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Mathematical modeling of drying characteristics of tropical fruits

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Abstract

In this study, a heat pump dryer was designed and produced in which drying air temperature was controlled with PID. PID controlled heat pump dryer was experimentally tested in drying tropical fruits such as kiwi, avocado and banana. Drying air temperature was kept at 40 °C with the accuracy of ±0.2 °C. Drying air velocity changed between 0.03 m/s and 0.39 m/s. Initial moisture contents of the kiwi, avocado and banana were 4.31, 1.51 and 4.71 g water/g dry matter, which were dried to 0.75, 0.35 and 0.5 g water/g dry matter moisture contents in 6 h. Afterwards the moisture ratios were analyzed with "STATGRAPHIC" computer program by using semi-theoretical models and empirical values. Correlation and standard error of estimation (SEE) and R^2 values were achieved.

Keywords: Tropical fruit; Drying; Heat pump dryer; PID control

1. Introduction

Drying means the fluid extraction in a material. In technical drying, outer intervention is applied to the drying operation and the moisture in the material is removed with the use of various methods. Therefore, drying is described as the mitigation of the moisture of the material to be dried to the desired drying values within a particular period of time. The whole units, which help the material achieve the drying values within a particular period and which comprise various components (heating, moisture extraction), are referred to as the drying system [1].

Drying operation comprises the evaporation of the water first of all, and then extraction phase of the evaporated water from the system. During the evaporation there is a need for high energy. Therefore, drying operations are those in which high energy is used.

In this study, heat pump dryer controlled PID were designed. Dryers which were designed and manufactured was experimentally analyzed during tropical fruit drying. At the same time, experimental results which were obtained under the same climatic conditions were analyzed with semi-theoretical drying models and error analyses were found. Drying models used in the analysis of drying characteristics are usually theoretical, semi-theoretical or purely empirical. Some semi-theoretical drying models which have been widely used are presented in Table 1 [2].

The moisture ratio (MR) and drying rate (DR) during drying experiments were calculated using the following equations:

$$\mathrm{MR} = \frac{M - M_e}{M_0 - M_e} \tag{1}$$

$$\mathrm{DR} = \frac{M_{t+\mathrm{d}t} - M_t}{\mathrm{d}t} \tag{2}$$

where M, M_0, M_e, M_t and $M_{t+\mathrm{d}t}$ are the moisture ratio, moisture content, initial moisture content, equilibrium moisture content, moisture content at "t" and moisture content at "$t + \mathrm{d}t$" (g moisture/g dry matter), respectively, "t" is drying time (min). However, the moisture ratio (MR) was simplified to M/M_0 of the $(M - M_e)/(M_0 - M_e)$ [3].

After computing the moisture ratio using the thin layer (5 mm thick) drying data, the "STATGRAPHICS" (Version XV.I for WINDOWS) statistical software package for non-linear regression analysis was used for moisture

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Nomenclature

a	regression constant	M_0	initial moisture content, g water/g dry matter
n	regression constant	t	time, min
b	regression constant	T_{abs}	absolute temperature, 40 °C for HPD
c	regression constant	V	variable air velocity, m/s
k	drying rate constant, min^{-1}	HPD	heat pump dryer
MR	moisture ratio, M/M_0	SEE	standard error estimate
M	moisture content, g water/g dry matter	MC	moisture content, dry bases
M_e	equilibrium moisture content, g water/g dry matter		

Table 1
Mathematical models given by various authors for drying curves

Model no.	Name	Model equation	References
1	Newton	$MR = \exp(-kt)$	[4,5]
2	Page	$MR = \exp(-kt^n)$	[6,7]
3	Modified Page	$MR = \exp(-(kt)^n)$	[8,9]
4	Henderson and Pabis	$MR = a \cdot \exp(-kt)$	[6,10]
5	Logarithmic model	$MR = a \cdot \exp(-kt) + c$	[11]
6	Wang and Singh	$MR = 1 + at + bt^2$	[12]

ratio against drying time and to determine the constants listed in Table 1 for the six selected drying models [13].

2. Experimental setup

Heat pump dryer, which was analyzed in the experimental drying of tropical fruit, is shown in Fig. 1. Dryer consists of the heat pump system, axial fan, thermocouple and process control equipment, invertor and drying chamber. Heat delivered in the condenser is re-extracted from the evaporators at the exit of the drying chamber.

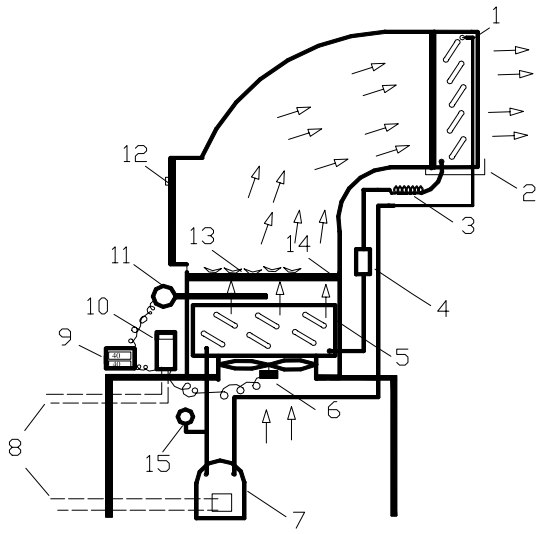

Fig. 1. Schematic diagram of the experimental setup. 1. Evaporator; 2. Condensed water; 3. Capillary tube; 4. Dryer filter; 5. Condenser; 6. Axial fan; 7. Compressor; 8. Power supply; 9. Process control equipment; 10. Invertor (AC variable speed drive); 11. Thermocouple (T, Pt-100); 12. Lid; 13. Sliced fruit; 14. Shelf; 15. Manometer.

PID controlled heat pump dryer adjusts the cycle of the axial fan according to the temperature value which is set in process control device. If the set value is higher than the temperature (drying air temperature), which is measured with the thermocouple, the flow of the air which is blown from the axial fan decreases. Thus, lower flow outer air is passed through the condenser so as to ensure that the temperature reaches the set value. If the set value is less than the temperature (drying air temperature), which is measured with the thermocouple, air velocity of the air blown from the axial fan increases. Thus, fresh air with a bigger flow is passed through the condenser so that the temperature (drying air temperature) which is measured with the thermocouple reaches the set value.

When the temperature (drying air temperature), which is measured by the thermocouple, reaches the set value, in other words, drying air temperature is equated with the set value, the fan adjusts the air velocity by means of the invertor according to the measured temperature value. In heat pump dryer process, temperature control device is set to 40 °C and aims to keep the drying air temperature at the set value.

3. Experimental procedure

Before the experiments launched in the heat pump dryer, the tropical fruits namely, kiwi, avocado and banana were peeled off and the following preparations were made.

- Peeled off fruits were sliced at the thickness of 5 mm.
- The fruits sliced at the thickness of 5 mm were dried in a drying oven at 70 ± 3 °C.
- During the drying period of 5 h, weight measurement was made once an hour. At the end of two consecutive measurements, absolute dry weight was considered to be achieved on the condition that the weight changed less than 1%. One percent accurate digital weight measurement instrument (METTLER TOLEDO) was used for weight measurement.

Initial moisture content of the fruit was calculated from Eq. (3).