Drying Kinetics of Chilli Pepper in a force Convection Indirect Solar Drying

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Abstract: - In this study the experimental study was performed to determine the thin layer drying of Chilli pepper in a force convection indirect solar drying. The results for typical clear and cloudy days were presented. The drying curves are formed by the measurement of the material moisture content as a function of time. The system consists of two main parts: heat collector and the food drying cabinet. The food cabinet was made out of the plywood, this plywood was painted as in black color and it is been sealed carefully by using quality wood glue. Polystyrene is used at the upper part and lower part of the food cabinet so that the air will flow to the compartment, this will reduce the turbulence flow and then it will let the smoother air flow in and out of the food cabinet. Twelve different thin layer drying models were compared with respect to their coefficient of determination ($R^2$), reduced chi-square ($\chi^2$) and root mean square error (RMSE) were selected to better estimate the drying curves. The performance of these models was investigated by non-linear regression analysis using statistical computer program (SPSS package). The entire models were showed a good fit to the drying data. However, the Page drying model was showed a better fit to the experiment data among other models.

Keywords: - thin layer drying, Chilli pepper, force convection indirect solar drying

1 Introduction

Agricultural products have been an important source to the human being from those days. Until now human beings are depends on agricultural product for food source. This is why drying process plays an important role in the food preservation. The food contains an amount of water activity or watery food get spoil faster if it is kept for some time without any extra activity on it. Therefore, drying process is took place by enhances the resistance of the high humid products against the degradation by decreasing the water activity of the product. Around 30\% to 40\% of the food production such as vegetables, meats and fruits are losses in developing countries due to the spoilage. Drying method is widely used in the developing countries as the preservation methods to improve the food stability, reduce the microbiological activity, the chemical change while storage and to encapsulates the original flavor of the product [1].

Drying is one of the most energy intensive unit operations that easily account for up to 15\% of all industrial energy utilizations. From 1980s, apart from the rise in energy prices, legislation on pollution, working conditions and safety requirements have become more stringent. To meet these requirements and optimize energy consumption, new technologies in drying method and dryer design have been in demand. Solar-drying technology offers an alternative which can process the vegetables and fruits in clean, hygienic and sanitary conditions to national and international standards. It saves energy, time, occupies less area, improves product quality, makes the process more efficient and protects the environment [2].

Thin layer equations describe the drying phenomena in a unified way, regardless of the controlling mechanism. They have been used to estimate drying times of several products and to generalize drying curves. In the development of thin layer drying models for agricultural products, generally the moisture content of the material at any time after it has been subjected to a constant relative humidity and temperature conditions is measured and correlated to the drying parameters [4]. Several thin layer equations available in the literature for explaining drying behavior of agricultural products have been used for sweet potato slices, for garlic...
slices, for pistachio, for grape, for rough rice, for black tea, for banana and for prickly pear peel [3].

The objectives of this study were to determine the thin layer drying characteristics of chilli pepper in a force convection indirect solar drying and to propose mathematical model for the drying curves. The chilli pepper is one of the best sources of vitamins to the human and besides that chili pepper also rich in beta-carotene and minerals including potassium. Chilli pepper which normally been dried and milled form commonly used as a spice in a food or as a flavor in food intake. According to the research, chili contains high moisture content which estimated around 300% to 400% db after harvest. [4]

2 Experiment Set Up

The system consists of two main parts which are the heat collector and the food cabinet (Figures 1 and 2). The food cabinet was made out of the plywood. This plywood is painted as in black color and it is been sealed carefully by using quality wood glue. Polystyrene is used at the upper part and lower part of the food cabinet so that the air will flow to the compartment. It was used to let the smoother air flow in/out of the food cabinet, i.e. reduce turbulence flow happened. Approximate of 520.45g of chilli pepper is weighted and has been made as initial weight of the chilli pepper for the experiment. The chilli peppers are placed evenly in the drying tray that was placed then in the drying cabinet. The chilli is placed inside the cabinet shelf is to avoid the direct exposure to the solar radiation and also to produce a hygiene dried chilli at the end of the experiment. The drying cabinet and the flat-plate collector are placed at the open placed as shown in the Figures 91 and 2) to get the maximum sun exposure. An angle of 35° are fixed from the ground for the flat-plate collector. Once the system is setup, the experiment is conducted for different set of weather to get the efficient reading. The experiments is conducted for 8 hours from 9.00am until 5.00pm.

Fig. 1. Side view of the indirect solar dryer

Fig. 2. Front view of the indirect solar dryer

3 Mathematical Model

Semi-theoretical thin layer drying models were used widely in the analysis of drying characteristics. For this study, twelve models were tested, as shown in Table 1.

The Moisture Ratio (MR) can be calculated using the equation below:

\[ MR = \frac{(M-Me)}{(Mo-Me)} \]  

The amount of moisture in a product can be calculated as below:

\[ %MC_{db} = \frac{W_w}{W_d} (100\%) \]

The goodness of the fit, higher values of (R²) and lower values of chi-square (X²) and RMSE indicate better goodness of fit model was selected to best describe the drying behavior of chilli pepper. These can be calculated as:
Where MR_{exp,i} is the ith experimentally observed moisture ratio, MR_{pre,i} is the ith predicted moisture ratio, N the number of observations and n the number of constants.

\[ R^2 = \frac{\sum_{i=1}^{N}(MR_{exp,i} - MR_{pre,i})^2}{\sum_{i=1}^{N}(MR_{exp,i})^2} \quad (3) \]

\[ \chi^2 = \sum_{i=1}^{N} \frac{(MR_{exp,i} - MR_{pre,i})^2}{N} \quad (4) \]

\[ RMSE = \left[ \frac{1}{N} \sum_{i=1}^{N} (MR_{pre,i} - MR_{exp,i})^2 \right]^{\frac{1}{2}} \quad (5) \]

Table 1. Mathematical models applied to the drying curves

<table>
<thead>
<tr>
<th>Model No.</th>
<th>Model Name</th>
<th>Equation</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Newton</td>
<td>MR = exp(-kt)</td>
<td>[5]</td>
</tr>
<tr>
<td>2</td>
<td>Page</td>
<td>MR = exp(-kt^n)</td>
<td>[6]</td>
</tr>
<tr>
<td>3</td>
<td>Modified Page (I)</td>
<td>MR = exp[-(kt)^n]</td>
<td>[7]</td>
</tr>
<tr>
<td>4</td>
<td>Modified Page (II)</td>
<td>MR = exp[-(kt)^n]</td>
<td>[8]</td>
</tr>
<tr>
<td>5</td>
<td>Henderson and Pabis</td>
<td>MR = a exp(-kt)</td>
<td>[9]</td>
</tr>
<tr>
<td>6</td>
<td>Logarithmic</td>
<td>MR = a exp(-kt) + c</td>
<td>[10]</td>
</tr>
<tr>
<td>7</td>
<td>Two term</td>
<td>MR = a exp(-k_0 t) + b exp(-k_1 t)</td>
<td>[11]</td>
</tr>
<tr>
<td>8</td>
<td>Two-term exponential</td>
<td>MR = a exp(-kt) + (1 - a)exp(-kt)</td>
<td>[12]</td>
</tr>
<tr>
<td>9</td>
<td>Wang and Singh</td>
<td>MR = 1 + at + bt^2</td>
<td>[13]</td>
</tr>
<tr>
<td>10</td>
<td>Diffusion approach</td>
<td>MR = a exp(-kt) + (1 - a)exp(-kt)</td>
<td>[14]</td>
</tr>
<tr>
<td>11</td>
<td>Verma, Bucklin, Endan, &amp; Wratten (1985)</td>
<td>MR = a exp(-kt) + (1 - a)exp(-gt)</td>
<td>[15]</td>
</tr>
<tr>
<td>12</td>
<td>Modified Henderson and Pabis</td>
<td>MR = a exp(-kt) + b exp(-gt) + c exp(-ht)</td>
<td>[16]</td>
</tr>
</tbody>
</table>

4 Results and Observations

A statistical software (SPSS) package was used in the analysis of the raw data obtained from the drying experiments. The experiment of drying the chillies was done for different weather conditions. The results for sunny and cloudy day conditions were presented. The whole experiments were carried out over a period of time spanning 8 hours each. The experiment was started at 9.00 a.m. and lasted till 5.00 p.m. each time. Figure 3 shows the hourly average values of solar radiation and ambient temperature for typical sunny day in December for Malaysia, while Figure 4 shows the hourly average values of solar radiation and ambient temperature for typical cloudy day in December for Malaysia.

Fig. 3. Solar radiation & ambient temperature versus time for typical sunny day
Fig. 4. Solar radiation & ambient temperature versus time for typical cloudy day

Figure 5 shows the collector efficiency against time. The maximum value was 50% at the clear day while the maximum value of 14.2% was at cloudy day. For all the two days, it was observed that, the highest percentage of efficiency of the flat-plate collector occurred around 11.00 a.m. to 1.00 p.m., which usually the hottest time of the day.

Fig. 5. Collector efficiency

Drying experiments were performed for chilli peppers in indirect forced solar drying at two different weather conditions (sunny and cloudy days). The average main drying temperature of 43.27 °C has been achieved in drying cabinet for clear day while for cloudy day the average main temperature of 28.34 °C has been achieved. The maximum temperature in the drying cabinet for clear day was 55.1 °C at 1 p.m., while maximum temperature for cloudy day was 35.4°C at 2 p.m. Figure 6 shows the moisture ratio relation of the chilli pepper in indirect forced solar drying for the two different weather conditions (sunny and cloudy days).

Fig. 6. Moisture Ratio versus Time (h) curves

The list of twelve thin layer models were used as shown in table 1 to develop the drying model to simulate the drying curves of the chilli pepper in indirect forced solar dryer. These twelve models used to see the changes of the moisture content with the time. By using SPSS software, we determine several parameters namely a, b, c, k, k0, k1, and n respectively where k, k0, k1 is the constants value besides the value of R2, X2 and also the RMSE value (Table 2).

The best-fit model is chosen by looking at the highest value of R² and the lowest value of the X² and RMSE. The range for the R² are from 0.8658 – 0.9991. for the X² value the range are from 0.122 x 10⁻³ – 5.241 x 10⁻³, and for the RMSE value the range are from 0.0106 – 0.8356. So from the results obtain, we can see that Page model is the best-fit model among the twelve models mention above. The Page model obtain the value of R² = 0.9991, X² = 0.122 x 10⁻³, and RMSE = 0.0106. Figures (7 and 8) show the Page model drying behavior of the chilli pepper under indirect solar drying for sunny and cloudy day, respectively.

Fig. 7. Page model drying Curve of chilli pepper (Sunny day)
5 Conclusions
Indirect solar drying system has been designed and evaluated. The drying behavior of chelli pepper was investigated under force convection indirect solar drying system for different Malaysian climatic conditions. Based on the results obtain, Page model shows as the best-fit model compare to the rest of the models by having the highest value of $R^2$ and the lowest value of the $X^2$ and RMSE.

References:


