

Mathematical Simulation of Longan Fruit Drying

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ABSTRACT

The objectives of this study were to develop a mathematical model and to simulate longan drying for evaluating the optimum conditions. The specific energy consumption and average drying rate were used for the verification of the model. It was found that the simulated results agreed with some of those experiments. The effects on the specific energy consumption of drying air temperature, fraction of air recycled, and specific air flow rate were described. It was found that the specific air flow rate, drying air temperature and fraction of air recycled affect significantly on specific energy consumption. However, the effects of specific air flow rate and drying air temperature on specific energy consumption were small when fraction of air recycled was big. Additionally, it was also concluded that the optimum specific energy consumption of 3.3 MJ/kg-water occurred at fraction of air recycled of 95%, specific air flow rate of 28 kg-dry air/h-kg dry longans, drying air temperature of 75°C and drying time of 33 h.

Key words : dehydration; energy consumption; fruit; modeling

INTRODUCTION

Longans are an important commercial fruit in the north part of Thailand. Fresh longans have high moisture content; thus, they can be stored for a short period of time. Longan drying process can extent a period of time for preservation and can reduce loss arising from seasonal glut. Dried longans are widely consumed as a dried fruit, made longan juice, put in cake, and so on. Basically, conventional hot air dryers are the most widely used for the production of dried longans. In the literature, there are few reports on longan drying. Vongnichakul and Phanvuch (1997) evaluated the drying constant and sorption isotherms of longan drying. Sitthipranee (1990) suggested that the drying air temperature for longan fruit drying using hot air

dryer should be 75 °C. Sitthipong *et al.* (1992) and Sitthipong *et al.* (1988) tested and modified existing dryers of longans by experiments. The goal of their study was to meet the technical and economic requirements for the drying of longans. The investigation of optimum drying conditions can be recovered by experiments or computer simulation. Therefore, a mathematical model for longan drying needs to be developed.

The objectives of the present work are to develop a mathematical model and to simulate longan fruit drying. The effects of drying air temperature and specific air flow rate on energy consumption are investigated. Also, the effects of dryers with and without air recirculation on energy consumption are described.

MATERIALS AND METHODS

Development of mathematical model

A mathematical model of a cabinet dryer is composed of drying model and performance model. The assumptions of the model are as follows: thermal equilibrium exists between moist air and longans, the walls of the dryer are adiabatic, the internal energy changes of the dryer and longans are negligible. The schematic diagram of a cabinet dryer is shown in Figure 1. The details of the model are as follows:

Drying model

The moist air properties at outlet drying chamber can be calculated by using the principle of mass and energy conservation to control volume 1 in Figure 1. From mass conservation, the increase of the moist air is equal to the decrease of moisture content in the product. It is given by equation (1).

$$\Delta t m_d (W_{do} - W_{di}) = m_p (M_i - M_f) \quad (1)$$

From energy conservation, it is assumed that moist air and product are in thermal equilibrium. The equation can be derived from the first law of thermodynamics. It is given by the following relationship.

$$m_d [C_a T_{di} + W_{di} (h_{fg} + C_v T_{di}) - C_a T_{do} - W_{do} (h_{fg} + C_v T_{do})] = 0 \quad (2)$$

The model for calculating longans moisture content during drying is based on the thin layer drying rate equation developed by Vongnichakul and Phanvuch (1997). They are given by equations (3) to (5).

$$M_f = M_i + (M_{eq} - M_{in}) \Delta t K \exp(-Kt) \quad (3)$$

$$K = 0.0023(T_{di} + 273) - 0.739 \quad (4)$$

$$M_{eq} = A [RH_{di} / (1 - RH_{di})]^B \quad (5)$$

$$\text{Where, } A = 2.3015 - 0.00615(T_{di} + 273) \\ B = -1.3453 + 0.00507(T_{di} + 273)$$

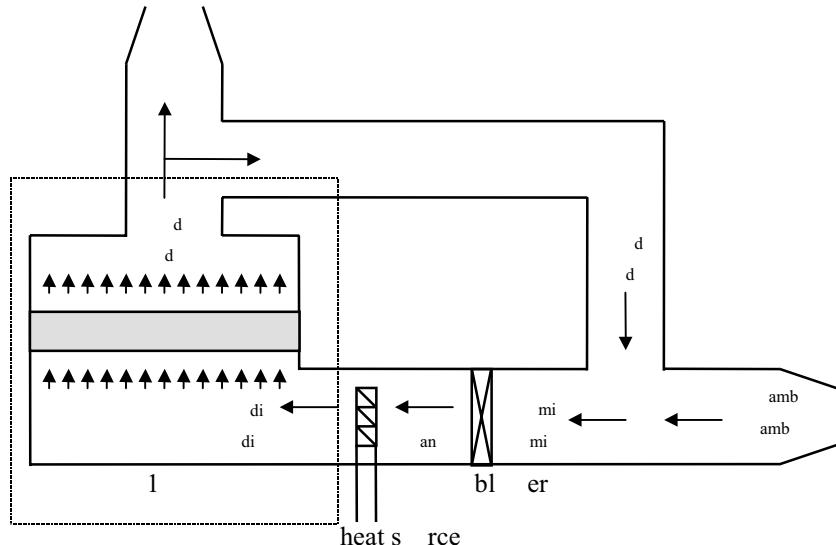


Figure 1 Schematic diagram of a cabinet dryer.

Performance model

The performance of dryers is defined as specific energy consumption (SEC) and average drying rate (DR). They can be written as

$$\text{SEC} = (2.6E + Q_h) / [(M_{in} - M_f)m_p] \quad (6)$$

$$\text{DR} = m_w / DT \quad (7)$$

Simulation procedure

A computer program for dryers with and without air recirculation has been developed to evaluate the effects of drying air temperature, specific air flow rate and fraction of air recycled on specific energy consumption. The simulation flow chart is shown in Figure 2. The inputs are as follows: the initial moisture content of longans, the specific air flow rate, the drying air temperature, the fraction of air recycled, and the other constants (such as $\Delta t = 0.01 \text{ h}$, $C_a = 1.006 \text{ kJ/kg} \cdot ^\circ\text{C}$, $C_v = 1.88 \text{ kJ/kg} \cdot ^\circ\text{C}$). The humidity ratio of air entering drying chamber (W_{di}), the humidity ratio of air leaving drying chamber (W_{do}), and equilibrium moisture content (M_{eq}) are the guess values. The steps of the calculation are as follows: the drying model is calculated, and then the W_{di} , W_{do} and M_{eq} are checked. If they are not equal to the guess values, the new guess values will be calculated by using Newton-Raphson technique, and the system model is calculated again. The calculation continues until the guess values are relatively equal to the new ones. The next step is to check the relative humidity of air leaving drying chamber whether it is feasible. If it is higher than 1, the moisture condensation is calculated, and then the variables are recalculated. Finally, the performance model is calculated. The after drying moisture content of longans is checked. If it is higher than the desired value, the before drying moisture content is replaced by the after drying moisture content, and then the time step is advanced. The calculation continues until the

moisture content of longans is less than or equal to the desired value.

RESULTS AND DISCUSSION

Verification of mathematical model

The experimental results of longan fruit drying conducted by Sitthipong *et al.* (1992) and the simulated results are shown in Table 1. The experimental and simulated drying conditions are fraction of air recycled of 90%, specific air flow rate of 33.7 kg-dry air/h-kg dry longans, and initial moisture content of 316% dry-basis. The other conditions are also shown in Table 1. Specific energy consumption and average drying rate are used for the verification of the mathematical model. It can be observed that the simulated results agree with some of those experiments. The simulated results of specific energy consumption (Batch No. 5, 7, 8, 10 and 15) are nearly the same as that from the experimental results. The difference is less than 10%.

Effect of specific air flow rate

Figure 3 shows the effect of specific air flow rate (SAF) on specific energy consumption (SEC) and drying time (DT) at drying air temperature 70° C. The simulated drying conditions are SAF varying from 6 to 40 kg-dry air/h-kg dry longans, RC of 0%, 50% and 95%, initial longan-weight of 1000 kg, ambient temperature of 35°C, ambient humidity ratio of 0.015 kg-water/kg-dry air, and initial and final moisture content of 316% and 42% dry-basis, respectively. It is found that SEC depends upon the SAF, namely, the SEC decreases with increasing SAF to a minimum point, and then the SEC increases due to an excessively air flow rate. It is also found that DT depends upon the SAF, namely, the DT decreases rapidly with increasing SAF when SAF is small, afterwards, the DT is nearly constant. Furthermore, it can be clearly seen that if RC

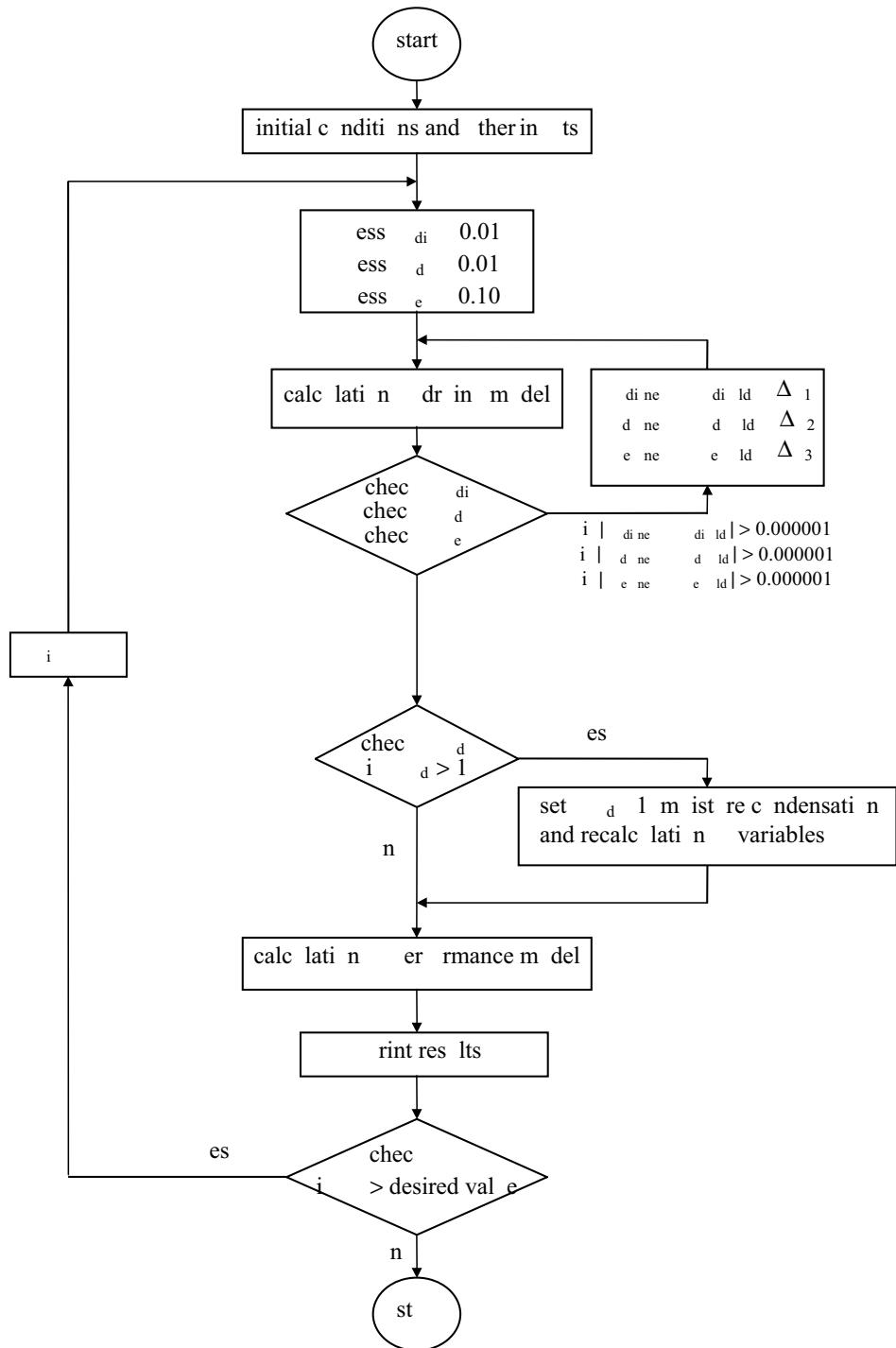


Figure 2 Simulation flow chart.

Table 1 Experimental and simulated results of longan fruit drying.

Batch No.	Fresh weight (kg)	Dried weight (kg)	Drying air temp. (°C)	Experimental results			Simulated results		
				DT ^{1/}	DR ^{2/}	SEC ^{3/}	DT ^{1/}	DR ^{2/}	SEC ^{3/}
1	805	259	65	48	11.4	3.5	57	9.6	6.3
2	950	301	64	75	8.7	3.9	64	10.1	6.0
3	1080	357	63	73	9.9	4.2	62	11.7	5.5
4	960	310	73	55	11.8	4.2	36	18.1	4.8
5	900	310	75	49	12.0	4.4	33	17.9	4.8
6	1000	315	75	59	11.6	4.1	34	20.1	4.7
7	1000	329	75	63	10.7	4.2	31	21.6	4.5
8	965	340	74	60	10.4	4.5	29	21.6	4.4
9	1000	317	73	61	11.2	4.2	37	18.5	4.8
10	1000	332	77	58	11.5	4.5	27	24.7	4.3
11	930	340	64	55	10.7	4.4	47	12.6	5.3
12	810	277	65	53	10.1	4.2	50	10.7	5.9
13	1050	375	63	73	9.2	4.1	52	13.0	5.2
14	1000	314	68	68	10.1	4.1	51	13.5	5.4
15	1000	319	73	60	11.4	4.3	37	18.4	4.8

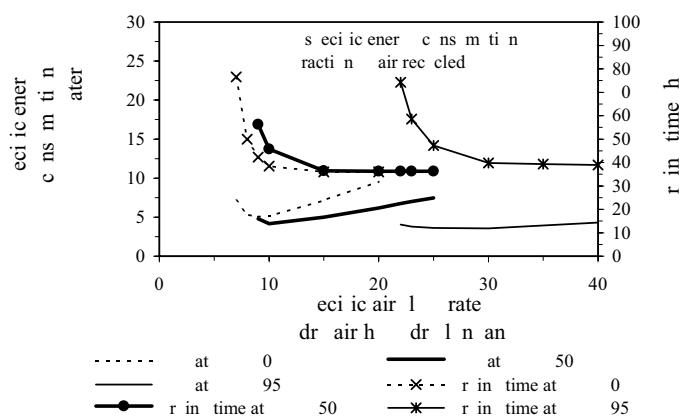
^{1/} Drying time, h^{2/} Average drying rate, kg-water/h^{3/} Specific energy consumption, MJ/kg-water

Figure 3 Effect of specific air flow rate on specific energy consumption at various fractions of air recycled. (initial longan-weight of 1000 kg, initial moisture content of 316% dry-basis, final moisture content of 42% dry-basis, ambient temperature of 35°C, ambient humidity ratio of 0.015 kg water/kg dry air and drying air temperature of 70°C.)

increases, the minimum SEC decreases slightly and the optimum SAF increases while the drying time is relatively equal.

Effect of drying air temperature

The effect of drying air temperature on SEC are also study. Figure 4 shows SEC versus drying air temperature at various SAFs and RCs. The simulated drying conditions are drying air temperature varying from 60 to 80°C, RC of 0% and 95%, and SAF of 10,12, 25 and 28 kg-dry air/h-kg dry longans. Other conditions are the same values as the previous conditions. It is found that the drying air temperature affects markedly on SEC especially in the case of dryer without air recirculation, namely, the SEC decreases with increasing drying air temperature to a minimum point, and then the SEC increases. For the dryer with air recirculation (RC of 95%), when SAF increases, the minimum SEC decreases and the optimum drying air temperature increases.

However, the drying air temperature should not exceed 75°C due to the limitation of product quality.

Effect of fraction of air recycled

Figure 5 shows the effect of fraction of air recycled on SEC and drying time at various drying air temperatures. The simulated drying conditions are RC varying from 0 to 97%, SAF of 28 kg-dry air/h kg-dry longans and drying air temperature of 65, 70 and 75°C. Other conditions are the same values as the previous conditions. It is found that the SEC decreases with increasing RC to a minimum value, and then the SEC increases since humidity ratio in the drying air is an over high value. Consequently, the drying time grow up. The minimum SEC of 3.3 MJ/kg-water occurs at RC of 95%, SAF of 28 kg-dry air/h/kg dry longans, drying air temperature of 75°C and drying time of 33 h.

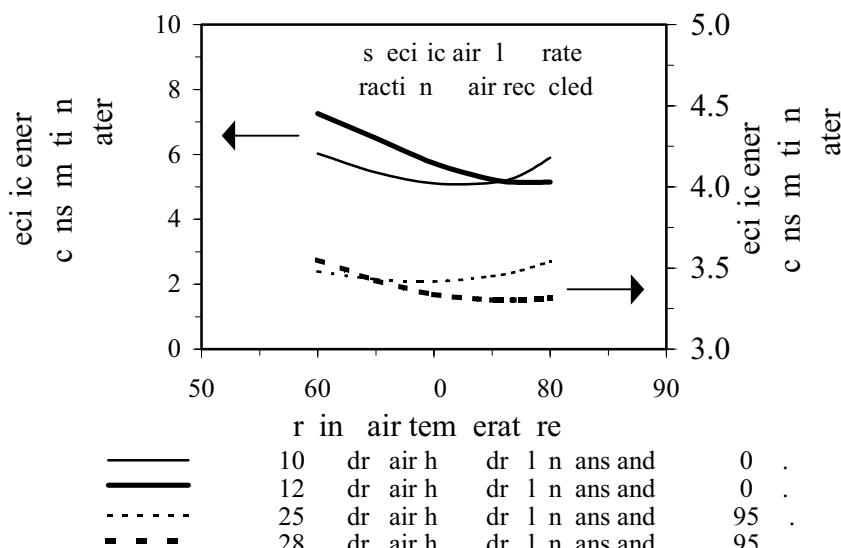


Figure 4 Effect of drying air temperature on specific energy consumption. (initial longan-weight of 1000 kg, initial moisture content of 316% dry-basis, final moisture content of 42% dry-basis, ambient temperature of 35°C and ambient humidity ratio of 0.015 kg water/kg dry air)

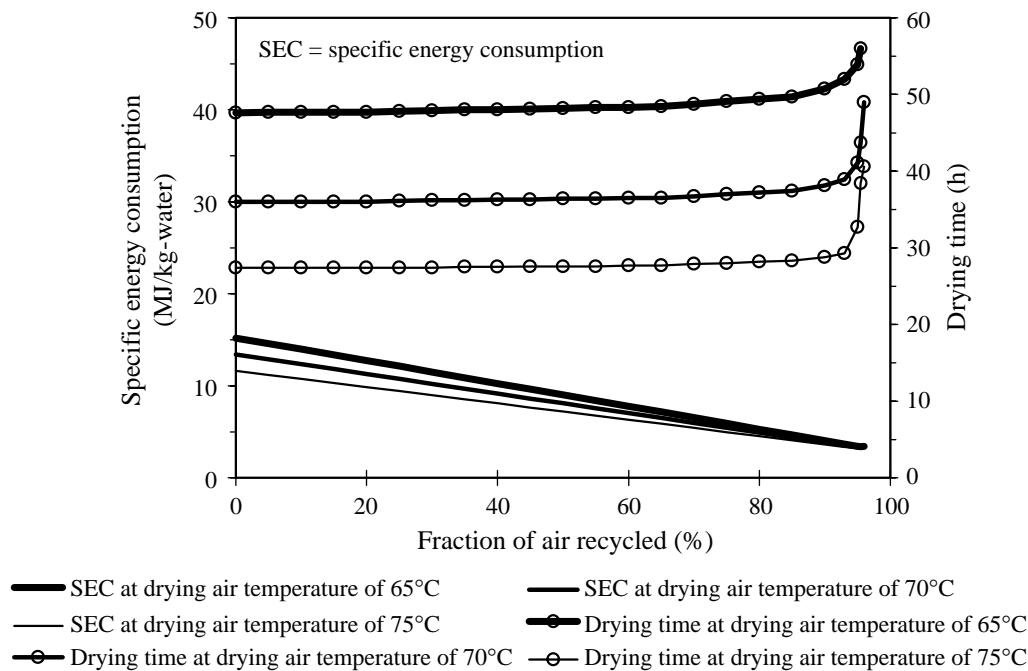


Figure 5 Effect of fraction of air recycled on specific energy consumption at various drying air temperatures. (initial longan-weight of 1000 kg, initial moisture content of 316% dry-basis, final moisture content of 42% dry-basis, ambient temperature of 35°C and ambient humidity ratio of 0.015 kg water/kg dry air, specific air flow rate of 28 kg-dry air/h- kg dry longans.)

CONCLUSION

The mathematical model of longan fruit drying predicts fairly the drying rate and specific energy consumption. The specific air flow rate, drying air temperature and fraction of air recycled affect significantly on specific energy consumption. However, the effects of specific air flow rate and drying air temperature on specific energy consumption are small when fraction of air recycled is big.

RECOMMENDATIONS

Further study is needed to improve the mathematical model and to clarify the physical and

thermal properties of longan drying. Diffusion model is also needed to be developed. In addition, the effect of drying air temperature on product quality should be studied.

NOMENCLATURE

C	specific heat capacity, $\text{kJ/kg}\cdot^\circ\text{C}$
CV	control volume
DT	drying time, h
DR	average drying rate, $\text{kg}\cdot\text{water}/\text{h}$
E	the rate of electricity consumption, kJ/h
h_{fg}	specific evaporated enthalpy, kJ/kg
K	drying constant, h^{-1}
M	moisture content, decimal dry-basis
m_p	dry mass of product, kg-dry longans

m_d	mass flow rate of dry air, kg-dry air/ h
m_w	mass of water evaporated from longans, kg-water
Q_h	the rate of heat consumption, kJ/h
RC	fraction of air recycled, %
RH	relative humidity , decimal
SAF	specific air flow rate, kg-dry air/h-kg dry longans
SEC	specific energy consumption, MJ/kg-water
t	drying time , h
Δt	time interval, h
T	temperature, °C
W	humidity ratio , kg-water/kg-dry air

Subscripts

a	air
amb	ambient condition
di	entering drying chamber
do	leaving drying chamber
eq	equilibrium condition
f	after drying
fan	after blower
i	before drying
in	initial condition
mix	after mixing
v	vapor

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LITERATURE CITED

Sitthipranee, P. 1990. Longan drying. Industry Journal 33(8) : 36-39.

Sitthipong, N., A. Hirun, W. Klongpanich, P. Thertoon, T. Siratanapanta, S. Thavornnun, and S. Kamalaspitak. 1988. Multi-crop Dryers Project. Final report (Phase 1), IDRC File No. 3-P-88-0234. Department of Mechanical Engineering Chiang Mai University.

Sitthipong, N., A. Hirun, P. Siripabpra, P. Rerkriangkrai, S. Achariyaviriy, S. Thavornnun, A. Promwungkwa, and S. Kamalaspitak. 1992. Multi-crop Dryers Project. Final report (Phase 2), IDRC File No. 3-P-88-0234. Department of Mechanical Engineering Chiang Mai University.

Vongnichakul, R. and R. Phanvuch. 1997. Study of equilibrium moisture content and drying constant of longans. Master of Engineering Thesis, Department of Mechanical Engineering, Chiang Mai University, Chiang Mai.