

## Simulation Model for Heat Pump-Assisted Dehumidified Air Drying for Some Herbs

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**Abstract:** A computer simulation model for the heat pump dehumidified air drying for garlic and white mulberry leaves was developed. The Modified Page model was found suitable in describing the drying curves. The computer simulation model was verified against heat pump dehumidified drying data of garlic and white mulberry leaves. The results revealed that drying air temperature and relative humidity influenced the drying curves and were included in the model. The computer simulation model was able to calculate the yield of dried products with very low deviations.

**Key words:** Heat pump dehumidified drying % Herb % Model % Simulation

### INTRODUCTION

Drying of fruits and vegetables has been found in various applications. Basically, conventional hot air dryers are used for drying. The main problem is that the conventional hot air dryer results in low product quality due to high drying air temperature which causes the shrinkage of the products. A heat pump is essentially an air-condition system operated in reverse. Unlike normal air conditioning systems, the heat exchanger in focus is the condenser. The basic components of the heat pump system comprise an expansion valve, two heat exchangers (evaporator and condenser) and a compressor [1]. The principal advantages of heat pump dehumidified dryers (HPD) emerge from the ability of heat pumps to recover energy from the exhaust as well as their ability to control the drying air temperature and humidity [2].

Recently works on heat pump dehumidified dryers were Orgura *et al.* [3] for a control strategy for chemical heat pump dryer, Saensabai and Prasertsan [4] for condense coil optimization and component matching and Pal and Khan [5] for calculation steps for the design of different components. Moreover, various types of product have been dried in experimental heat pump dehumidified dryers. Dried product include biomaterials [6] sawn rubber, wood and banana [7] banana [8] holy basil [9] garlic [10] mangoes [11] ginger [12] composite food products [13] red pepper [14] protein [15] and white mulberry leaves [16]. Simulation model of the heat pump dehumidified dryer were developed by Gopalnarayanan

and Radermacher [17] for clothes drying, Alves-filho *et al.* [18] for fruit and root drying and Achariyaviriya *et al.* [19] for fruit drying. The computer simulation model for heat pump dehumidified drying for herbs has not been available. In this work, the computer simulation model was programmed in the BASIC language.

### MATERIALS AND METHODS

A computer simulation model of a heat pump dehumidified dryer consisted two parts, namely, characteristics of drying and drying yield. The assumptions are made as follows: the rate of moisture loss is assumed to be proportional to the moisture remaining to be lost where K and N were used in the model and drying yield is able to calculate from drying ratio. The moisture loss during heat pump dehumidified drying is described by means of thin layer equations, combined with the relationship between the drying exponent and relative humidity of drying air temperature.

The percentage moisture content (wet basis) of herbs can be written:

$$X_{w.b.} = \frac{X_{d.b.}}{1+X_{d.b.}} \times 100 \quad (1)$$

The percentage moisture content (dry basis) of herbs can be written:

$$X_{d.b.} = \frac{X_{w.b.}}{1-X_{w.b.}} \times 100 \quad (2)$$

The value for relative humidity and temperature of drying air was given by the linear model as

$$RH = C_1 + C_2 T \quad (3)$$

The equilibrium moisture contents,  $X_e$ , were given in the form of Modified Oswin for garlic and Modified Henderson for white mulberry leaves.

Modified Oswin model

$$X_e = \frac{C_3 + C_4 T}{\left[ \frac{1}{RH_e - 1} \right]^{1/C_5}} \quad (4)$$

Modified Henderson model

$$X_e = \left[ \frac{\ln(1 - RH_e)}{-C_3(T + C_4)} \right]^{1/C_5} \quad (5)$$

The value for K was given by Arrhenius model

$$K = C_6 \exp\left(-\frac{C_7}{T + 273.15}\right) \quad (6)$$

The value for N was given by the exponential model proposed by Rapsus and Driscoll [20].

$$N = C_8 \times RH^{C_9} \times \exp\left(\frac{C_{10}}{T}\right) \quad (7)$$

where  $C_1$  to  $C_{10}$  were given in Table 1.

The moisture content of the herbs can be written using the Modified Page model.

$$X = (X_o - X_e) \exp(-Kt)^N + X_e \quad (8)$$

The experimental data ( $X_m$ ) and predicted data ( $X_p$ ) are fitted by minimizing the standard error of estimate (SEE).

$$SEE = \sqrt{\frac{\sum_{i=1}^n (X_m - X_p)^2}{n-1}} \quad (9)$$

where  $n-1$  gives the number of degrees of freedom of the fitted equation.

Drying yield was determined in term of drying ratio (DR) as follows.

$$\text{Drying ratio} = \frac{\text{Weight of trimmed product before drying}}{\text{Weight of dried product after drying}} \quad (10)$$

Percent deviation (PD) of the drying yield could be calculated from experimental ( $Y_m$ ) and predicted yield ( $Y_p$ ) as follows.

$$\text{Percent deviation} = \frac{(Y_m - Y_p)}{Y_m} \times 100 \quad (11)$$

**Desorption Isotherms:** The herbs were placed on a pre-weight drying tray in order to proceed to the drying process using a tray dryer (Armfield limited, England) at 60°C to obtain seven different levels of moisture content [21]. The dried herbs of 0.5 g were measured for equilibrium relative humidity at 20, 34.9 and 49.7°C by using Novasina manometer (TH 2/TRD-33/BS, Switzerland) that is specially designed for temperature controlled measurement of water activity or relative humidity at equilibrium state. The temperature of the measurement chamber is regulated to set point by a controller with accuracy to 0.2°C and its range is 0-50°C.

**Air Drying Procedure:** The tray dryer (Armfield limited, England) comprises an air duct mounted on a floor standing frame to give a comfortable working height for the operator. Air is drawn into the duct through a mesh guard by a motor driven axial flow fan impeller whose speed can be controlled to produce a range of air velocity up to 1.5 m/s in the duct. The air passes over an electrically heated element controlled by a power regulator to provide a variation in air temperature up to a maximum of 80°C at low air velocities.

The air passes into the central section of the duct where four trays of material to be dried are suspended in the air stream. The trays are carried on a support frame which is attached to a digital balance with an accuracy of 0.01 gm mounted above the duct and in which the total weight is continuously indicated. The trays are inserted or removed from the duct through a latched side door with a glass panel for viewing purposes.

The effect of drying air temperature on the drying process of sliced garlic and white mulberry leaves were investigated (Table 2) and were dried in thin layer at 40, 50 and 60 °C in a tray dryer (TD) (Armfield limited, England) and a heat pump dehumidified dryer (HPD) [9]. An anemometer (MODEL 3K-27V No.7680-00) with an accuracy of 0.01 m/s was used to measure air velocity. The air velocity of both dryers was maintained constant

Table 1: Sources of drying data for computer simulation model of heat pump dehumidified drying

Type	Variety	Linear model for RH	Desorption isotherm		Rapusas and	
			$X_e=f(RH,T)$	Arrhenius model	Driscroll model	References
Garlic	Srisakes	$C_1=0.49737$	Modified Oswin	$C_6=12,790$	$C_8=4.3668$	[6]
		$C_2=-0.00639$	$C_3=13.64532$	$C_7=4,437.18$	$C_9=0.3111$	
			$C_4=-0.049775$		$C_{10}=-41.4069$	
			$C_5=1.255749$			
White mulberry leaves	Bureerum 60	$C_1=0.53778$	Modified Henderson	$C_6=664.62996$	$C_8=0.3439$	[16]
		$C_2=-0.00743$	$C_3=0.0004$	$C_7=2,997.58832$	$C_9=-0.2711$	
			$C_4=122.1615$		$C_{10}=23.8925$	
			$C_5=0.7796$			

Table 2: Standard error of estimate (SEE) %d.b. for some herbs

Type/Variety	Standard error of estimate (SEE) % d.b.	
	50°C	60°C
Garlic/Sreesakes	3.94	6.72
White mulberry leaves/Bureerum	5.50	5.64

Table 3: Drying yield of the dried products

Dried Products	Weight of product before drying (g)	Drying ratio (DR)	Measured (g)	Predicted (g)	Percent Deviation (%)
Garlic	196.29	2.442	80.42	80.3808	0.049
White mulberry leaves	34.34	3.525	9.74	9.7418	-0.018

at 0.5 m/s. A relative humidity meter (VAISALA MODEL HMP-5D) with an accuracy of 0.01% RH was used to measure the relative humidity (RH) of drying air. An average relative humidity of air throughout the drying was used. The weight loss of the sample was recorded every 5 minutes by using a data logger (DT 800 Data Taker, America). The drying was terminated when the moisture content of the sample was reduced to 7.5 % w.b.

**Solution Procedure:** The relative humidity of drying air was calculated from equation 3, equilibrium moisture content of herbs from equation 4 and 5, drying constants, K, from equation 6, drying exponent, N, from equation 7, moisture content of herbs from equation 8 and then drying yield from equation 10. The procedure is subsequently repeated for updated moisture content marching forward in time. The numerical solution was programmed in BASIC language.

## RESULTS AND DISCUSSION

The experimental data for the heat pump dehumidified drying of garlic and white mulberry leaves are summarized

in Table 1. As can be seen in Fig. 1 and 2, all drying was in the falling rate period. The Modified Oswin and Modified Henderson models gave the best fit to the  $X_e = f(RH_e, T)$  equation form for garlic and mulberry leaves respectively (Table 1).

The Modified Page model gave the best fit to the moisture content and time for both garlic and mulberry leaves. The exponent, N, added to the drying constant and drying time of Newton model to increase the dependency of temperature and relative humidity of drying air in heat pump dehumidified dryer. This can be noted that the RH and drying temperature of drying air influenced K and N values in the Modified Page model. The computer simulation was compared with the experimental data of Boonnattakorn *et al.* [10] for garlic and Phoungchandang *et al.* [16] for white mulberry leaves. The experimental and predicted drying data are presented in Fig. 1 and 2. The computer simulation model for garlic and white mulberry leaves gave good agreement with the experimental drying data at 50°C and 60°C with low SEE (Table 2). The computer simulation model was also used to calculate drying yield from equations (10) and (11). The computer calculation yielded percent

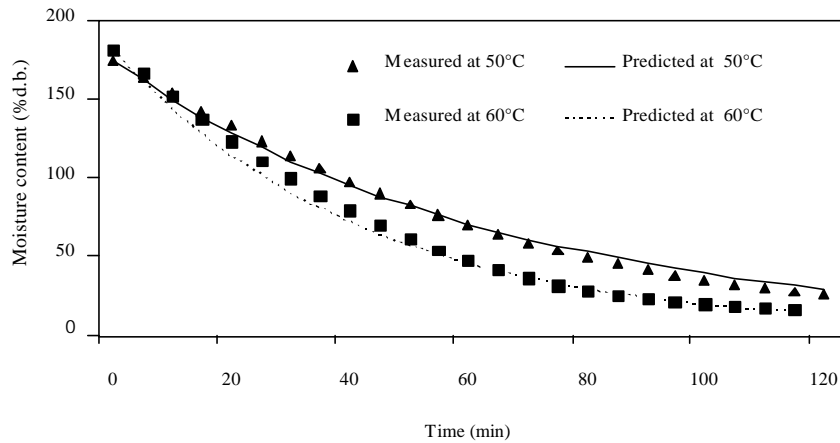


Fig. 1: Garlic moisture content as predicted using the computer simulation model compared with the observed experimental data

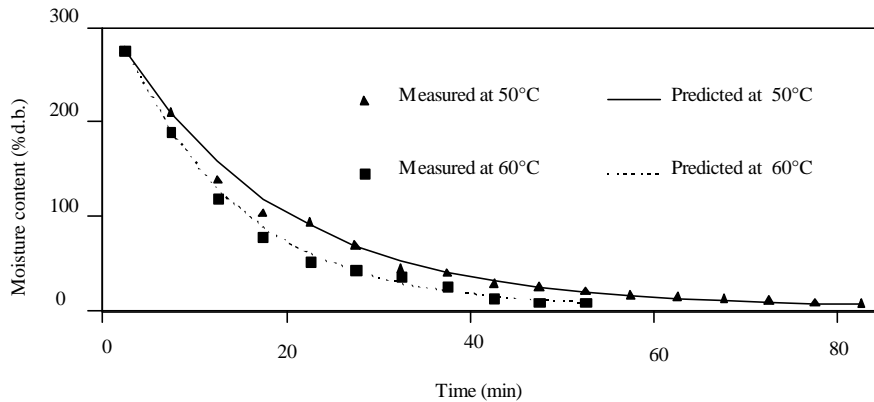


Fig. 2: White mulberry leaf moisture content as predicted using the computer simulation model compared with the observed experimental data

deviation of 0.049 and -0.018 % for garlic and white mulberry leaves respectively. The differences were very low (Table 3).

### CONCLUSIONS

A computer simulation model of the heat pump dehumidified drying for some herbs (garlic and white mulberry leaves) has been developed and shown to be in good agreement with experimental results. The model is generally applicable to the air drying of herbs in a single layer and sufficiently adaptable to examine the effects of relative humidity and temperature of the drying air. The computer simulation model was also able to calculate the yield of the dried products with very low deviations.

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#### NOMENCLATURE

$C_1-C_{10}$	constant
DR	drying ratio
K	drying constant, 1/mim
n	number of data points
N	drying exponent
PD	percent deviation, %
RH	relative humidity, decimal
T	temperature, °C
X	moisture content, %
Y	yield of drying

#### Subscripts

e	equilibrium
d.b.	dry basis
o	initial
m	measured
p	predicted
w.b.	wet basis