Performance of Heat Pump Dryer for Kaffir Lime Leaves and Quality of Dried Products under Different Temperatures and Media

N. Poomsa-ad, K. Deejing, and L. Wiset

***Abstract*—**This research is to study the performance of heat pump dryer for drying of kaffir lime leaves under different media and to compare the color values and essential oil content of final products after drying. In the experiments, kaffir lime leaves were dried in the closed-loop system at drying temperatures of 40, 50 and 60 ^{o}C. The drying media used in this study were hot air, CO_2 and N_2 gases. The velocity of drying media in the drying chamber was 0.4 m/s with bypass ratio of 30%. The initial moisture content of kaffir lime leaves was approximately 180-190 % d.b. It was dried until down to a final moisture content of 10% d.b. From the experiments, the results showed that drying rate, the coefficient of performance (COP) and specific energy consumption (SEC) depended on drying temperature. While drying media did not affect on drying rate. The time for kaffir lime leaves drying at 40, 50 and 60 ^{o}C was 10, 5 and 3 hours, respectively. The performance of the heat pump system decreased with drying temperature in the range of 2.20-3.51. In the aspect of final product color, the greenness and overall color had a great change under drying temperature at 60 ^{o}C rather than drying at 40 and 50 ^{o}C. When compared among drying media, the greenness and overall color of product dried with hot air at 60 ^{o}C had a great change rather than dried with CO_2 and N_2.

***Keywords*—**airless drying, drying rate, essential oil content

I. INTRODUCTION

THE kaffir lime (*Citrus hystrix* D.C., Rutaceae), also known as kieffer lime and limau purut, is a lime native to Laos, Indonesia, Malaysia and Thailand, used in Southeast Asian cuisine. Its hourglass-shaped leaves (comprising the leaf blade plus a flattened, leaf-like leaf-stalk or petiole) are widely used in Thai and Lao cuisine (such as Tom Yum). The leaves can be used in the form of fresh or dried product.

The heat pump dryer (HPD) is an alternative method for drying agricultural products with low energy consumption, relative humidity and low drying temperature [1]. The color and aroma qualities of dried agricultural products using heat pumps were better than those products using conventional hot air dryers, but the HPD was more economical system than other systems although the initial cost was higher [2][3]. The use of inert gas for drying sensitive materials including food products is another important expect of HPD drying technology. The use of inert gas to replace air should permit dried products without occurring oxidative reactions [4]. Moreover, it can reduce browning, shrinking, and can lead to quick rehydration [5] [6]. Products with excellent color and retention of vitamin C, and the overall quality of the dried product from using inert gas were also very high and were similar to products obtained from vacuum or freeze drying [7]. The objectives of this research were to study the performance of heat pump dryer for kaffir lime leaves drying under different media and to compare the color and the essential oil content of final products after drying.

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II. MATERIALS AND METHODS

A. Experimental Setup

A schematic diagram of the HPD using R22- refrigerant is shown in Fig. 1. The apparatus has two circuits; one for the drying air and the another one for the refrigerant. It comprises of a drying section, 1.64 kW reciprocating compressor, 5.27 kW evaporator, a forward-curved-blade centrifugal blower driven by a 0.75 kW motor, 5.45 kW internal condenser and 5.45 kW external condenser and 40x0.064 in^2 capillary tube. An external condenser is combined with an internal condenser. Practically, the solenoid valve is opened to bypass the refrigerant to reject the excess heat at an external condenser when the drying air temperature is higher than a setting temperature. The evaporator bypass air ratio is constant at 60 %.

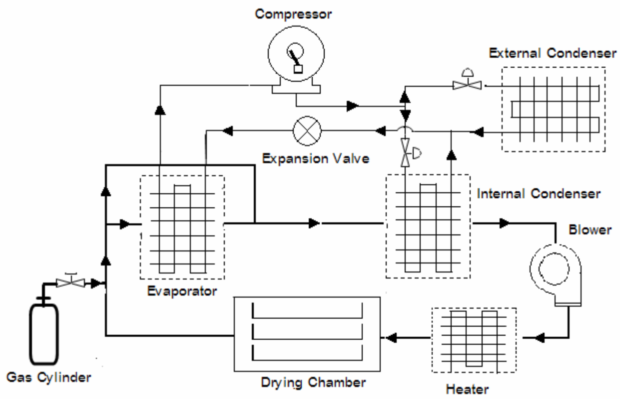

Fig.1 Schematic diagram of heat pump dryer system

B. Material

Kaffir lime leaves were collected from a local area in Kantarawichai, Mahasarakham province, Thailand. The mature leaves with dimension approximately 5 x 10 cm were harvested and stored in the cool room at 5°C. Before experiment, it was warmed to room temperature. A sample approximately 300 g was prepared for each drying experiment. The moisture content was determined by the oven method at temperature of 103°C for 24 hr.

C. Experimental Procedure

The experimental conditions were set up as follows: initial moisture contents of 180-190% dry basis, drying media temperatures of 40, 50 and 60°C at a fixed superficial velocity of 0.4 m/s, with hot air, CO_2 and N_2 as drying media. Each sample was approximately prepared for 300 g for each drying condition. Sample was dried until the final moisture content down to 28% d.b.

After drying, Sample was slowly cooled down to ambient temperature and kept in a seal plastic bag for 2 weeks in a refrigerator at 2-5 °C before quality testing.

D. Dryer performance

The measured data of temperatures, air flow rates and the mass of material under drying were used to estimate the drying characteristics of kaffir lime leaves. Moisture contents, moisture ratio (MR) and the drying rate (DR) were the important factors describing the characteristic of the drying process. These are defined as

$$MR = \frac{M_t}{M_i} \quad (1)$$

$$DR = \frac{(m_{p,i} - m_{p,f})}{t} \quad (2)$$

The dryer performance is evaluated by its average moisture extraction rate: (kg water evap./h), specific energy consumption; SEC (kJ/kg water evap.). The productivity and specific energy consumption (SEC) for heat pump assisted dryers are defined as

$$SEC = \frac{E_u}{(m_{p,i} - m_{p,f})} \quad (3)$$

$$COP_{hp} = \frac{\dot{Q}_e}{W_c} \quad (4)$$

E. Color measurement

Color of the samples before and after drying was determined using a Hunter Lab Colorimeter (Mini Scan XE Plus, Hunter Associates Laboratory Inc., Reston – Virginia, USA). The colorimeter was standardized with black and white calibration tiles (L=93.78, a=-0.91, and b=0.68). Each sample was measured at two different locations and twenty samples were used in each experiment. Lightness (L), Greenness (a) and yellowness (b) were recorded. The overall color change values (ΔE) is expressed as

$$\Delta E = \sqrt{(L_0 - L)^2 + (a_0 - a)^2 + (b_0 - b)^2} \quad (5)$$

F. Determination of Essential Oil Content

The kaffir lime leaves after drying were minced and grinded. Then, the 60 g of sample were mixed with 500 ml water and immediately hydrodistilled for 7 hr. The oil was extracted from the distillate with Methanol (Dist. MeOH). After filtration, the solvent was removed by distillation under reduced pressure in a rotary evaporator at 45°C. The essential oil content was given as

$$\text{Essential oil content (\%)} = \frac{\text{weight of essential oil}}{\text{weight of initial product}} x100 \quad (6)$$

III. Results and Discussion

The moisture content of kaffir lime leaves dried under different drying media at the same drying temperature was not difference. Generally, higher drying temperature led to a lower moisture content at any time as shown in Fig. 2. The moisture content removal inside the leaves was higher at higher drying temperature due to the moisture diffusion is accelerated by high temperature. The drying rate clearly decreases with increasing of drying temperature. Moisture content of kaffir lime leaves in all drying media was similarly at the same drying temperature.

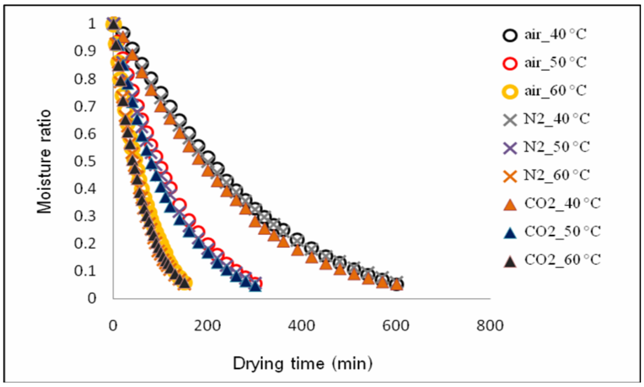

Fig.2 Moisture ratio of kaffir lime leaves during drying by heat pump dryer under different conditions

The performance of heat pump dryer for kaffir lime leaves under different drying media and temperatures is presented in Table I. The results show that drying temperature affects on the drying rate, COP and SEC. At high drying temperature results in the increasing of drying rate, the decreasing of COP and SEC. This due to the energy consumption was more affected by the drying time than drying temperature that used to remove the moisture content to safe level. In Addition, the drying media had no effect on drying rate, but it affected on COP and SEC as the different heat capacity of each gas.

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TABLE I
PERFORMANCE OF HEAT PUMP DRYER FOR KAFFIR LIME LEAVES UNDER DIFFERENT MEDIA AND TEMPERATURES

Drying Media	Air			CO_2			N_2		
Drying Temperature (°C)	40	50	60	40	50	60	40	50	60
Drying Time (hr)	10.0	5.0	2.5	10.0	5.0	2.5	10.0	5.0	2.5
Drying Rate (kg water evap./h)	0.31	0.61	1.22	0.30	0.61	1.22	0.30	0.61	1.22
SEC (MJ/kg water evap.)	26.84	17.11	11.91	27.40	17.15	11.87	27.88	16.36	12.53
COP_{hp}	2.62	2.42	2.21	3.51	3.33	3.01	2.58	2.38	2.20

TABLE II
COLOR VALUES AND ESSENTIAL OIL CONTENT OF KAFFIR LIME LEAVES UNDER DIFFERENT MEDIA AND TEMPERATURES

Drying medium	Drying temperature (°C)	a	ΔE	Essential oil content (%)
Air	40	$-9.60^{a}\pm1.42$	$8.15^{a}\pm1.42$	$1.18^{a}\pm0.09$
	50	$-4.83^{b}\pm1.15$	$12.50^{b}\pm1.83$	$1.22^{a}\pm0.10$
	60	$-2.99^{c}\pm1.03$	$14.78^{c}\pm1.16$	$0.89^{b}\pm0.04$
N_2	40	$-9.50^{a}\pm1.02$	$6.52^{a}\pm0.53$	$1.22^{a}\pm0.14$
	50	$-8.03^{a}\pm1.26$	$7.77^{a}\pm1.19$	$1.19^{a}\pm0.12$
	60	$-4.80^{b}\pm1.32$	$11.78^{b}\pm1.37$	$0.93^{b}\pm0.04$
CO_2	40	$-8.34^{a}\pm1.59$	$7.13^{a}\pm0.57$	$1.19^{a}\pm0.13$
	50	$-8.57^{a}\pm0.52$	$8.02^{a}\pm0.98$	$1.20^{a}\pm0.09$
	60	$-4.72^{b}\pm1.10$	$11.96^{b}\pm1.67$	$0.92^{b}\pm0.04$
Fresh leaves		-11.62 ± 1.97	NA	1.44 ± 0.03

Different superscripts in the same column mean that the values are significantly different at 95% confidence level ($\alpha = 0.05$)

The a (greenness) and ΔE (overall color change) values were assessed in dried kaffir lime leaves and presented in Table II. It indicates that both values of kaffir lime leaves obtained from different drying media are not significantly difference at the drying temperature of 40 and 50 °C under CO_2 and N_2. The discoloration of products is more affected by drying temperature than drying medium. This may be the pigment degradation during drying process and browning reaction occurring, resulted in the color changes, especially under air drying. For a value, a is negative value which indicated the green direction. When comparing among media, the results is interesting in the drying using N_2 and CO_2 as drying media, it could maintain the greenness of kaffir lime leaves, especially at 60°C. This may be during drying using those gases in the system can prevent the oxidation reaction which might be another reason resulted in color change.

The essential oil content of dried kaffir lime leaves is presented in Table 2. The fresh one is 1.44% essential oil. It indicates that the essential oil is sensitive by drying temperature as the loss is increased at higher temperature. This due to the volatile compound can evaporate during drying.

This finding is corresponded with previous studies [7][8] that the higher drying temperature caused the losses of essential oil content of dried product. However, the drying media do not affect on the essential oil content as the statistic results are not significantly different ($p \geq 0.05$).

IV. CONCLUSIONS

Based on the experimental results of the present work, the following conclusions could be drawn

- Drying rate, the coefficient of performance (COP_{hp}) and specific energy consumption (SEC) depended on drying temperature while the drying media did not effect on drying rate.
- The greenness and overall color change of product dried with hot air at 60 °C had a great change rather than dried with CO_2 and N_2.
- The essential oil content decreased as the drying temperature increased but not significantly difference by drying media.

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V. Nomenclature

a_0	Greenness before drying
a	Greenness after drying
b_0	Yellowness before drying
b	Yellowness after drying
COP_{hp}	Coefficient of performance
DR	Drying rate, kg water evap/h
L_0	Lightness before drying
L	Lightness after drying
M_i	Initial moisture content, % dry basis
M_t	Moisture content at time, % dry basis
$m_{p,i}$	Initial mass of wet product, kg
$m_{p,f}$	Final mass of wet product, kg
E_u	Electrical energy consumption, kJ
$\dot{Q}_e$	Heat reject at evaporator, kW
t	Drying times, h
SEC	Energy consumption, kJ/kg water evap.
W_c	Compressor Work, kW

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