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TECHNICAL NOTE

IMPROVEMENT IN THE EFFICIENCY AND CAPACITY OF CHOPPED SPRING ONION DRYING

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ABSTRACT

Appropriate strategy for drying chopped spring onion with a batchwise flat bed was investigated. Both experimental and simulated results such as product quality, drying capacity and energy consumption were taken into consideration. For simulation work, equations of drying parameters such as specific heat, equilibrium moisture content and thin layer drying were first developed from the lab-scale experimental results. Then a mathematical model including shrinkage for a batchwise flat bed drying was developed. The model was tested with the results obtained from a food processing plant with an acceptable accuracy. Appropriate drying strategy was then investigated. The approximate conclusion was that the drying should be devided into 3 stages. In the 1st stage, drying air temperature was 80 °C, specific air flow rate was 33.9 m^3/min - kg dry matter and drying time was 0.5 h. In the 2nd stage, drying air temperature and drying time were kept unchanged but specific air flow rate was decreased to 13.5 m^3/min - kg dry matter. In the final stage, drying air temperature was decreased to 67 °C, specific air flow rate was also decreased to 6.8 m^3/min - kg dry matter and drying time was approximately1.7 h. Following the suggested strategy, specific primary energy comsumption was 6.2 MJ/kg H_2O, drying time was 2.7 h and product quality was maintained. It was proven that energy consumption was approximately 70% of that of the present practice in the plant.

INTRODUCTION

Drying process consumes a significant fraction of energy in food industry. The Royal Food Processing Plant at Phang district, Chiang-mai province, produces dry chopped spring onion and supplies for ready-to-eat noodle factories. Chopped spring onion is dried in batch in flat bed dryers. Energy inputs are mainly steam for heating air by using a cross-flow heat exchanger and electricity for driving a fan. Studies of drying performance have been investigated during the past few years. Wanabadinimit (1990) found experimentally that the efficiency of batch drying of chopped spring onion was relatively low. Two-stage drying was therefore proposed. Partly dry and shrunken spring onion from the two batches of the first stage were mixed into one batch during the second stage in order to increase the bed thickness. Wieneke (1991) confirmed the low drying efficiency and suggested to recycle exhausted air particularly during the second stage. However, it may need to invest more and the operation may also be disturbed. Sripawatakul (1991) recommended appropriate drying air temperature, 80 °C during the first stage and 50 °C during the second stage. Though several suggestions were made, optimum drying strategies were still inconclusive. Therefore, the objective of this paper was to investigate optimum strategies for drying chopped spring onion. Product quality, drying capacity and energy consumption were taken into consideration. The work was limited to the flat bed dryers operated in The Royal Food Processing Plant. Both experimental and simulated results obtained from a mathematical model developed herein were employed in this study.

MATERIALS AND METHODS

Mathematical Model

The major assumption for deriving the mathematical drying model is the existing of thermal equilibrium between the chopped spring onion and the drying air. Detail is available in Soponronnarit (1988). Figure 1 shows control volumes, CV_1, CV_2 and CV_3 for deriving equations based on energy and mass conservation.

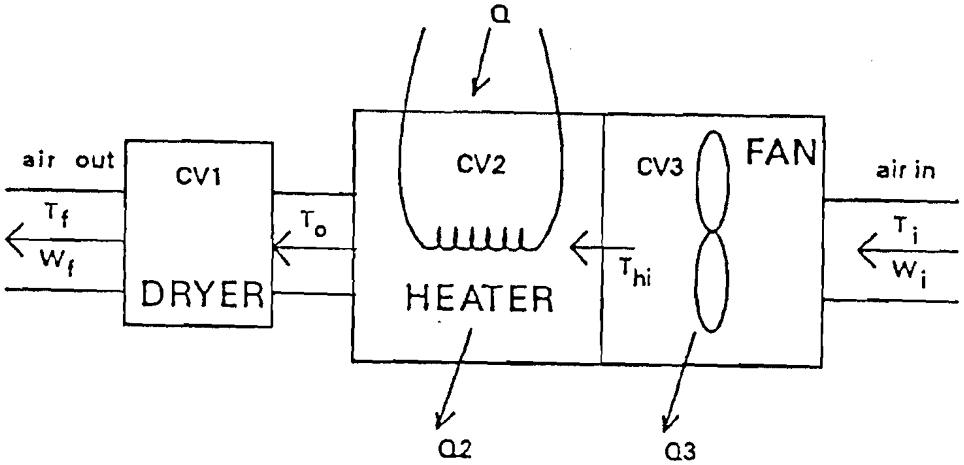

Fig.1 Control volumes

Air temperature rises while flowing through the fan. It can be determined from the following equation

$$T_{hi} = T_i + \Delta P / [(C_a + W_i C_v) \eta_f \rho_a] \qquad .....(1)$$

where
T = air temperature, °C
W = air absolute humidity, kg H_2O / kg dry air
C = specific heat, kJ/kg - °C
ΔP = pressure drop, kPa
ρ_a = air density, kg/m^3
η_f = fan efficiency, decimal

i means fan inlet, hi means fan outlet, a means dry air and v means vapor. Energy input required for the electrical motor to drive the fan is determined as the following.

$$W_m = W_s / \eta_e \qquad .....(2)$$

W_s means shaft work at the fan and η_e is the efficiency of the electrical motor.

Air temperature rise while flowing through the heater can be determined by the following equation.

$$T_o = T_{hi} + Q/[m_a (C_a + W_i C_v)] \qquad .....(3)$$

m_a means air flow rate in kg/s, Q means heat input in kW and T_o means air temperature at the heater outlet in degree Celsius.

Considering a particular thin layer in the chopped spring onion bed for a certain period, equations of energy and mass balance can be written as follows.

$$C_aT_o + W_o(h_{fg} + C_vT_o) + RC_{pw}\theta = C_aT_f+W_f (h_{fg}+C_vT_f) + RC_{pw}T_f \qquad .....(4)$$

$$W_f - W_o = (M_o - M_f) R \qquad .....(5)$$

where
M = moisture content of chopped spring onion, decimal dry-basis
θ = temperature of chopped spring onion, °C
h_{fg} = latent heat of vaporization of moisture, kJ/kg H_2O

R is the ratio of dry mass of chopped spring onion to mass of dry air flowing into the thin layer during the calculation period. Subscripts o, f and pw mean before and after drying and chopped spring onion respectively.

A thin layer drying equation of spring onion with the form of Page's (1949) equation was developed in this study. It can be written as the following.

$$(M - M_{eq}) / (M_{in} - M_{eq}) = \exp (-Kt^N) \qquad .....(6)$$

where $K = \exp (-4.6788 + 0.073218\ T - 0.19866/V - 0.00024000\ T^2)$
$N = \exp (0.014273 - 0.012680\ T + 0.050060/V + 0.000053000\ T^2)$

V means air superficial velocity in m/s and subscripts in and eq mean initial and equilibrium respectively. The equation is valid for the range of air velocity of 0.2 - 0.8 m/s and temperature of 40 - 80 °C. During calculation, it is differentiated with time and substituted by finite differences.

An empirical equation of equilibrium moisture content of spring onion with the form of Modified Halsey's equation (Iglesias and Chirife, 1976) was developed in this study. It is written as the following.

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$$M_{eq} = [\exp(1.844 - 0.01540\,T) / (-\ln(RH))]^{(1/1.361)} \qquad .....(7)$$

During drying, shrinkage of the bed of chopped spring onion was very significant. The shrinkage equation was developed in this study as the following.

$$V = 0.025505 + 0.0048120\,M - 0.00034227M^2 + 0.0000094700\,M^3 \qquad .....(8)$$

where V = specific volume , m^3/kg dry matter

Experiments

There were experiments of specific heat, equilibrium moisture content, thin layer drying and batchwise flat bed drying. For each experiment, spring onion with a diameter of 4-8 mm was chopped into an approximate length of 4 mm.

Specific heat was determined by a calorimeter method with mixing between chopped spring onion and warm water.

Equilibrium moisture content was determined by static method with saturated salt solution, KNO_3, NaCl, $Mg(NO_3).6H_2O$, $MgCl_2.6H_2O$ and LiCl controlled at constant temperature of 38, 50, 62 and 74 °C. Moisture content of chopped spring onion was determined by oven method with 103 °C for 24 hours.

Thin layer drying rate was determined by conducting experiment in the laboratory for a wide range of constant temperature measured by thermocouple, type K, connected with a data logger with an accuracy of ± 1 °C. Air velocity was measured by a hot wire anemometer.

Experiment of batchwise flat bed drying of chopped spring onion was conducted at the Royal Food Processing Plant at Phang district, Chiangmai province. Detail of the dryer is shown in Figure 2. Approximate 100 kg of wet chopped spring onion was loaded each batch with an initial depth of 10 cm. Moisture content of spring onion at several depths was measured by the air oven method. Dry and wet bulb temperatures of air were measured.

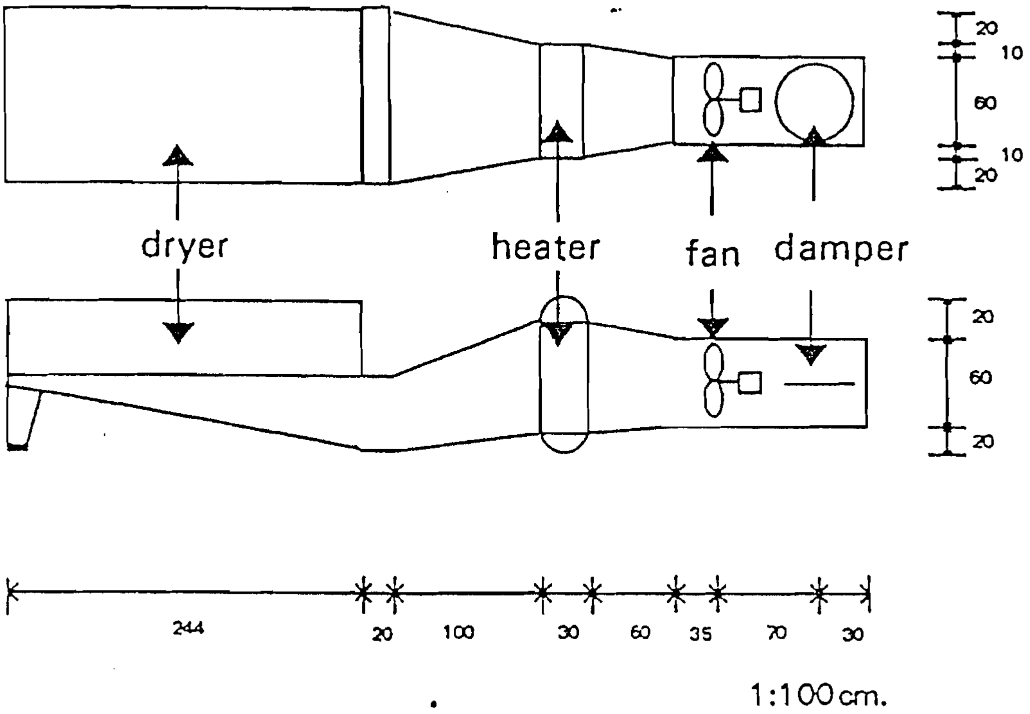

Fig.2 Detail of experimental dryer

Investigation of Drying Strategy

The accuracy of the mathematical model was tested with the experimental results. Product quality was observed during both thin layer drying and batchwise flat bed drying. Major factors affecting product quality were temperature and drying time. The appropriate air temperature was concluded and recommended from the experimental results. Then the mathematical model was employed for determining appropriate specific air flow rate (air flow rate per unit mass of chopped spring onion).

RESULTS AND DISCUSSION

Specific Heat

Specific heat of chopped spring onion was proportional to moisture content as shown in Figure 3. The relationship can be expressed as the following equation.

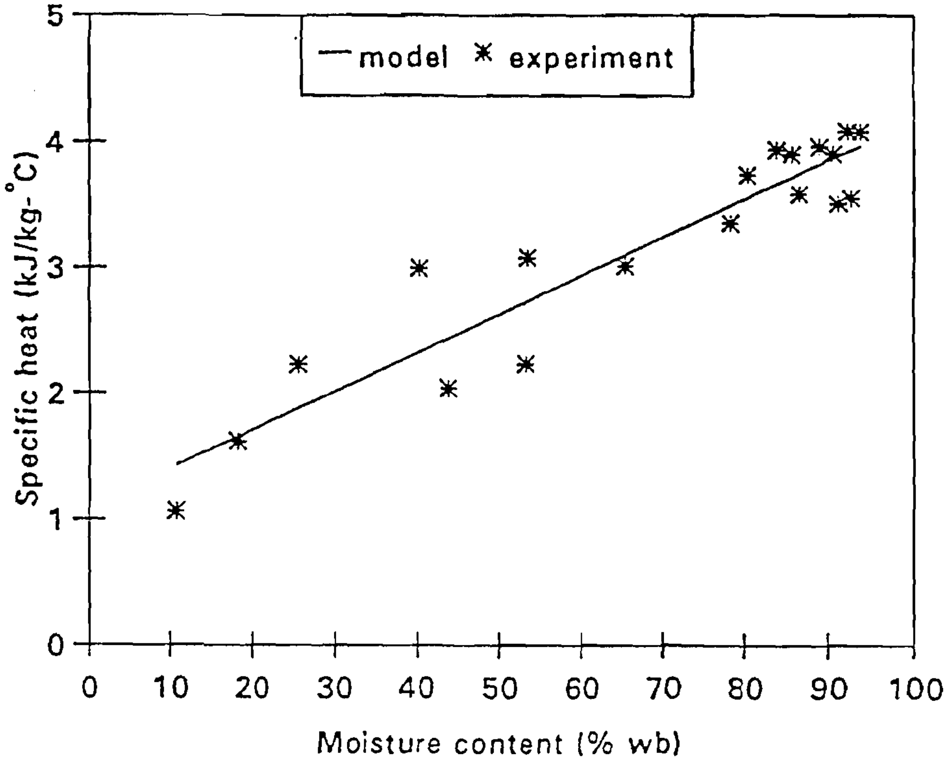

Fig. 3 Relationship between specific heat of spring onion and moisture content

$$C_{pw} = 1.10396 + 0.0305244\ M_{wb}$$

where M_{wb} is moisture content in percent wet-basis.

Equilibrium Moisture Content

Modified Halsey's equation (Iglesias and Chirife, 1976) was found better compared to Chung and Pfost's (1967) equation and Henderson's (1952) equation as shown in Figure 4. The equation has been presented as in Equation (7).

Thin Layer Drying

Page's (1949) equation could predict drying rate of thin layers relatively well as shown in Figure 5. The equation has been presented as in Equation (6).

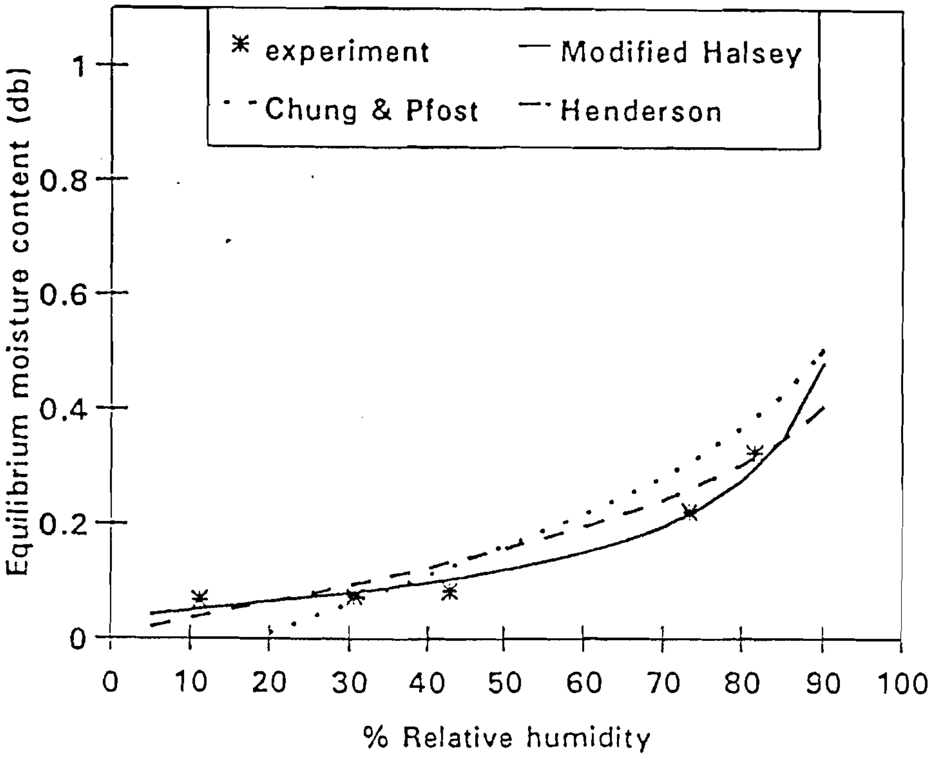

Fig.4 Isomoisture curves of spring onion at 62°C

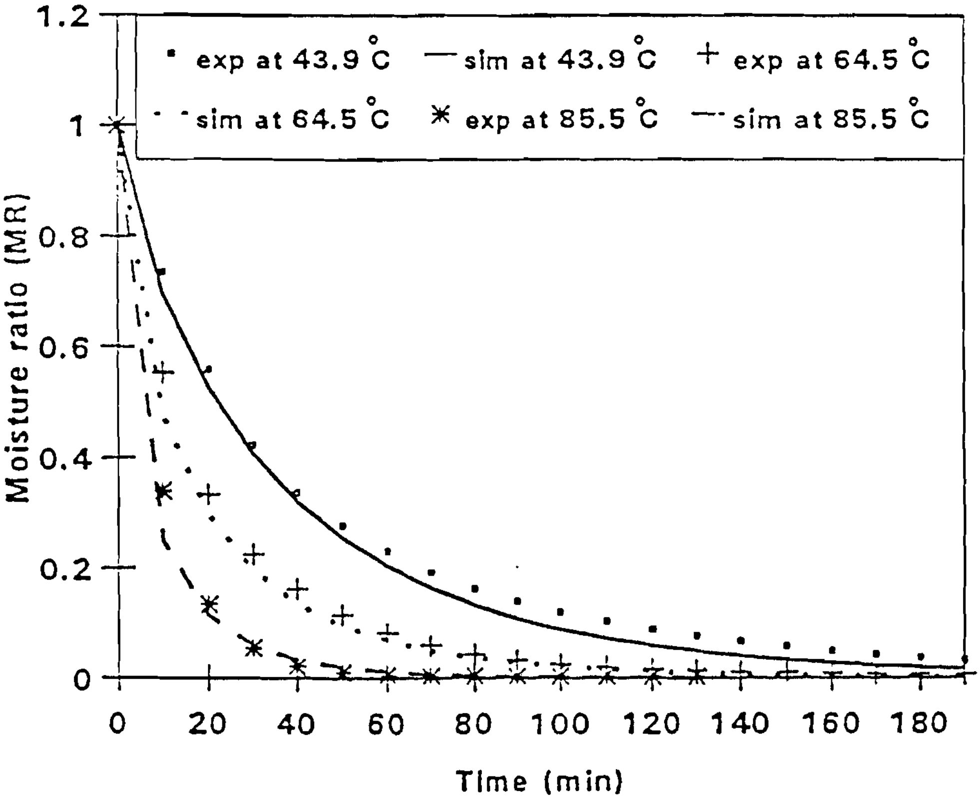

Figure.5 Evolution of experimental and simulated (Page,1949) moisture ratio of spring onion at a superficial velocity of 0.2 m/s

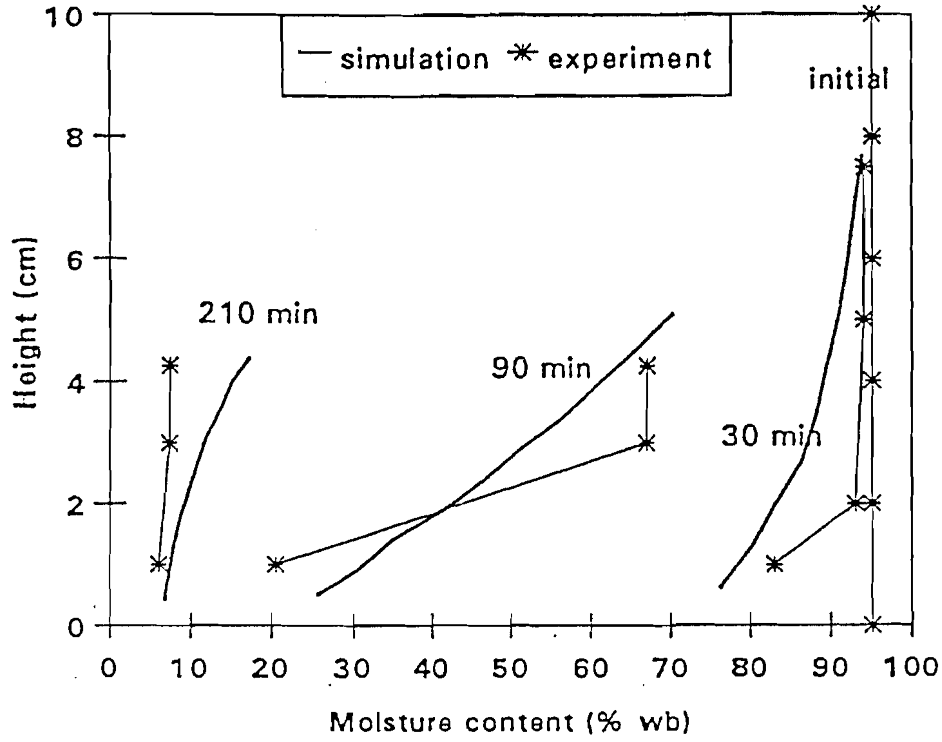

Fig.6 Comparison between simulated and experimental moisture content of spring onion at different heights

Accuracy of Mathematical Model of Batchwise Flat Bed Drying

Figure 6 compares experimental and simulated moisture profile in a batchwise flat bed dryer employed in the Royal Food Processing Plant. Correlation is relatively good.

Energy input to the dryer comprises energy in the steam for heating air and electricity for driving the fan. Total primary energy consumption is the summation of energy in the steam and electrical energy multiplied by a conversion factor of 2.6. It was noted that the latter contributed only 4-7% during several test runs. Table 1 compares experimental and simulated results of average moisture content of spring onion and total primary energy consumption. The correlation is relatively good. There were 3 types of test runs, i.e, nos. 1 and 2 classified as one-stage drying, nos. 3, 4 and 5 classified as two-stage drying and nos.6 classified as three-stage drying. The three-stage drying was the most attractive in terms of both shorter drying time and lower energy consumption. It was observed that higher air temperature and higher air flow

Table 1 Experimental and simulated results of spring onion drying

test no	temp (°C)	specific air flow rate (m^3/min-kg-dry matter)	drying time (h)	initial moisture content (% wb)	final moisture content (% wb)		primary energy consumption (MJ/kg H_2O evap.)	
					sim^1	exp^2	sim	exp
1	73	11.1	4.00	94.6	8.5	7.5*	6.90	8.90
2	66	22.2	4.00	94.9	9.3	8.3	9.49	10.01
3	78	20.6	1.50	94.6	11.1	9.1*	8.32	9.11
	63		1.50					
4	72	24.0	1.50	95.0	10.7	6.8	9.41	9.66
	62		2.00					
5	67	31.3	1.85	94.6	13.9	10.0	10.63	9.69
**	67	10.4	1.15					
6	80	28.1	0.50	94.1	6.6	6.9*	5.85	6.56
	80	21.1	0.50					
**	75	7.0	1.85					

* Product turned brown　　1 Simulation　　2 Experiment

** Three beds were mixed into one bed

rate were used during the initial stage and then followed by lower air temperature and lower air flow rate during the final stage. However, the air temperature during the final stage was still too high and caused the product turn brown. It was also observed that the product did not turn brown if the air temperature was lower than 67 °C during the final stage as indicated by test run nos. 2, 4 and 5.

Drying Strategy

The mathematical model of batchwise flat bed drying was employed in order to investigate the influences of specific air flow rate during the second stage and air temperature during the third stage on both drying time and energy consumption.

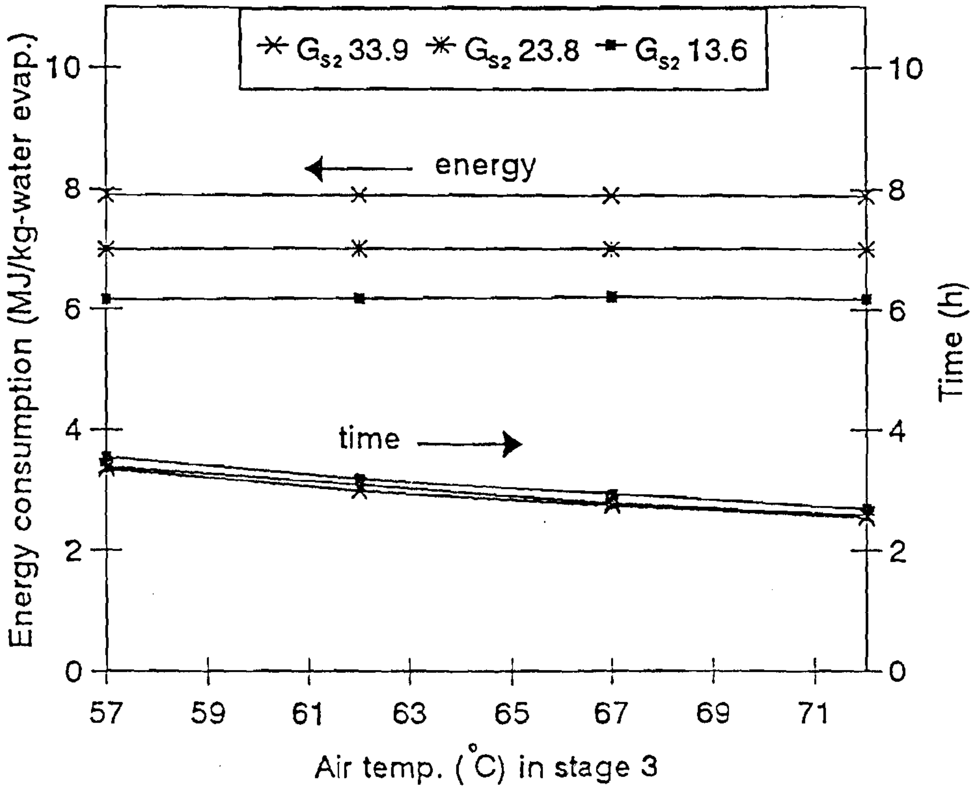

Fig.7 Effect of specific air flow rate in stage 2 and air temperature in stage 3 on specific primary energy consumption and drying time
[Air temperature in stage 1 = 80 °C, 0.5 h
Air temperature in stage 2 = 80 °C, 0.5 h
Specific air flow rate in stage 1 = 33.9 m^3/min-kg dry matter
Specific air flow rate in stage 3 = 6.8 m^3/min-kg dry matter
G_{s2} = Specific air flow rate in stage 2, m^3/min-kg dry matter]

Results from Figure 7 indicates that energy consumption decreases with specific air flow rate during the second stage while drying time is relatively constant. However, during the third stage, energy consumption does not depend on air temperature but drying time increases when air temperature decreases. It may be concluded that the specific air flow rate during the second stage drying should be 13.6 m^3/min - kg dry matter and air temperature during the third stage should be 67 °C. Product quality in terms of colour will be maintained while energy consumption and drying time are close to the minimum values. During the first stage drying, air temperature is 80 °C and specific air flow rate is 33.9 m^3/min - kg dry matter. Drying air temperature during the second stage is also 80 °C. Specific air flow rate during the third stage is 6.8 m^3/min - kg dry matter. Drying time for both first and second stages is 0.5 h. Total drying time is 2.7 h. Total specific primary energy consumption is 6.2 MJ/kg water evaporated. This is approximately 30% less compared to the current practice at the Royal Food Processing Plant (test nos. 5). In general practice, the specific air flow rate can be reduced by mixing partially dried spring onion obtained from a few predried batches in stead of reducing total air flow rate. This will enhance the increase of total drying capacity.

CONCLUSION

From this study, it may be concluded as follows.

1. The mathematical model of batchwise flat bed drying of chopped spring onion developed herein is accurate. The model includes the developed equations of specific heat, equilibrium moisture content, thin layer drying and bed shrinkage.

2. It has been proven by both experimental and simulated results that the three-stage drying method is efficient in terms of good product quality, shorter drying time and lower energy consumption compared to the current practice at the Royal Food Processing Plant. Detail of operating condition is recommended.

RECOMMENDATION

Though energy consumption could be reduced significantly and drying time was also shortened without any modification of the existing equipments, new techniques of drying such as fluidized bed drying should be investigated especially for new installation.

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