Thin layer drying

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RESEARCH ARTICLE

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Thin Layer Modelling of Celery Leaf Under Vibrating Fluidized Bed Drying Process

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Celery has been use widely in herbal medicine, dietary program, food and beauty because it has many advantages. Celery has high water content which can be easily damaged even with a little time storage. As a solution for the problem, a research to drying the celery leaf is conducted. The thin layer drying behavior of celery leaves for temperature range of 45, 50, 55, and 60 °C was determined in a vibrating fluidized bed dryer with dimension of 2350 mm × 300 mm. The experimental data were compared and evaluated using Henderson and Pabis, Newton, Modified Page, Logarithmic and Two Term Exponential mathematical model. The Logarithmic model satisfactorily the thin layer drying characteristic of celery with average coefficient of determination (R^2) of 0.9952, root mean square error (RMSE) of 0.02099 and sum square error (SSE) of 0.006036.

Keywords: Celery, Fluidized Bed Dryer, Moisture Content, Thin Layer Modeling, Vibrating Dryer.

1. INTRODUCTION

Celery (Apiumgraveolens, Family Apiaceae) is a rich source of vitamin C and contain great amount of dietary fiber. Celery has been used widely in herbal medicine to decrease cholesterol level and high blood pressure maintaining also dietary program. Several studies have reported that celery has pharmacological activity on antimicrobial, anti-inflammatory, anti-arthritis, antiulcerogenic, antihyperlipidemia and anti-hypertension.[1] In beauty world, celery has been known as one of natural treatment for hair and skin. Celery vitamin content can be a great help in hair luxuriance and skin treatment which related with acne. Celery has a high water content which can be easily damaged even with a little time storage. As a solution for the problem a research to drying the celery leaf is conducted. The aim of the research is to dry celery leaf for a better and longer storage without decreasing its vitamin content.

Drying is one of the methods for food preservation and its reflect the important aspect of food processing. This research use vibrating fluidized bed drying (VFBD) as drying equipment. Vibrating fluidized bed dryer in Mechanical Engineering laboratory of Vocational School Diponegoro University has been developed and researched in the process of drying tea. This equipment has been used to dry green tea from moisture content of 78.1% to 4.1% at a temperature of 70 C and a 1.09 m/s air velocity in 45 minutes.[2] Drying experiment is conducted then the result is compared with mathematical model applied in drying such as Page model, Henderson and Pabis and MidiliKucluck model.[3,4] Mathematical modeling is one of important process in the research for drying losses minimization and optimize the drying condition.[4] Thin-layer drying is a commonly used method for determining the drying kinetics of fruits and vegetables. Suitable thin layer drying model can be used to predict the drying kinetics. Some researchers have studied the drying of fruits and vegetables using thin-layer drying models.[4,6–9]

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2. EXPERIMENTAL DETAILS

2.1. Materials

2.1.1. Sample Preparation

Celery leaves are bought from traditional markets in Semarang, Central Java.

2.1.2. Drying Equipment

Vibrating Fluidized Bed Dryer (VFBD) used in this study has dimensions of 2350 × 300 mm drying area (Fig. 1). The heater source is a LPG burner, that will heat the air exhaled by the centrifugal blower. The temperature and humidity ratio were measured using thermometer and RH meter which are placed at inlet section, drying bed and outlet section. Another equipment used in this research were analitical balance (OHAUS Pioneer TM PA2102C), anemometer (Lutron-AM 4205A), inverter and multimeter.

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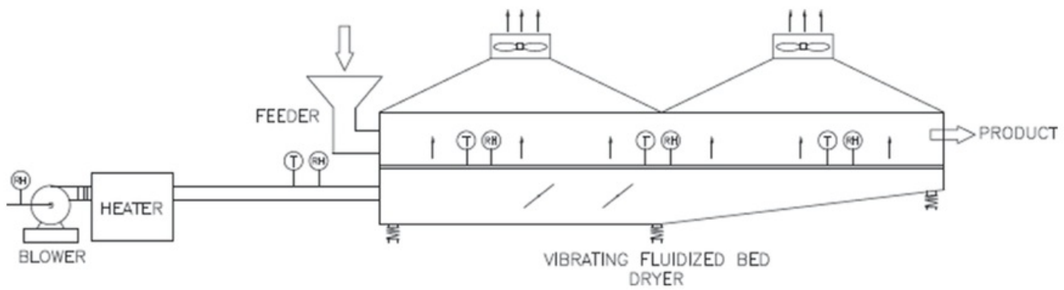

Fig. 1. Schematic diagram of vibrating fluidized bed dryer.

Table I. Evaluated mathematical model.

No	Name	Mathematical model	Reference
1	Henderson and Pabis	$MR = a \cdot \exp(-k \cdot t)$	[11]
2	Newton	$MR = \exp(-k \cdot t)$	[3]
3	Modified page	$MR = \exp(-k \cdot t)^n$	[10]
4	Logarithmic	$MR = a \cdot \exp(-k \cdot t) + c$	[9]
5	Two term exponential	$MR = a \cdot \exp(-k \cdot t) + (1-a) \cdot \exp(-k \cdot a \cdot t)$	[3]

2.2. Method

The effect of temperature variation on drying characteristics will be studied by adjusting the drying at 4 variations of temperature. The thermostat was set at the desired temperature variation of 45, 50, 55, and 60 °C. The air flow rate was set at maximum blower capacity. After the celery leaves came out of the drying output section, then weighed and put into the feeder again repeatedly until a constant weight was reached.

The experimental data at four different temperature were fitted to five thin layer drying model listed in Table I using Matlab. The dimensionless moisture ratio (MR) of celery leaf were calculated by, $MR = (M_t - M_e)/(M_o - M_e)$ where M_t, M_o and M_e are MC at any given time, initial MC and equilibrium MC (% w.b.), respectively. The value of M_e may be relatively small compared to M_t and M_o, so the equation can be simplified to $MR = M_t/M_o$.[10]

3. RESULTS AND DISCUSSION

Water content of celery at the beginning of drying is 87 and 88%, to equate water content at the beginning of drying, hence used dimensionless number that is moisture ratio. The drying characteristics shown by the relationship between the moisture ratio and the drying time at various temperature variations are shown in Figure 2. Air temperature is varied from 45°, 50°, 55° and 60 °C, while the air velocity is set at the minimum fluidization speed. The higher the drying temperature, the drying process will be faster. This is consistent with research on grain drying in vibrating fluidized bed dryers.[12]

The models were evaluated based on RMSE, correlation coefficient (R^2) and sum square error (SES). The statistical parameter details are presented in Table II. The Henderson and Pabis, Newton, Modified Page, Logarithmic and Two Term Exponential obtained a coefficient of determination (R^2) greater than the acceptable R^2 value of 0.93 at all drying temperature.[13] The highest coefficient of determination and the lowest RMSE and SSE was Logarithmic model. Hence the Logarithmic model gave better predictions than other four mathematical model, and satisfactorily described the thin layer drying characteristic of celery.

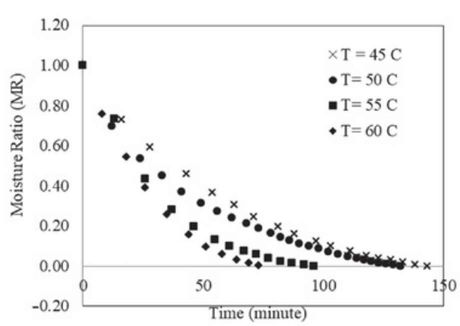

Fig. 2. Drying curve of celery leaves at different temperature variations.

Table II. Coefficient and statistical parameter of several mathematical models.

Model name	Temp (C)	k	Constants	R^2	RMSE	SSE
Henderson and Pabis	45	0.02095	a = 1.029	0.9867	0.03385	0.01719
	50	0.02443	a = 0.9867	0.9911	0.02310	0.01280
	55	0.03604	a = 1.047	0.9883	0.03418	0.01402
	60	0.04200	a = 1.034	0.9866	0.04110	0.01520
Average				**0.9882**	**0.03306**	**0.01480**
Newton	45	0.02047		0.9858	0.03392	0.01841
	50	0.02469		0.9909	0.02288	0.01308
	55	0.03485		0.9859	0.03593	0.01678
	60	0.04082		0.9852	0.04101	0.01682
Average				**0.9869**	**0.03343**	**0.01627**
Modified page	45	0.03358	n = 0.6097	0.9858	0.03503	0.01841
	50	0.02443	n = 1	0.9908	0.02351	0.01326
	55	0.05313	n = 0.6558	0.9859	0.03739	0.01678
	60	−0.03204	n = −1.274	0.9852	0.04323	0.01682
Average				**0.9869**	**0.03479**	**0.01632**
Logarithmic	45	0.01842	a = 1.126 c = −0.05	0.9952	0.02035	0.006213
	50	0.02080	a = 1 c = −0.04	0.9952	0.01726	0.006853
	55	0.03130	a = 1.083 c = −0.05	0.9955	0.02118	0.005382
	60	0.03711	a = 1.073 c = −0.05	0.9950	0.02515	0.005694
Average				**0.9952**	**0.02099**	**0.006036**
Two term exponential	45	0.02608	a = 1.669	0.9929	0.02480	0.009222
	50	0.02433	a = 0.9999	0.9908	0.02351	0.01326
	55	0.04828	a = 1.865	0.9991	0.00964	0.01116
	60	0.04	a = 1	0.9849	0.04366	0.01716
Average				**0.9919**	**0.02540**	**0.01270**

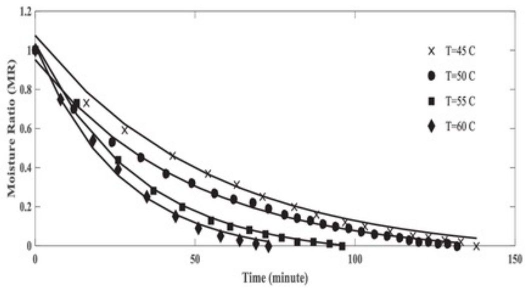

Fig. 3. Comparison of Logarithmic model and experimental data.

4. CONCLUSION

A vibrating fluidized be dryer system was designed, constructed and tested for celery drying. The shortest drying time is achieved at 60 °C and air flow rate of 1.09 m/s which is 73 minutes. The Logarithmic model satisfactorily the thin layer drying characteristic of celery with average coefficient of determination (R^2) of 0.9952, root mean square error (RMSE) of 0.02099 and sum square error (SSE) of 0.006036.

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