solar collector built up temperature of 66°C. At the same time, four-sided black surface of drying chamber radiates more heat compared to Dnbc and Dnbc. The drying rate for natural sun drying was higher than Dabc because the P.minus Huds leaves were dried on stainless steel sheets under direct sun light. For experiment Dnbc, the ambient air flow through the fan into drying chamber, thus no temperature build up inside the drying chamber. The tray temperature for Dnbc was similar to ambient air temperature. The silver grey surface on the aluminium drying chamber had lower spectrum-absorptance product compared to black surface, thus minimal of heat radiation pass through the grey colour aluminium drying chamber.

Fig. 3 illustrates the relationship between dimensional moisture ratio and drying time. Drying curves for Dabc and Dnbc are overlapped. Experiment Dnbc, Dabc and Dnbc required same duration of 70 min to reach equilibrium moisture content. Duration required for experiment Dnbc was 180 min, while the drying time required for a natural sun drying experiment was 105 min.

Experiments using solar dryer with solar collector require less time to achieve equilibrium compared to natural sun drying [2,4]. Presence of solar collector cause temperature builds up in the drying chamber during experiment Dabc and Dnbc. Efficiency of collector for Dnbc and Dabc varied from 27.5 - 44.9% and 28.5 - 59.2% respectively. Heat radiate through four-sided black surfaces of a drying chamber during experiment Dnbc, however the temperature on tray for NSD highly depend on the ambient air.

The five thin layer modelling equations were fitted to the drying curves. The best fit models shows highest value of R², low value of RMSE and \(\chi^2\). The results showed that Page model was the best fit model for describing drying curve of Dabc, Dnbc and Dnbc whereas Midilli et al. model was the best fit model for describing drying curve of Dnbc and NSD.

### 4. Conclusions

Page model was the best fit model for describing drying curve of Dabc, Dacb, and Dnbc whereas Midilli et al. model was the best fit model for describing drying curve of Dnbc and NSD. Value of R², RMSE and \(\chi^2\) for Page model is varied from 0.9993 to 0.9998, 0.00046E-05 to 9.6E-05, 0.23E-04 to 0.85E-04 respectively. For Midilli et al. model, value of R², RMSE and \(\chi^2\) is varied from 0.9981 to 0.9989, 5E-05 to 8E-05, 1.60E-04 to 2.70E-04 respectively. Overall, the Dabc solar drying system achieves the highest drying rate compared to others.

### References


### Nomenclature

- \(M_D\): Initial moisture content
- \(M_{eq}\): Equilibrium moisture content
- \(M_F\): Final moisture content
- \(M_{exp}\): Experimental moisture ratio
- \(M_{pred}\): Predicted moisture ratio
- \(t + dt\): Time interval
- \(D_{eff}\): Effective Diffusivity
- \(d\): Half thickness of leaves
- \(N\): Number of observations
- \(D_{abc}\): Drying Chamber in no black surface without solar collector
- \(D_{nbc}\): Drying Chamber in four-sided black surface without solar collector
- \(D_{abc}\): Drying Chamber in four-sided black surface with solar collector
- \(D_{nbc}\): Drying Chamber in two-sided black surface with solar collector
- \(T_{solar}\): Temperature of collector outlet
- \(G_T\): Solar irradiance of sloped plane
- \(\rho_w\): Density of air
- \(c_p\): Specific heat capacity of air
- \(T_{in}\): Temperature of collector inlet
- \(A_{co}\): Collector aperture area
- \(MR_{nec}\): Mean value of experimental moisture ratio
- \(\eta_{co}\): Instantaneous efficiency in % for the application experimental
- \(\chi^2\): Results showed that Page model was the best fit model for describing drying curve of Dabc, Dnbc and Dnbc whereas Midilli et al. model was the best fit model for describing drying curve of Dabc and NSD.